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Energy Citizenship in Positive Energy Districts—Towards a Transdisciplinary Approach to Impact Assessment

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Abstract: It is commonly assumed by the projects demonstrating concepts for positive energy districts in cities across Europe that citizens want and need to be involved in the development of these concepts as an essential condition for positive energy districts to be deployed successfully and to achieve the expected societal goals. Six different research and innovation projects are investigating the different forms of energy citizenship in positive energy districts and their impacts. They aim to apply a transdisciplinary approach to collaborative research and to impact assessment. The interim results are described, and preliminary conclusions on impact are drawn. The projects each used different approaches to engaging citizens, while differentiating between different groups. Progress is monitored but only fragmentary evidence on the impact has been gathered. Transdisciplinary approaches are being developed but are still immature.

Keywords: energy citizenship; citizen engagement; energy transition; positive energy districts; PED; impact assessment; transdisciplinary; multidisciplinary

1. Introduction

The involvement of citizens and energy communities is seen as a key pillar of the energy transition process [1–9]. Citizens interact with the technical energy systems, since they are both the subject and object of social innovation in the energy society, and they are emerging economic actors in the energy markets. To design and optimise fair, inclusive, and just energy transition pathways, it is a requirement to have suitable policy making, good collaborations between stakeholders, realistic business models, and citizens who play an active role in shaping and accelerating the socio-technological energy transition [10,11].

The role of citizens and citizen organisations in both driving and facilitating the energy transition towards climate neutrality and inclusivity has gained much attention among scientists, local policy makers, and the private sector. It is in this context where the notion of "energy citizenship" arises, as a placeholder for new social roles and responsibilities for citizens in an energy system in constant transformation [2–6,12]. The term energy citizenship represents the active participation of citizens in the energy system—such as adopting renewable technologies, joining energy communities, supporting local initiatives, and participating in policy decision-making [13] and in the energy economy in their multiple roles as users, protesters, supporters or prosumers, and involving energy consciousness and literacy as well as sustainable energy practices [8,14]. It concerns both the actions of individual citizens and collective citizens' initiatives and organisations.

In the energy transition, decentralisation towards local technological (energy system) and local economic systems is being explored increasingly, which could potentially offer important synergies with local social innovation initiatives in the city. More concretely, the model of energy-positive districts (PED), which enhances decentralisation, aims to capture the benefit of local energy system, economic and social innovations [15]. Through engaging and facilitating citizen participation, the role of the citizen transforms from a passive consumer to an active participant in the transition as, for example, the initiator of new, local, energy initiatives, by becoming a member of such an initiative or by changing role from consumer to prosumer or by contributing to scientific research and monitoring processes [16].

This paper presents and discusses the methods, strategies, and expected impacts for citizen engagement applied in six different European research and innovation projects in Positive Energy Districts, focusing on their research approaches and the observed impacts. Through this multiple project view, this paper (1) assesses the progress towards a transdisciplinary research approach and methodology focused on impact assessment, (2) reflects this approach towards ongoing research and innovation (R&I) projects on positive energy districts, where energy citizenship aims to co-drive the technological, economic and social innovations, and (3) explores conclusions on the potential and limitations of energy citizenship in the energy transition and developing policy recommendations in strengthening energy citizenship.

The following three research and innovation questions are addressed:

1. How can citizens potentially engage in positive energy districts and thus contribute to the societal objectives of PEDs?
2. What is the interest in, acceptance and uptake of citizens of these options to engage in the energy systems of positive energy districts?
3. What impact from citizen engagement is observed and validated already in the ongoing demonstration projects of positive energy districts?

In addition, we address the added value of transdisciplinary research in answering these questions and explore how much progress has been made in the projects so far in applying transdisciplinary research methodologies and approaches. This paper presents considerations towards a methodological framework for transdisciplinarity in impact assessment on energy communities in PEDs. The current practice is illustrated for ongoing PED R&I projects. Finally, recommendations are given to speed up the progress towards transdisciplinarity in PED-related R&I projects.

2. Positive Energy Districts as an Instrument in Urban Energy Transition

PEDs are a new concept for energy planning at neighbourhood and city scale. They consist of delimited areas of buildings, public spaces, and infrastructure that together create a total positive annual energy balance, meaning that the area will deliver, on average, an energy surplus to be shared with its surrounding urban or peri-urban areas.

PEDs are 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 integration of different systems and infrastructures and interaction between buildings, the users and the 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 [15,17] (Figure 1).

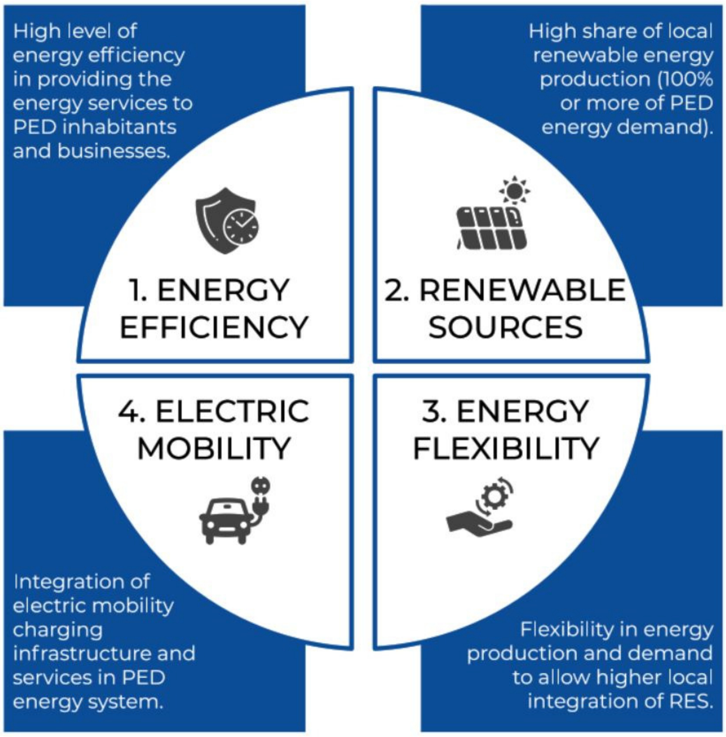

Figure 1. Components of the energy system of a Positive Energy District. Reproduced with permission under open access from [15].

PEDs can be understood as a localised response to the overall European energy transition. They are a way to accelerate the green transition and refurbishment wave. They combine within a second approach local renewable energy generation, energy demand reduction, building efficiency measures, local energy storage, local balancing and exchange of energy, and the activation and engagement of citizens and other stakeholders.

PEDs are an inherently scalable concept that can grow locally and include a mix of new and old buildings. PEDs are not merely energy projects; they require the combination of many relevant city functions, such as energy planning, (electric) mobility planning, urban planning, (open) information and communication technology (ICT), sustainability plans, etc. This is part of the complexity discourse in cities and the city being a primarily social complex system [18–21]. They should include all of these aspects together with the ambition to create a liveable citizen-oriented city that can ensure social and societal value.

The hypothesis is that for developing as well as scaling-up locally—and for replication within EU cities—more is needed than external investment or government initiatives alone. Citizens and local stakeholders and their needs must be integrated into local processes and must be provided with the tools and incentives to take responsibility for their own communities, invest in local solutions for local needs and have the ability to exploit these investments for their own benefits (or shape local strategies, regulations, and other incentives) [21].

The definition of the expected impact of energy citizenship in PEDs is based on the societal objectives that PEDs are supposed to be able to achieve, shown in Table 1. Given the holistic perspective on PEDs, this comprises a long list of societal objectives. An initial challenge to interdisciplinarity is that the perceived scope of expected impacts differs between the research disciplines. The energy system analyst tends to prioritise the energy performance of PEDs, while the sociologist focuses on the social impact.

Table 1. Societal objectives associated with PEDs.

Energy	Environmental	Social	Economic
• Increased renewable energy sources (RES) • Energy savings • Flexibility/reduce congestion • E-mobility	• Climate change mitigation • Other emissions • Circularity	• Democracy • Wellbeing • Quality of life • Inclusivity • Energy justice • Reducing energy poverty	• Lower energy cost • Better business cases for local RES • New energy services and products • Mobilising private capital for investments

From a research and innovation perspective, the holistic approach to PEDs poses a particular challenge:

- The innovations and measures that collectively establish and comprise a PED cover different domains, ranging from the installation of batteries for energy storage to motivating residents to establish an energy community.
- The societal objectives also cover different policy domains, as shown in the table.
- Finally, the impact pathways that link innovations and measures to the societal impacts they aim to achieve is complex: technical innovations have an impact on economic and social impacts; social measures have an impact on greenhouse gas emissions and energy efficiency.

As a result, the challenge of research and innovation projects is to identify, pilot and evaluate the impact of citizen engagement through energy citizenship, in its different forms, working towards societal impact across the societal goals, considering the synergies and trade-offs with the other non-social PED components and innovations.

3. The different Modes of Energy Citizenship in PEDs

The projects demonstrating the PED concept in cities across Europe assume that citizens should want and need to be involved in these new energy concepts, so they are successfully deployed in the long term. However, further research is needed to understand in what ways and in what roles can citizens be engaged in PEDs [22]. This section explores the different modes of energy citizenship.

3.1. Individual Citizenship

Energy citizenship can be expressed through the engagement of individuals or households. This includes purchasing green energy, supporting/engaging in energy retrofits, engaging in sustainable lifestyles, and actively participating in PED design and operation. A hypothesis is that living in a PED district will motivate residents towards behavioural changes, e.g., in the ATELIER project [23]. Behavioural change is both a strategy for citizen engagement and an expected outcome of citizen engagement.

3.2. Local Energy Initiatives

Citizens can also engage with the energy system through collective initiatives. This can range from taking part in non-formalised groups that motivate neighbours towards energy savings, to becoming active market entities as part of local energy initiatives (LEIs). These are communities of households who self-organise to meet their energy demand with locally produced green energy, as a well as promoting energy savings [24].

3.3. Energy Citizenship through Local Energy Communities

Through the Clean Energy for all Europeans package, the EU has introduced the concept of energy communities in its legislation, notably as citizen energy communities and renewable energy communities [25]. The Directive on common rules for the internal electricity market includes new rules that enable 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 [26]. In addition, the revised Renewable Energy Directive aims to strengthen the role of renewables self-consumers and renewable energy communities [27]. From the business model point of view, citizens are empowered to occupy a central role in Local Energy Communities (LECs), Renewable Energy Communities (REC), or similar concepts that could potentially support PEDs as a new energy market model [15]. Most R&I projects on PEDs are investigating local energy communities as the potential driver of PED development and operation.

3.4. Energy Communities as Aggregators

Distributed energy resources (DERs) are small and medium-sized power resources connected to the distribution network. Aggregators bundle DERs to engage as a single entity—a virtual power plant—in power or service markets. The services they could offer are load shifting, balancing and local flexibility [28]. Concepts differ in how they distribute generation and grid operation. In +CityxChange, one concept is that of a Community System Operator (CSO), which can either be owned and operated by a community, a set of buildings, or the grid operator as a shift in business models [29]. This business model is being piloted extensively across the EU. In practice, this means that members of a citizen energy community mandate a coordinator (system operator) to trade with the energy markets on their behalf.

3.5. Local Peer2Peer Energy Trading (P2P) and Flexibility Trading within an Energy Community

The P2P model creates an online marketplace where prosumers and consumers can trade electricity, without an intermediary, at their agreed price. Trading based on P2P models could make renewable energy more accessible, empower consumers and allow them to make better use of their energy resources [30]. In addition, participants in local flexibility markets could trade with each other [31–34]. For example, this implies that a resident allows the central system operator to (partly) control its electric appliances, heat pump and electric vehicle charging to collective reduce peak loads, for which the resident receives a financial fee (Figure 2). There is limited experience in demonstrating this model.

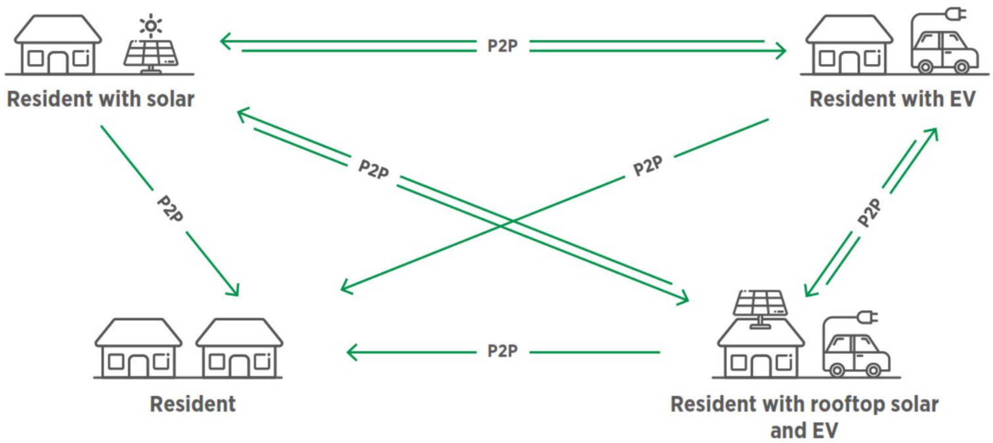

Figure 2. Peer to peer trading (P2P). Reproduced with permission under open access from [30].

3.6. The Energy Citizen as Energy Market Player

In most R&I projects on PEDs, the collective energy and flexibility trading models (aggregators) are regarded as a key innovation in achieving the impact on energy transition, in particular the increased share of RES in local energy systems. In most cases, individual P2P energy and flexibility trading is also investigated. These can be seen as new modalities of energy citizenship that go beyond the more traditional individual roles described above.

These models rely on citizens being able and willing to (1) become members of energy communities; (2) commit to external trading through a central operator, and (3) even take an individual role as a market player in P2P trading. Ability and willingness as well as the related drivers and barriers are therefore main topics for research in this area.

In this respect, a distinction can be made between active versus passive engagement, and whether it makes a difference when considering energy citizenship. If a citizen signs a contract with the operator of the PED energy system, which allows the operator to actively control the personal assets automatically to optimise the local system with economic benefits for the citizens (for example, if appliances are turned off to reduce peak load automatically without intervention of the residents) is this still a form of citizenship? From an impact point of view, it does not make a difference compared to active management by the resident. From a sociological perspective, it may do. The lack of consensus among researchers is a barrier towards interdisciplinary research; there is no common object of research. In this paper, we consider passive citizenship also.

3.7. Impact Pathways on Energy Citizenship

In the previous section, we identified, first, a long list of societal impacts that PEDs could achieve through the engagement of citizens, and (2) a list of different ways that energy citizenship could be included in PED design and operation (Figure 3). For assessing the impact of energy citizenship, impact pathways need to be drawn that depict the project logic and the causal relationships. For example, an impact pathway described the causal relationship on how establishing a PED energy community can lead to increased RES in the PED. The pathway addresses the intermediate steps related to the willingness to join energy communities, the willingness to pay more for local RES and, as a result, the improved business cases. Defining these cross-domain and cross-disciplinary pathways requires a transdisciplinary approach.

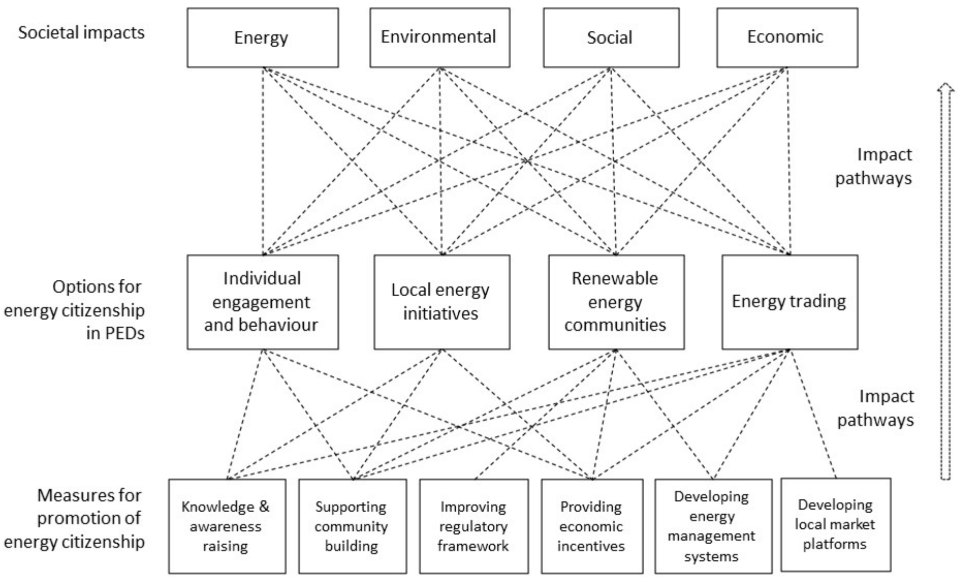

Figure 3. Impact pathways from energy citizenship towards societal impact.

4. Transdisciplinary Research on Energy Citizenship in PEDs

In this section, we discuss different perspectives on multi-, inter- and transdisciplinary research, and adopt a definition for the purpose of this paper. Multidisciplinary research arises when multiple disciplines investigate a single problem but do so as if each were working within their own disciplinary setting [35]. Multidisciplinary research is thus characterised by gathering knowledge from various disciplines and enriching the knowledge about that problem by adding multiple views, but without crossing disciplinary boundaries [35,36]. In other words: people from different disciplines working together, each drawing on their own disciplinary knowledge.

Research on energy participation has shown the importance of multidisciplinary approaches [37–39]. For example, Romero et al. [40] demonstrated the contribution of applying Mixed Method research [41] in generating rich data on buildings' occupants' subjective value when managing their energy consumption. By combining motivational (e.g., Self-Determination Theory in work environments [42], in situ occupancy monitoring [43–45] and interaction design methods, holistic knowledge has been generated. This knowledge aims to describe and explain occupants' behaviour towards energy management. It provides a holistic understanding of what drives occupants to manage their energy and how the practice of managing can be optimised to reach a higher and more active involvement.

Interdisciplinary research integrates knowledge and methods from different disciplines, using a real synthesis of approaches. Interdisciplinarity is a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession. Interdisciplinarity studies draw on disciplinary perspectives and integrate their insights through construction of a more comprehensive perspective. One of the biggest challenges in interdisciplinary research is achieving effective communication between experts from different disciplines in order to create a level playing field amongst (project) participants and be able to let them confront, debate, and negotiate ideas and perspectives in order to facilitate sufficient integration of knowledge [29,30]. Transdisciplinarity is a reflexive research approach that addresses societal problems by means of interdisciplinary collaboration as well as the collaboration between researchers and extra-scientific actors. Its aim is to enable mutual learning processes between science and society where integration is the main cognitive challenge of the research process [46].

For the purpose of this paper, we adopt the definitions from the SHAPE-ID project on shaping inter- and transdisciplinary research practices in Europe, as this project is based on a recent mapping and scanning of both literature and practices, consolidated with consultations of a broad range of practitioners (Table 2) [47,48].

Table 2. Definition of multi-, inter-, and transdisciplinary research. Reproduced with permission under open access from [47,48].

Multidisciplinary	**Interdisciplinary**	**Transdisciplinary**
• Juxtaposes separate disciplinary approaches around a common interest • Where researchers from each discipline work in a self-contained manner • Little cross fertilisation ("integration") among disciplines or synergy in the research outcomes	• Involves bodies of knowledge derived from more than one discipline. • Strives for collaboration between disciplines. • Aims to integrate knowledge, at least to some extent.	• Intends to transgress boundaries between disciplinary knowledge • Intends to integrate different bodies of knowledge and create new knowledge • Develops new interdisciplinary research methods • Tends to imply active co-creation of knowledge between academic and societal partners

4.1. The Need for Transdisciplinary Research in PEDs

In research and innovation (R&I) projects in climate neutral, smart, and inclusive cities, the perspective and role of citizens is being increasingly recognised and addressed. For the Smart Cities and Communities Programme under Horizon 2020, which funded several of the project presented as case studies in this paper, the objective of R&I projects is described as bringing together research, cities, industry and citizens to demonstrate solutions and business models that can be scaled up and replicated, and that lead to measurable benefits in energy and resource efficiency, new markets and new jobs. R&I projects are always structured around demonstration projects. The question that arises is how applied research can support the design and implementation of effective policies and actions of public and non-public stakeholders for energy citizenship to have the maximum contribution to the range of public/societal goals.

Speeding up the energy transition requires an encompassing approach that needs to bring together social, economic, and technical aspects. Therefore, most current R&I projects are emphasising the need to move from multidisciplinarity (people from different disciplines working together, each drawing on their disciplinary knowledge) to interdisciplinarity (integrating knowledge and methods from different disciplines, using a real synthesis of approaches). In the area of energy citizenship, the involvement of non-academics in research is important, thus requiring transdisciplinary approaches.

Energy-positive districts (PED) can be achieved through the integration of technical, economic and community-level social innovation. One of these innovations, collective energy citizenship through local energy communities, could potentially contribute to environmental, economic, and social objectives, of which climate change mitigation has the highest priority. These communities could facilitate local energy system optimisation, raise private capital for renewable energy, and promote sustainable behaviour. The ex-ante and ex-post assessment of these impacts is crucial to the selection and design of communities' models and for deciding on the role of this innovation in urban energy and climate mitigation policies [34–36].

This impact research requires a transdisciplinary approach, which intends to transgress boundaries between disciplinary knowledge; integrate different bodies of knowledge and create new knowledge; develop new interdisciplinary research methods; and imply active co-creation of knowledge between academic and societal partners:

1. The promotion of energy citizenship in PEDs could have an impact on the social, economic, energy and environmental societal goals.
2. The promotion of energy citizenship comprises a range of measures from social interventions, such as providing information and motivation; technical measures, such as providing the ICT platform for trading, and the interfaces between residents and the energy systems; and economic incentives (pricing).
3. The impact of intervention along the impact pathways should imply many interlinkages and dependencies between the domains and disciplines.

4.2. How to Assess the Progress towards Transdisciplinarity?

In current practice in R&I in the area of energy transition, research is still multidisciplinary, involving separate disciplinary approaches around a common interest, working in a self-contained manner and with little cross fertilisation ("integration") among disciplines or synergy in the research outcomes.

The next question is how to assess and evaluate ongoing R&I projects on the progress towards an inter- and transdisciplinary research. The starting point is to "promote problem-driven interdisciplinary research, prioritising the scientific problems behind the energy transition instead of disciplinary preoccupations" [48]. The following is a tentative list of areas for evaluation on the progress towards transdisciplinarity. This framework is the basis of the evaluation framework of the case studies presented in the following section.

1. Level of common vision across disciplines on PEDs and energy citizens as object of research, impact targets and pathways between research outcomes and impact.
2. Progress in development and application of shared research methodology and impact assessment framework, complementing disciplinary approaches.
3. Progress on qualitative and quantitative (interim) results on impact indicators towards societal goals
4. Levels of citizen's involvement in the design and implementation of research (beyond being the object of research).
5. Initial structure of the project proposal that might enable or constrain, already from the beginning, inter and transdisciplinary approaches.

6. Evaluation of the project activities envisioned at proposal stage/first year of the project to gain potential missing knowledge/experience to reach desirable levels of inter- or transdisciplinarity (depending on what is desirable according to the project goals).
7. Level of common vocabulary/terminology among different disciplines (and non-academic actors) and efforts made to reach a common "glossary" as a starting point for the project.

5. Case Studies of Six European Smart City Projects

This section presents six case studies of R&I projects, which together illustrate a set of multiple different approaches to researching the models of energy citizenship in PEDs and the evaluation of impact, and varying approaches to interdisciplinary research. Four projects are focused on PEDs (ATELIER, +CityxChange, MAKING-CITY, and POCITYF). The project MySMARTlife, though not focused on PEDs, addresses the same set of innovations. They are all part of the EU's Smart Cities and Community Programme. Finally, ENERGE addresses education as a key intervention for energy citizenship.

5.1. Amsterdam Bilbao Citizen-Driven Smart Cities (ATELIER)

ATELIER is an EU-funded Smart City project aiming to create and replicate Positive Energy Districts within two lighthouse cities, Amsterdam and Bilbao, and six fellow cities [23]. Co-creation, citizens' energy communities, and behavioural change are the main strategies for citizen engagement. The project, with a duration of 5 years, is currently in its third year. In this phase, the project's approach and detailed activities are being designed and tested. Ongoing activities include collaboration with existing energy communities in the district that serve as testing grounds and to establish so-called Innovation Ateliers that serve as a multi-stakeholder platform, addressing upscaling of specific PED innovations.

ATELIER as a research and innovation project is similar to +CityxChange, POCITYF and MAKING-CITY in the high-level objectives for the role of citizens in the project. Co-creation, citizens' energy communities, and behavioural change are the main strategies. The concept of energy citizenship is not yet introduced explicitly in ATELIER. The PED demonstration in Amsterdam has commenced construction. This is supported by increased exchange and cooperation with other ongoing projects, and an internal interim evaluation process. Ongoing activities include [23,49]:

- Collaborating with previously established energy communities in the district that serve as testing grounds and as inspiration for the new larger scale communities that will be established in the Amsterdam demonstration.
- Establishing so-called Innovation Ateliers that serve as a multi-stakeholder platform addressing issues coming up amongst the stakeholders during the innovation project, as well as upscaling of specific PED innovations, such as energy communities.
- Organising artistic interventions and low-threshold activities with residents in the area related to energy transition, in cooperation with local organisations. The activities are expected to offer the possibility to learn about (more) community initiatives in the energy transition and learn about preferred participation roles of various actors. Some activities had to be cancelled due to the pandemic.

The preliminary findings are:

- The main components of the Amsterdam PED demo are two new developments (blocks of buildings) as well as an established smaller community. This implies for the new developments that the future inhabitants were not directly involved in the design of the buildings. The scope for co-creation and citizens' energy communities is therefore limited to specific components of the PEDs only.
- The work package structure, with a separate WP for citizen engagement and a separate one for the demonstration projects, is common for this kind of R&I project. However, this structure hampers breaking the silos towards multidisciplinary work methods, as cross-cutting activities are not core business. A common research methodology across disciplines is still under development, allowing an interdisciplinary way of working.

- There is a need for a common vision across project partners and involved stakeholders, who are predicted to be impacted by energy citizenship as a hypothesis. For example, will energy citizenship contribute to a reduction in greenhouse gas emissions as well as to social objectives?
- Related to this is the need to map the impact pathways starting from the project's interventions to the desired impact. This will help to identify synergies and trade-offs between different targets. To this purpose, the Innovation Ateliers will address energy communities, and a Theory of Change is being developed.
- The citizens and future inhabitants of the Amsterdam PED are primarily higher income. Upscaling and replication of PEDs in Amsterdam requires the transition to other demographics in the city. The methodology for assessing the different impacts and the interventions is still under development.
- The resident's willingness to participate in community level and peer2peer trading may be low, due to lack of clarity on conditions and risks, among other reasons.

In the area of energy citizenship, the impact research is still primarily multidisciplinary. The concept as well as the focus of the expected societal goals are very dependent on the framing by the disciplines and individual researchers. Additionally, a transdisciplinary approach, involving citizens in the research activity itself, still needs to be established.

5.2. +CityxChange: Positive City Exchange

Within +CityxChange, the lighthouse cities Trondheim (Norway) and Limerick (Ireland) are developing demonstration projects in climate-friendly and sustainable urban environments towards Positive Energy Blocks and Districts [29]. They are understood as a way to increase and integrate local renewables in an approach driven by cities, citizens, and stakeholders as part of the local energy transition. +CityxChange places particular emphasis on the role of citizens as co-innovators—explorers, ideators, designers and diffusers—in the co-creation and replication of Positive Energy Blocks and Districts [29,50]. Main demos towards this are six interconnected CommunityxChange solutions which can operate as an integrated toolkit, focusing on citizen empowerment through measures including citizen observatories in the form of innovation labs and activation of the local innovation ecosystems through innovation playgrounds [51], together forming an urban living lab approach (Figure 4); implementation of open calls for citizen solutions; a Positive Energy Champion Network; and investment and engagement activities to enable citizens to invest in their own buildings for efficiency measures and local energy generation.

The work is informed by Arnstein's ladder of participation [52], the transtheoretical model of behaviour change [53], and is placed within an overarching framework of Open Innovation 2.0 [54] and Quadruple Helix collaboration [55]. A specific focus lies on process innovation and social innovation aspects.

The project aims at multilevel impacts, ranging from individual engagement measures, events, or labs, up to strategic alignment of cities and overhauling city transition processes. Preliminary insights gained so far, which will be further validated, include [56–58]:

- Cities use different governance process partnership models, and physical solutions to implement PEDs, dependent on local context.
- Non-technical factors such as streamlining, organisational relationships, funding approaches and stakeholder engagement are crucial for complex projects such as this one.
- Understanding and working with regulatory barriers on energy trading is vital [59,60].
- Designing, implementing, and managing PEDs needs ongoing monitoring, evaluation, mitigation, and adaptation, based on what is learnt during the activities.
- Initial stakeholder mapping for project development should be revisited and refined as the PED matures.
- Reanalysis of technical feasibility in areas and buildings for specific measures is necessary.

- With the right stakeholders involved and suitable local and political anchoring, adaptations and pivoting are possible (for example regarding COVID-19 impacts), and may ultimately strengthen stress-tested solutions. While initially defined (technical) impacts may have to be reduced, resilience and replicability may be increased.
- Financial costs are still one of the significant barriers to scaling.
- Complex projects in cities can benefit from a portfolio approach addressing a range of contexts and linked with the EU Cities Missions.
- The citizen role of co-innovator has been adopted by the project in activities such as citizen labs, innovation playgrounds, and hackathons. In the Positive Energy Champion Campaign, citizens were observed to migrate across various co-innovator roles and themes when developing and implementing their individual step-by-step plans for change [61].
- Citizens engaged to date demonstrate a strong commitment to the clean energy transition but can feel disempowered by the need for systemic change.
- We cannot make this only the responsibility of citizens. A fair distribution of risks and benefits between citizens and professional stakeholders is important.
- Societal benefits as a societal mission should be linked with climate action.

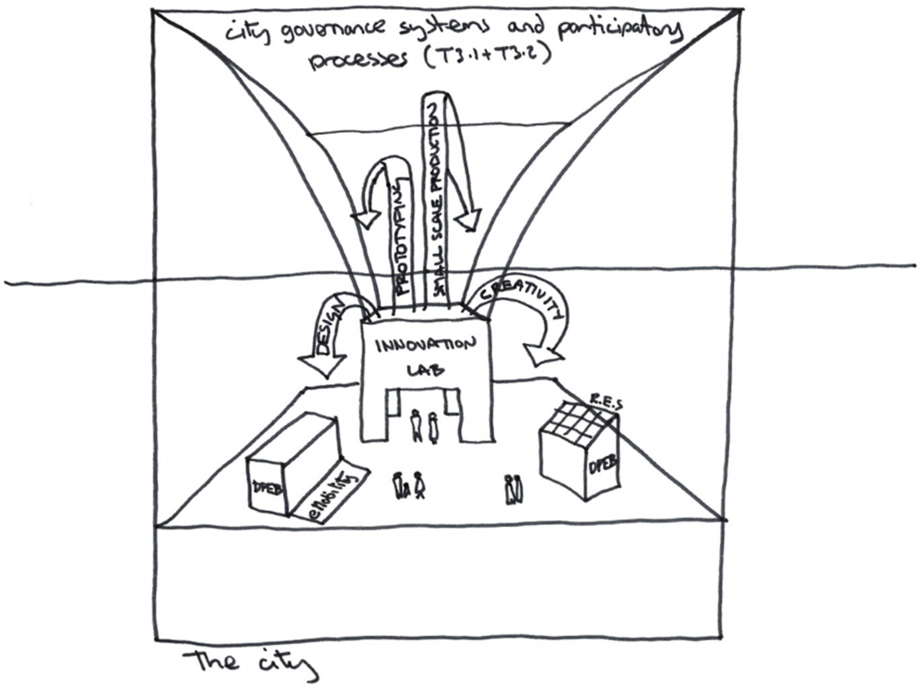

Figure 4. Illustration of the DPEB Innovation Lab concept. Reproduced with permission under open access from [51].

5.3. ENERGE: Energising Education to Reduce Greenhouse Gas Emissions

The ENERGE project will improve recognition among the whole secondary school population of the issues (climate, societal, economic, environmental) associated with excessive greenhouse gas (GHG) emissions [62]. ENERGE addresses this need to engage school actors in low-cost energy efficient solutions, as well as to target behavioural, communal, and organisational interventions. By means of monitoring building sensors (e.g., electrical, indoor climate, etc.), sociological studies, and new educational approaches, ENERGE creates a systemic and holistic understanding of how schools engage in energy and GHG mitigation. ENERGE will be demonstrated in thirteen secondary schools in France, Germany, Luxembourg, Ireland, the Netherlands, and the UK. An integrated ENERGE platform puts together novel data interactions and teaching strategies for engaging students and teachers in new energy and comfort practices. Students are involved in the design of the ENERGE solution and at a later stage in the design and execution of energy efficiency interventions, using their schools as living labs.

The project has analysed the education governance structures in Europe in general and in the six pilot countries specifically, to investigate the decision-making power of secondary schools in Europe. Whilst around a third of European countries grant a high degree of autonomy to schools for managing financial and human resources, in a small group of countries—Germany, Greece, France (primary education), Cyprus, Luxembourg (primary education), Malta and Turkey—schools have very limited or no freedom in this area [63]. In general, schools have more autonomy on operational expenses than on capital expenditures. Empowering students to increase the energy efficiency of their schools and experiment with new energy concepts is therefore limited by the level of autonomy a school has, as is the possibility for school headmasters and teachers to introduce living lab-style education.

By means of two rounds of co-design sessions, the project has generated contextual knowledge on the present understanding, values, practices and preferences surrounding energy and comfort in European secondary schools. The co-design sessions were conducted in the first year of the project, and combined techniques from context mapping and stakeholder analysis. Small groups of students and teachers were invited to participate in sensitising activities prior the sessions and the sessions themselves, representing each the thirteen schools.

Archetypes have been preliminary defined to provide an overview of the diverse level of awareness and active commitment to engage in meaningful discussions as well as actionable practices for change. The archetypes were framed under the four quadrants of conformism considering the following two dimensions [64]: (1) The user's mindset towards managing indoor climate at school, and (2) his/her activeness of taking sustainable actions (e.g., speaking up his/her mind, initiating a school event). Each archetype illustrates the characteristics, needs and wishes of potential users. Figure 5 illustrates the archetypes in the four quadrants of conformism. Below is a brief description of each:

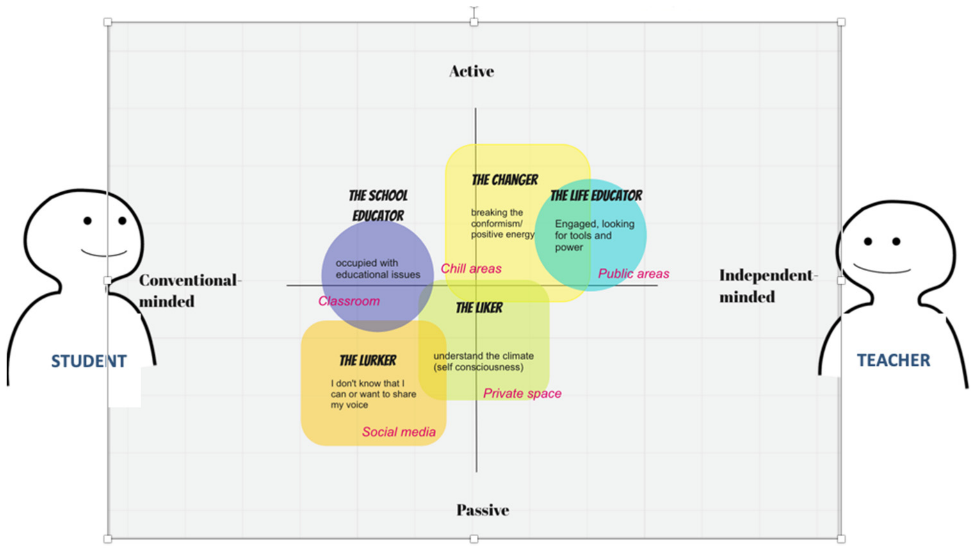

Figure 5. ENERGE school archetypes describing attitudes towards energy management on two dimensions the level of awareness and active commitment. Reproduced with permission under open access from [62].

The *Changer* is the most active potential user who cares and fights for creating a greener school environment. This group dares to break the conformism and challenge the tradition. Although they are just a minority group among the students, they want their voices to be heard.

The *Liker*, is aware of the impact of the climate change, but prefers to stay modest with his/her options. This group want to be cool and be liked by their peers. Being an anonymous/low-key contributor is acceptable but speaking up is way too nerdy.

The *Lurker* represents the majority of the students, who do not want to share or do not know sharing his or her opinion can make a difference. This group is a bigger fan of social media than our planet.

The *School Educator* represents the teacher who is fully dedicated in the educational obligations and has little time for tasks beyond. Practicability and efficiency are the key.

The *Life Educator* is the teacher who is highly engaged in coordinating and promoting the green actives at the school. They are passionate about passing on the knowledge of sustainability to their students and colleagues. New tools and platforms related to the climate are favoured by this group.

In general, students show little initiative in terms of actively engaging in changes, due to reasons such as accepting the status quo and keeping a "cool image" of being uninterested. However, there are also students showing interest for change yet not actively engaging in it, and a smaller group of students who are actively involved while feeling the need to involve others to make impactful changes. From teachers, the work pressure indicated the presence of two archetypes: one that focuses their teaching efforts on covering all aspects in the educational curriculum, and one that explores ways to apply the knowledge into societal issues, such as sustainability.

With regard to preferences, both teachers and students express the need to (a) generate awareness and an evidence-based understanding of the implications of their school needs and activities on energy use, and (b) generate a critical mass of actors in the school to be effective in acting and making changes.

The presented knowledge has been used as input for the first intervention to be deployed at all schools. The intervention aims to explore and define the role of energy and comfort data visualisations and interactions, to increase awareness and activate students and teachers. By means of interactive challenges, the intervention aims to help students and teachers to identify relevant comfort and energy issues and understand their impact. The first iteration of the intervention will focus on students' and teachers' engagement by involving desired qualities such as, "fun", "challenging" and "social". In later iterations, the focus will lie on (a) integrating knowledge generated by other partners in the project in relation to teaching modules, energy strategies and social practices for change; and (b) scaling up issues, actions and impact across ENERGE schools and ultimately to schools outside ENERGE.

5.4. MAKING-CITY

MAKING-CITY aims to demonstrate the possibilities of the PED concept by implementing and/or replicating the findings of two lighthouse cities, Groningen and Oulu, in six follower cities in Europe [65]. One of the main challenges for developing PED districts is raising awareness among residents on the energy transition and relating this to the local issues, such as climate adaptation, (e-)mobility and public green. In Oulu, an operational model was adopted based on community "bridges" and forums that are publicly accessible, whereas in Groningen, Unified Citizen Engagement Approach (UCEA) was developed, which involves individuals, local initiatives, and the municipality.

Currently, the UCEA is being tested and evaluated in several neighbourhoods in Groningen in collaboration with several local energy initiatives. The UCEA is an integrated approach which combines the perspectives of the individual, the cooperative and the municipality, suggesting pathways and interactions for each of the three actors in the process. In accordance with the flexible nature of the citizen engagement process, it is a dynamic and iterative model, suggesting tools and methods that could be utilised to achieve certain milestones in energy transition. The key challenges are:

- Building a solid foundation of community trust is essential for any type of intervention to be supported by the neighbourhood. In Groningen, the erosion of trust in (local) government due to the earthquakes in the region makes the community weary of government interventions in their neighbourhoods.

- Tenants stated that they are often not involved in meetings organised by local energy initiatives, because they are not applicable to their situation and/or it lacked a personal approach.
- Students are often afraid of possible reprisals by their landlords by bringing up issues surrounding sustainability.
- Shortage of (professional) manpower is a frequently occurring issue in local energy initiatives.
- Several stakeholder groups, such as (social housing) tenants, (international) students and private landlords are seldom approached or addressed in energy-related activities and campaigns.
- Communication surrounding energy-related activities is often perceived to be insufficient, inefficient or (inadvertently) excludes certain groups of residents.

Furthermore, the lighthouse cities have developed a series of questionnaires and tools with the aim of facilitating the co-creation of PED-designs in six follower cities (Leon, Spain; Kadikoy, Turkey; Bassano del Grappa, Italy; Lublin, Poland; Trencin, Slovakia; Vidin, Bulgaria). These modular questionnaires include a variety of topics relating to energy, such as consumption, generation, efficiency and flexibility as well as questions pertaining to mobility and social cohesion (development of local communities). The data from the questionnaires will be utilised to construct potential indicators that will help the FWCs to realise their own PEDs and encourage them to further develop City Visions 2050.

The objectives of the cities vary from one to another, depending on local community development readiness in their respective contexts. Four of six FWCs would like to know their citizens' needs/vision for the city district, directly or indirectly related to energy. The desired insights range from creating awareness about energy transition/needed measures, to gathering opinions about measures/concepts, to insights into the needs/visions on how to improve the living standards of citizens. Most of the FWCs have an overall plan (e.g., SEAP, SECAP) and two of them have taken action to consult citizens on their preferences in specific solutions. They have already utilised a few tools, such as hackathons, workshops, webinars, ateliers, online surveys, online platforms, meetings, door-to-door surveys, thematic games, debates, public consultations.

In addition, they would like to develop festivals, conferences and workshops in the city as well as webinar platforms, mobile applications, educational materials and e-participation and consultations. Most of the cities face barriers to realising citizen engagement activities. These barriers need to be considered, as COVID-19 measures prohibit certain activities and events. Furthermore, low awareness and low interest among citizens relating to the topic, limited time, high costs, limited authorisation to act and difficulty to reach target groups (e.g., elderly) can complicate matters further.

The barriers could be overcome by financial and technical support as well as subsidies from public bodies and energy markets, by raising awareness and performing measures by involving the local community, selecting the right platforms at the right time, conducting training programs for certain stakeholders (on sharing information and to promote better collaborations) and sharing information on renewable energy through open data platforms. The initial recommendations for the citizens of FWCs are therefore as follows:

- The Unified Citizen Engagement Approach incorporates different stakeholders and provides insights into what to share and communicate and how to collaborate in each phase of the transition of a neighbourhood.
- This strategy also provides a good framework to recommend usage of specific measures, methods and tools in the different phases of the energy transition.
- There are two main activities at the start of the energy transition: a social(-economic) analysis with citizens and a technical analysis of the target neighbourhood. Citizen engagement starts in this first phase.

A detailed analysis will be conducted soon to encourage FWCs in developing energy communities to sustain the energy transition and PED implementations in the already designed areas under the MAKING-CITY project.

5.5. mySMARTLife

The mySMARTLife project aims to make the three lighthouse cities of Nantes, Hamburg, and Helsinki more environmentally friendly by reducing the CO_2 emissions of these cities and increasing the use of renewable energy sources [66]. As part of an open innovation strategy to engage citizens to demonstrate the possibility of efficiently addressing the energy transition issue whilst keeping high-quality living standards, mySMARTLife explored the topic of raising social awareness and acceptance of change by developing key factors that can help raise awareness for social acceptance and engage citizens directly in the development of the transformation. The project involves citizens in the urban transformation, either as consumers/users or as city "planners". The three lighthouse cities have implemented interventions in the field of energy, mobility, and ICT, exploring the key barriers these cities have encountered during the implementation phase and how they tried to overcome them.

As part of this analysis, mySMARTLife explores the individual acceptance journey for each intervention based on the process of design, delivery, and implementation of each action and on who has influence in the acceptance journey (individual/household, local community/town stakeholders and national/regional policies or stakeholders) at which point of the implementation process. These influence levels were characterised as miso (individual/household), meso (local community/town stakeholders) and macro (national/regional policies and/or stakeholders) [67].

Based on these two categories, three types of acceptance journeys were developed: the binary (inflexible), the semi-flexible and the flexible acceptance journey. By looking at each of the individual case studies under the lens of the acceptance journey concept, it is advised when actions should be taken towards whom so social acceptance can be leveraged in the best possible way (intervention points or engagement points).

It is useful for all the actors in a smart city project to better understand the underlying structure of their interventions and, through their understanding, adapt the process of community engagement. This will allow for an increase in social acceptance.

One of the first lessons learnt is that by analysing the individual acceptance journey for each intervention based on the phases of design, delivery, and implementation of each action and on who has influence during the acceptance journey (individual/household, local community/town stakeholders and national/regional policies or stakeholders), intervention points can clearly be defined.

If the increase in the level of influence that the user has will lead to an increase in acceptance, as such it is important to include the user as early as possible in the design and delivery phase of the interventions. It can also be demonstrated that this can be difficult when it comes to large-scale infrastructure measures. There is a need across all smart city projects to increase the influence of users at the town/community level and to allow users' views and perceptions to exert an influence at national and regional levels. Users must be heard and be able to influence interventions, in order to increase social acceptance [68].

5.6. POCITYF

POCITYF helps historical cities to become greener, smarter, and more liveable, while respecting their cultural heritage, by implementing and testing Positive Energy Districts in two lighthouse cities, Alkmaar and Evora, and six follower cities [69]. POCITYF brings together technology providers, grid operators, policy makers, and local communities to collectively work on integrated innovative solutions across the built environment, energy infrastructure, and e-mobility. Building upon the Arnestein ladder [52] and an initial qualitative study with stakeholders in the two lighthouse cities, a citizen engagement strategy framework was developed. This framework supports the exploration of strategies and initiatives to support citizens in evolving along their journey toward higher levels of engagement with sustainable energy solutions, from the initial awareness and usage, to more proactive activities such as sharing, co-designing and becoming ambassadors. This framework has been iteratively used in iterative co-creation workshops with citizens, lighthouse cities and fellow cities to gain feedback and develop tailored strategies to foster citizen engagement. One of POCITYF's key solutions is to have citizens become key stakeholders in the decision-making process to incorporate a peer-to-peer (P2P) energy trading platform. P2P energy trading empowers citizens to feel in control of their own energy flexibility and to create economic value in a direct way. P2P energy trading could also be leveraged to enhance a community's social cohesion by stacking non-energy-related services that have been identified as bringing added value to members and nudging people to adjust their behaviour.

5.7. Synthesis of Case Studies

Synthesis topic 1. Scope of modalities for energy citizens addressed in the projects—In what ways can citizens potentially engage in positive energy districts and thus contribute to the societal objectives of PEDs?

The six projects have different strategies for involving different citizens' populations in the design and implementation of PEDs, ranging from early stage involvement in the role of "urban planners" in the mySMARTLife project, to citizens becoming active energy traders in the POCITYF project, to citizens as co-innovators in +CityxChange. Promoting citizen engagement is very much in the foreground of all the projects. Most projects regard energy literacy as a key condition, as an understanding of the nature and role of energy in the world and daily lives, accompanied by the ability to apply this understanding to answer questions, solve problems, contribute to, or start initiatives, and make decisions.

Within the projects, the models of citizens' involvement are often spread across work packages, with engagement activities in a separate work package to the development of local energy trading platforms. As a result, there could be a lack of consistent shared vision across the different models for energy citizens. In particular, the model for energy citizenship that is most often related to the development of PEDs—energy communities operating the local energy systems and as energy market party—is not addressed by the same research group as the group working on addressing engagement.

Synthesis topic 2. What is the interest in, acceptance and uptake of citizens of these options to engage in the energy systems of positive energy districts?

Increasingly, across the projects, more insights are gained on the issue, which is crucial to assuring any impact from citizenship in PEDs. Still, few examples are available where citizens have been able to have a substantial impact on the design of PEDs, beyond the legally required consultation procedures. This was the case in exceptional advanced communities, which are not representative of other much larger citizen demographics that need to be engaged in replication of PEDs to achieve a wide-reaching impact. In many cases, property ownership is needed to participate in the energetic PED work with retrofits or installations of renewables on buildings. Tenants or citizens from other areas have limited options. Therefore, in many projects, for example +CityxChange, additional roles are identified, for example citizens as co-innovators, engagement of those people working, but not living in a PED area, as well as regulatory initiatives that would need to make it easier for citizens to participate instead of only larger commercial or municipal actors.

It is necessary to differentiate between different (groups of) citizens, and their varying capacities for participation, which align to the "system world" of development and planning in a variety of ways. It seems that some frontrunner groups of citizens with higher social or financial capital are more interested in, and capable of, engaging in ways that actually drive decisions in PED-development, whilst other residents mainly have the option to engage in activities stimulating "energy-conscious" individual behaviour. The mutual relationship between being a PED inhabitant and making lifestyle changes towards sustainable behaviour is also still very much a subject of research and no results are available yet.

The number of energy communities, particularly those developing local renewable sources, is growing, as are the impacts of these communities. In the Netherlands, 100,000 people already participate in local renewable energy projects [70]. Whether PEDs could become a new driver for building energy communities is not clear yet.

The development of local communities engaged in local peer2peer energy trading (P2P) and flexibility trading and acting as an energy market party is, so far, mainly technology-driven (development of ICT platforms and interfaces). Its rationale is based on societal costs and benefits (avoiding investment while improving resilience in the power infrastructure). There is still little evidence that citizens are willing to engage in sufficient numbers, especially those citizens beyond the initial frontrunner communities. In this case, "sufficient" means enough to ensure impact and viable business cases. In some cases, there appears to be a reluctance, even amongst frontrunner groups, as benefits are not recognised as outweighing the complexity and risks. Additionally, automatised approaches seem to be preferred [34].

Finally, we observe that in all projects, much time for research and development is needed in order to build the systems through which citizens can engage. This also applies to the development of the simple interfaces allowing interaction without the need for expert knowledge. It is difficult, therefore, to engage a representative group of citizens in these R&D activities.

Synthesis topic 3. What real impact from citizen engagement is already observed in the ongoing demonstration projects of positive energy districts?

In all projects, KPIs have been adopted on social impact and citizen engagement, but there is much variety in how they are defined, ranging from KPIs related to the mere number of events and participants, to KPIs on the progress made towards energy citizenship in terms of the share of local energy trading in the ATELIER project [71], or the impact on organisations that changed their energy behaviour in +CityxChange [72]. In most cases, the focus of the reported results and lessons learned has been on the barriers and drivers of citizen engagement, and not on the impacts that have been achieved so far, nor on the validation of the impact pathways. At this stage, only fragmentary results are available, for instance from the ATELIER project, where energy communities have been reluctant to adopt local energy trading, which provides valuable insight into evaluating the potential impact of this innovation [44]. The positive energy champion campaign of +CityxChange (see Section 5) has seen some behaviour change, mainly on the non-energy aspects, though also with initial changes around eMobility. It is noted that the projects referred to in this paper are on average about halfway through the project duration, with the initial phase focused on setting up the activities for citizen engagement. Results are expected to be seen in the later phases of the project only.

Synthesis topic 4. Progress towards transdisciplinarity impact assessment

We evaluate the progress based on the seven criteria as proposed by the SHAPE-ID project [30–32].

1. Level of common vocabulary/terminology among different disciplines (and non-academic actors) and efforts made to reach a common "glossary" as a starting point for the project. This remains, in many projects, a work in progress. For example, in +CityxChange, a glossary was initially built separately in the energy and citizen tasks, which then needed to be aligned through a longer process and has also since been added to its website. In ATELIER, there is a difference in perspective on energy citizenship from the technical, legal and sociological perspectives, which hampers a common evaluation of impact.
2. Level of common vision across disciplines on PEDs and energy citizens as an object of research, impact targets and pathways between research outcomes and impact. This is still very much a work in progress in all projects.

3. Progress in development and application of shared research methodology and impact assessment framework (impact pathways), complementing disciplinary approaches. In most projects, assessment methods are still multidisciplinary and derived from the separate disciplines. A challenge can be an actual deep evaluation of project interventions and their impact dependencies to project goals.
4. Progress on qualitative and quantitative (interim) results on impact indicators towards societal goals. The projects have adopted varied ways to measure the impact of their citizen engagement interventions, in most cases on the basis of Key Performance Indicators (KPI)-based tracking and performance evaluation. Significant differences in the approaches to KPIs can be observed, which make cross-project comparison very difficult.
5. Levels of citizens' involvement in the design and implementation of research (beyond being the object of research). Many projects organise citizenship consultations, but there are few examples that citizens have had an impact on the design of the PED and the design of specific innovations. In the case of new construction, it is impossible to involve the actual residents at the initial stages of the projects, as they have not moved in yet. Similar effects apply in mainly industrial or commercial areas, where engagement aims at users of the area, not residents, for example in a +CityxChange demo.
6. Initial structure of the project proposal that might enable or constrain, even from the beginning, inter and transdisciplinary approaches. The positioning of citizen engagement activities in the design of the projects varies. Some projects have separate work packages for citizen engagement, making it a mere isolated activity restricting multidisciplinary approaches, where other projects integrate citizen engagement with other, often more technical, activities during the project lifetime.
7. Evaluation of the project activities envisioned at proposal stage/first year of the project to gain potential missing knowledge/experience in order to reach desirable levels of inter- or transdisciplinarity (depending on what is desirable according to the project goals).

All in all, the R&I projects on PEDs are still in the early phases of developing a transdisciplinary approach to the impact assessment of energy citizenship towards the societal goals. While the projects are working to develop and apply this approach within each project's lifetime, the results in terms of full transdisciplinary impact assessment may be realised in the next generation of R&I projects' PEDs.

6. Discussion and Recommendations

In this paper, we have explored the hypothesis that citizens' engagement through energy citizenship is a key driver towards the societal impact of the energy transition in general, and in positive energy districts. Although there is a common understanding that the active support and involvement of citizens in the design and implementation of new collaborative energy concepts, such as PEDs, is necessary for the success of such concepts, there is no hard evidence yet that supports this claim. Some promising approaches were discussed in the case studies. Measuring the contribution or impact of citizen engagement on the success of new energy concepts has proven to be difficult. We see that research and innovation projects in this area are still at an early stage in developing approaches to rigorous impact assessment.

One of the main difficulties is the transdisciplinary nature of the projects and the combination of social, political, and technological interventions that are simultaneously conducted which obscure the impact of a single intervention. Another difficulty is the context-dependent nature of these solutions, which challenges the generalisation of rich yet contextualised knowledge. The lack of a common methodology for assessing the impact of energy citizenship hinders the direct comparison of the efficiency of strategies for citizen engagement across projects or cities.

A systemic perspective that is sensitive to the contextual determinants of each project should contribute to harmonising the measurement of citizen engagement activities and the related KPIs across the six projects. This is considered a first step towards an understanding of the role and importance of energy citizenship in the energy transition.

The following project approaches could be explored:

1. Avoid project designs that are only based on disciplines, such as those with a separate work package for social impact and citizen engagement, which hampers working in cross-disciplinary teams. Work packages are better structured around specific innovations or have strong integrations between the respective tasks and regular feedback between topics.
2. Develop a shared theory of change and shared impact pathways on energy citizenship across all project partners and disciplines.
3. Appoint so-called boundary spanners with the research team; individuals with multi-disciplinary knowledge, who can speak more than one disciplinary language. They can make the required links across the project.
4. Share and discuss the theory of change with the citizens. Do they share the same vision?
5. Invite citizens to the table when designing the research agenda for impact assessment and give citizens (or their representative) an active role in the research activities.

Finally, the authors recognise that the exchange and cooperation between R&I projects that address energy citizenship and PEDs is essential to assembling the necessary evidence on impact across the many modalities of citizen engagement, the broad spectrum of PED designs and the different city contexts in which PEDs are located. In particular, this exchange should collect and synthesise the emerging insights on impacts around specific modalities for energy citizenships, such as individual behavioural change and collective energy, building, mobility and societal engagement. Only collectively can we determine how far energy citizenship could contribute to the energy transition.

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