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Original research article

Combining storylines of energy citizenship with narratives of future-world evolutions to design transformative and socially informed energy transition scenarios

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ABSTRACT

Despite a growing body of research seeking to integrate social sciences into scenario-based research and modelling, climate policy analysis remains largely dominated by top-down approaches that underrepresent the sociopolitical dimensions of the energy transition, particularly at the local level. In this context, the concept of energy citizenship has gained increasing attention as a means of fostering more inclusive, democratic, and equitable energy systems. However, significant gaps exist regarding its conceptual clarity, operationalisation, and systematic integration into scenario-based research and modelling practices. This study addresses these gaps by presenting a novel interdisciplinary framework for transformative scenario design that explicitly links social innovations of energy citizenship with alternative future-world evolutions. We deconstruct energy citizenship into distinct patterns and trends and translate them into people-centred storylines that capture diverse forms of individual and collective engagement in the energy transition. These storylines are embedded within three future-world narratives inspired by the Shared Socioeconomic Pathways, while describing alternative long-term pathways in which citizen agency, social practices, and collective action play the central role. We construct a multilayered scenario space that enables systematic exploration of decarbonisation pathways informed by empirical research clarifying the concept of energy citizenship, while also testing the robustness of transition strategies under contrasting sociopolitical conditions. Overall, the proposed framework advances understanding of how energy citizenship can shape mitigation pathways, while also providing less stylised and more transparent assumptions for scenario-based modelling. It also offers a platform for continued exchange between modelling communities, policymakers, and practitioners, supporting more inclusive climate action.

1. Introduction

The European Union (EU) has set ambitious climate and energy targets through policy strategies such as the "Clean Energy for All Europeans Package" [1] and the "European Green Deal" [2], which aim for net-zero greenhouse gas (GHG) emissions by 2050 and call for a fundamental transformation of energy systems. Central to these ambitions is the EU's *Energy Union* strategy, which explicitly places people at the centre of the energy system, envisioning a future in which citizens both benefit from and actively participate in the energy transition [3]. Achieving these goals requires not only technological innovation and new infrastructure, such as smart grids and local electricity markets [4], but also socially just and inclusive decision-making processes. Incorporating citizens' perspectives, thus, can strengthen engagement, legitimacy, and acceptance, enabling policymakers to design regulatory environments that support sustained participation in the green transition [5].

Despite these policy aspirations, energy-related discourse and analysis have long prioritised technological optimisation and economic feasibility, often sidelining questions of governance, equity, and citizen agency [6]. This tendency is particularly evident in climate and energy

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Nomenclature

Acronyms and abbreviations

AACODS	Authority, Accuracy, Coverage, Objectivity, Date, and Significance (quality checklist)
BESS	Battery energy storage system
CAJ	Climate assembly and jury
CEC	Citizen energy community
CEIs	Collective energy initiative
CO_2	Carbon dioxide
DR	Demand response
EC	European Commission
E3	Energy-Environment-Economy
EU	European Union
EV	Electric vehicle
GenAI	Generative Artificial Intelligence
GHG	Greenhouse gas
HVAC	Heating, Ventilation, and Air Conditioning
IAM	Integrated Assessment Model
IPCC	Intergovernmental Panel on Climate Change
LED	Light emitting diode
NECP	National Energy and Climate Plan
NIMBY	Not In My Back Yard
P2P	Peer-to-peer
PV	Photovoltaic
RCP	Representative Concentration Pathway
REC	Renewable energy community
RES	Renewable Energy Source
SSH	Social Sciences and Humanities
SSP	Shared Socioeconomic Pathway
V2G	Vehicle-to-grid
VPP	Virtual power plant

modelling, where technoeconomic variables- that can more easily quantified- such as costs or system efficiency, tend to dominate, while societal dimensions are treated as secondary or exogenous [7]. Such approaches risk producing simplified scenarios that overlook equity considerations, social acceptance, or behavioural and lifestyle changes, thereby undermining the realism and long-term relevance of transition pathways [8]. Yet transitioning to decarbonised energy systems aligned with the EU's climate goals and the Paris Agreement is inherently a social process that does not always conform to least-cost optimisation principles [9].

In response, an expanding body of research seeks to integrate insights from the field of social sciences and humanities (SSH) into scenario-based research and modelling practices [10]. Accounting for societal dynamics allows modellers to better reflect real-world behaviour, design more effective policy interventions, and support inclusive decision-making [11], in line with the EU's commitment to "leave no one behind" [12]. Nevertheless, many scenario frameworks remain largely top-down and technocratic, underestimating social, cultural, and political dynamics; particularly at the local level, where implementation challenges are most acute [13].

Against this backdrop, the concept of "energy citizenship" has gained prominence as a lens for understanding and enabling more democratic, inclusive, and equitable energy systems [14]. Although no universally accepted definition exists, early work by Devine-Wright [15] framed energy citizenship as "*a view of the public that emphasises awareness of responsibility for climate change, equity, and justice (…) and the potential for (collective) energy actions*". Subsequent contributions have highlighted the multiple roles citizens can assume in the energy transition, including consumers, prosumers, supporters, or activists [16]. Despite its growing visibility, however, energy citizenship remains unevenly conceptualised and underutilised in both research and practice [17], with scholars and practitioners noting that what "citizenship" in the energy domain entails is still open to interpretation [18].

Recent interdisciplinary work drawing on psychology, economics, law, and political science has expanded understanding of energy citizenship and its drivers [19]. For example, Biresselioglu et al. [20] synthesise evidence across sociopolitical, economic, environmental, psychological, and ethical dimensions, identifying key determinants of citizen engagement. At the same time, these studies underline persistent limitations: empirical evidence remains fragmented, and the concept is rarely operationalised in ways that enable systematic integration into policy design or modelling practice. As a result, energy citizenship often remains a largely theoretical construct, with limited influence on how transition pathways are formulated and assessed.

Several studies have therefore called for greater attention to the concrete practices through which energy citizenship is enacted in everyday life [21]. This perspective shifts the focus from abstract definitions towards understanding how citizenship is performed, negotiated, and institutionalised across different contexts. In the words of Silvast & Valkenburg [22], "*the concept of energy citizenship (…) needs to include reflection on how citizens are positioned and how their membership is substantiated in concrete energy citizenship initiatives*". This reframing moves the debate from "who" qualifies as an energy citizen to "what" constitutes energy citizenship in practice [23], highlighting the need for analytical frameworks that can bridge conceptual insights with applied research.

However, despite the expanding literature, structured frameworks that explain how energy citizenship can be operationalised, categorised, and assessed over time- particularly within scenario-based research and modelling practices- remain scarce. The ambiguous nature of the concept, combined with the growing need to embed sociopolitical dimensions into scenario-based modelling practices, reveal two interconnected gaps: 1) the lack of operationalisation of energy citizenship and, 2) the absence of systematic approaches for integrating its diverse manifestations into scenario design. In this context, this study addresses these gaps and explores interdisciplinary connections between energy citizenship and scenario-based research by introducing a novel framework for scenario design that is transformative, by incorporating social innovations of energy citizenship to support socially informed, people-centred scenario-based research and modelling.

To do so, we begin by deconstructing energy citizenship into distinct trends and patterns of relevant citizen actions. Building on insights from the scientific literature, we translate the identified patterns into "people-centred" storylines- qualitative representations of energy citizens' agency and social practice as primary drivers of the energy transition. We then combine these storylines with three purpose-built future-world narratives informed by selected dimensions of the Shared Socioeconomic Pathways (SSPs). The SSPs are used as a conceptual reference space to encompass interdependent socioeconomic assumptions and quantitative projections. Though originally intended primarily for long-term climate and integrated assessment applications, we use SSPs to provide a parsimonious and model-agnostic set of contextual conditions that can be applied across spatial scales, modelling traditions, and participatory settings. The three narratives therefore neither reproduce nor replace the SSPs. They instead translate selected structural dimensions relevant to energy citizenship into reference, enabling, and constraining contexts, capturing a broad range of sociopolitical contexts and uncertainties [24]. In line with recent scenario-development efforts [25] that emphasise narratives as interfaces between social theory and modelling practice, the resulting framework is designed not to predict behaviour, but rather to make underlying assumptions explicit, support strategic dialogue, and imagine potential decarbonisation pathways

under contrasting social and institutional conditions.

To the best of our knowledge, this is the first framework to operationalise energy citizenship for the design of socially informed decarbonisation scenarios while explicitly accounting for uncertainty and the dynamic character of future developments. Its novelty lies in its modular, two-dimensional architecture, which allows people-centred storylines and structural future-world conditions to be varied independently or simultaneously. More specifically, the framework enables the exploration of "what-if" decarbonisation scenarios through:

i. Variation in individual/collective behaviour and decision-making based on patterns of energy citizenship, under constant external conditions.
ii. Variation in the broader sociopolitical and socioeconomic environment, under constant agency of energy citizens; thereby isolating the potential of future evolutions for climate change mitigation or adaptation.
iii. Simultaneous variation in both individual/collective expressions of energy citizenship and external conditions, allowing for in-depth assessment of plausible, contrasting and unexpected future evolutions.

2. Literature background

Representing individual and collective facets of energy citizenship in scenario-based research and energy modelling remains a significant challenge. While interdisciplinary collaboration has the potential to enhance realism and generate deeper insights into climate and energy transitions, systematic and replicable pathways for embedding social dimensions into quantitative scenarios are still underdeveloped [26]. Recent contributions have begun to address this gap by proposing strategies to connect social sciences with integrated assessment models (IAMs) and energy system models. For example, McGookin et al. [10] present a practical framework for public and stakeholder engagement in climate and energy modelling, identifying multiple entry points for participation while also highlighting persistent challenges related to stakeholder selection, power asymmetries, and the communication of uncertainty. Trutnevyte et al. [27] further identify three broad strategies for integrating social aspects into modelling practices- bridging, iterating, and merging. Among these, the merging strategy is the most ambitious, seeking to place technical, economic, environmental, and social factors on equal analytical footing. However, it also exposes fundamental difficulties associated with translating complex, context-dependent, and often intangible social concepts into formal model representations [26]. Along similar lines, Senkpiel et al. [28] engage social scientists and modellers in an interdisciplinary dialogue to examine which societal factors should be considered, how relevant data can be collected, and which theoretical pathways exist for meaningful integration. Their findings reinforce the conclusion that substantially deeper interdisciplinary collaboration is required to improve the robustness, transparency, and policy relevance of modelling outcomes.

Alongside these efforts, a complementary body of SSH-oriented and arts-based research examines climate and energy futures as cultural and imaginative constructions rather than solely as analytical projections. This literature demonstrates how stories and storytelling can reveal lived experience, tacit knowledge, affect, and social meaning that tend to remain obscured in formalised analyses [29]. Insights from these fields make visible the cultural and normative assumptions through which futures are constructed, while opening space for more plural, contested, and potentially transformative understandings of low-carbon transitions [30]. Science fiction and speculative design are particularly relevant in this regard. By rendering alternative technological, institutional, and everyday arrangements tangible, they enable examination of how different energy futures might redistribute agency, responsibility, risks, and benefits [31,32]. Participatory storytelling further extends this capacity by placing community perspectives and locally situated experience at the centre of energy-futures exploration [33].Utopian and dystopian imaginaries are therefore valuable not because they predict future developments, but because they expose normative commitments, social tensions, and possible consequences. Comparative analysis of positive and negative low-carbon visions has demonstrated how such imaginaries differ in their temporal orientation, degree of radicalism, and representation of technological and societal change [34], while the combination of science fiction and normative energy ethics has enabled critical examination of competing futures centred on renewable-energy abundance or sufficiency [35].

These are precisely the considerations that may be marginalised within traditional scenarios which are a part of quantitative modelling. Some efforts have already been expended in building a bridge between two worlds. Direct dialogue between climate-fiction writers and integrated assessment modellers has revealed complementary approaches to constructing plausible futures [36], while an arts-based intervention involving an integrated assessment model has demonstrated how artistic practices can stimulate reflection on the metaphors, assumptions, and epistemological and ethical choices embedded in model-based scenarios [37]. Such exchanges remain exceptional, however, and systematic procedures for translating SSH-based insights into transparent and traceable modelling assumptions remain underdeveloped. The unresolved challenge therefore lies less in the capacity of SSH scholarship to engage with the social dimensions of future transitions than in overcoming practical and disciplinary biases to connect these insights with modelling practice.

More specifically, empirical attempts to integrate social dimensions into climate and energy modelling have often focused on isolated variables, such as cost of capital [38], actor behaviour [39], or social acceptance [40]. While valuable, these approaches tend to treat social factors in a fragmented manner, limiting their ability to capture the systemic and cumulative nature of societal transformation [41]. A recent review by Amin et al. [42], covering 79 studies that integrate social aspects into energy systems modelling, identifies five dominant approaches used to incorporate public perspectives into modelling: (i) model co-creation, (ii) active stakeholder engagement, (iii) incorporation of insights from engagement processes, (iv) scenario development, and (v) scenario integration. The authors highlight scenario-based approaches- particularly when combined with participatory methods- as among the most promising avenues for embedding societal perspectives. At the same time, they note that many participatory efforts remain shallow, frequently limited to consultation or information provision rather than deeper forms of collaboration that influence scenario logic and modelling assumptions.

In response to the need for structured, socially informed scenario frameworks, the SSP framework has emerged as a foundational architecture for scenario-based climate research [24]. Developed to support integrated analysis of climate impacts, mitigation, and adaptation, it comprises five qualitative narratives describing alternative socioeconomic pathways according to the challenges they pose to mitigation and adaptation [43]. Compared to earlier frameworks such as the "Special Report on Emissions Scenarios" [44] and the "Representative Concentration Pathways (RCPs)" [45], the SSPs provide a more explicit treatment of socioeconomic drivers, institutional capacity, and sustainability challenges, enabling more nuanced analyses of human-environment interactions [46].

SSP1 ("Taking the Green Road") emphasises inclusive development, international cooperation, and environmental stewardship, resulting in low challenges to both mitigation and adaptation. SSP2 ("Middle of the Road") extrapolates historical trends with moderate progress towards sustainability and intermediate challenges to both. SSP3 ("A Rocky Road") depicts a fragmented world characterised by nationalism, conflict, and slow economic growth, resulting in high challenges to both. SSP4 ("A Road Divided") focuses on widening inequalities in human capital, economic opportunity, and political power, resulting in high challenges to adaptation but comparatively low challenges to

mitigation. Finally, SSP5 ("Taking the Highway") combines globally integrated markets, rapid technological progress, strong economic growth, and investment in human capital with energy-intensive lifestyles and continued fossil-fuel reliance, resulting in high challenges to mitigation but low challenges to adaptation. Together, these pathways offer an important reference space for identifying key global development uncertainties.

Despite their widespread adoption, the SSPs also have limitations. Scholars have pointed to their limited epistemological and ontological grounding and insufficient integration of SSH perspectives, resulting in the underrepresentation of sociocultural dynamics, political processes, and power relations that shape long-term transformations [47]. Additional concerns relate to their applicability at regional and local scales, where global narratives may not adequately reflect local sustainability priorities such as land use, food security, water management, or social equity [48]. Direct downscaling of global SSPs can therefore oversimplify planning contexts and obscure critical trade-offs between environmental protection and socioeconomic needs. Further limitations arise from their predominant use in long-term analyses extending to 2100, which may be poorly aligned with the urgency of near-term climate action and policy implementation [49]. Moreover, lifestyle change, reduced consumption, and other transformative social dynamics remain weakly represented, constraining the exploration of alternative socioeconomic futures beyond conventional growth-oriented pathways [50]. Recent research has consequently explored speculative utopian fiction as a critical and comparative tool for interrogating the SSP framework and broadening the range of societal futures against which its underlying assumptions can be assessed [51]. These shortcomings reinforce calls for more transparent, empirically grounded, and socially informed scenario frameworks that are capable of addressing uncertainty, diversity, and scale more effectively.

Taken together, these debates emphasise the need not only work closely by each other, but to actually adopt and integrate perspectives across the SSH and natural sciences to strengthen their treatment of equity, well-being, near-term relevance, and multiscale applicability in the development of scenario frameworks. In an effort towards transdisciplinary collaboration, this study selectively adapts and recombines structural dimensions of the original five SSPs to make them relevant to energy citizenship, resulting in three new parsimonious future-world narratives. Combined with people-centred storylines grounded in individual and collective expressions of energy citizenship, these narratives provide a socially informed framework that prioritises interpretability and remains compatible with diverse modelling traditions, participatory settings, and policy applications.

3. Methods

We employed a four-step methodological approach that integrates insights from an extensive body of literature with knowledge elicited from stakeholders. This combination allowed us to capture practical and real-world dimensions of energy citizenship that can be operationalised within scenario-based research and modelling practices (Fig. 1). As a first step, we identified diverse manifestations of energy citizenship and synthesised them into people-centred storylines. Then, using the SSPs as a conceptual reference, we developed three parsimonious future-world narratives describing contrasting socioeconomic and political conditions under which energy citizenship may unfold.

Typically, in scenario-based research, the terms "storyline" and "narrative" are often used interchangeably, and their meanings are not consistently distinguished across research traditions. Taken together, existing uses of the terms nevertheless indicate a difference in analytical emphasis: narratives tend to describe plausible future-world evolutions through their broader characteristics and underlying logic, whereas storylines tend to foreground the logically or causally connected unfolding of particular drivers, actions, and developments [52,53]. Following this distinction, in our study, we define "storylines" as focused

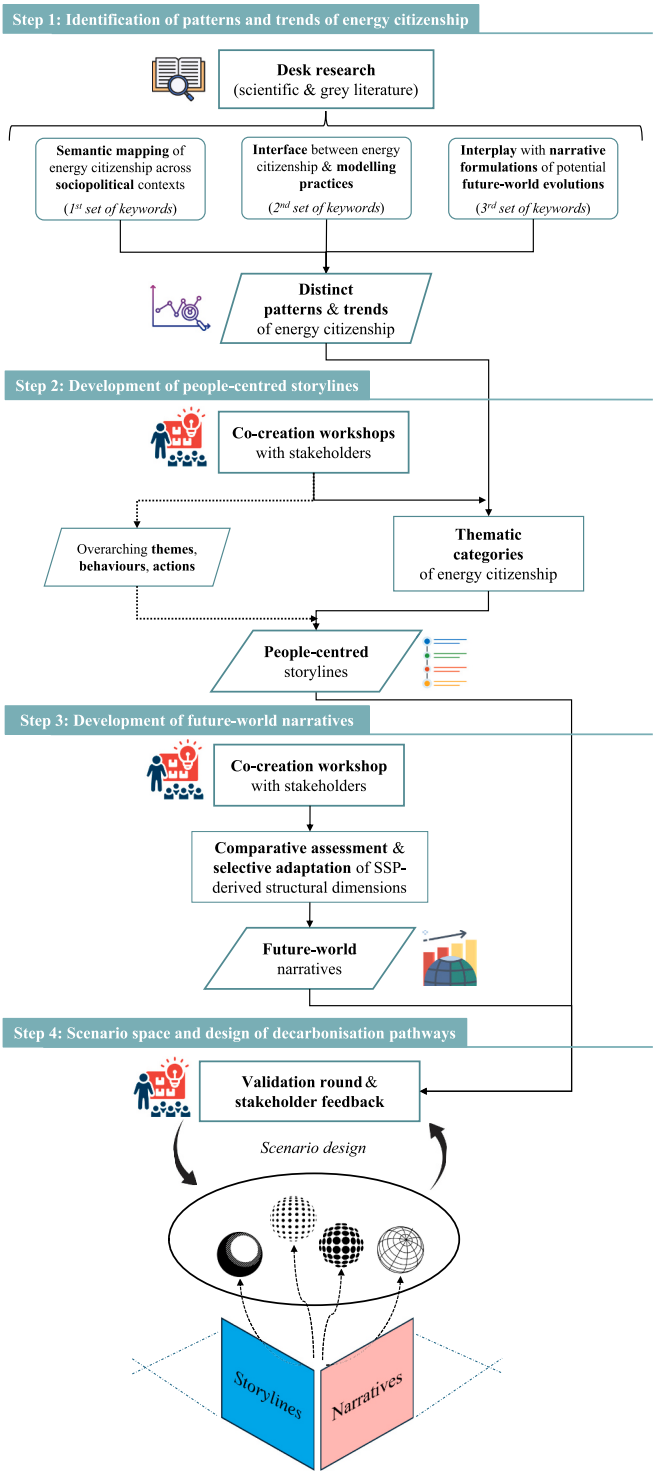


Fig. 1. Overview of the working approach applied.

representations of how particular configurations of citizen actions and practices may interact and shape the energy transition, while we define "narratives" as broader, internally coherent descriptions of the socioeconomic, political, and institutional contexts within which these actions unfold. Accordingly, the people-centred storylines constitute the actor-centred dimension of the framework, whereas the future-world narratives constitute its structural and contextual dimension.

Finally, we combined the developed people-centred storylines and future-world narratives to construct a two-dimensional scenario space within which decarbonisation pathways can be systematically explored.

Across all methodological steps, we explicitly accounted for multiple demographic groups and geographic scales by distinguishing between individual and collective forms of energy citizenship, and by situating these within future-world narratives that can be operationalised at local, national, and global levels. This ensured that the resulting scenario space could reflect socially and culturally diverse contexts rather than a single, scale-specific transition logic. This work was carried out from October 2022 to June 2024 as part of the European Commission (EC) funded Horizon 2020 project "ENCLUDE[1]".

3.1. Step 1: identification of patterns and trends of energy citizenship

The first step consisted of desk research aimed at mapping the breadth of existing literature on energy citizenship and its links to scenario-based research and climate and energy modelling. The review covered both scientific and grey literature, recognising that each source type contributes complementary insights. Peer-reviewed publications enabled the identification of conceptual foundations, dominant framings, and research gaps, while grey literature, such as policy reports or technical documents, provided insights into current policy agendas, implementation challenges, and emerging practices.

Scientific literature was identified through searches in "Web of Science" and "Scopus", supplemented by targeted searches in "ScienceDirect". Given the breadth and evolving nature of energy citizenship, the initial search covered publications from 2010 to 2023 to capture both the conceptual development of the field and the gradual evolution of the associated trends and patterns. The grey literature review had a more targeted purpose and focused on reports issued by technical, governmental, and regulatory bodies from 2019 onwards. This cut-off was chosen because 2019 marked the introduction of the "European Green Deal", which set the direction for much of the EU climate and energy policy developed thereafter. The shorter timeframe also reflects the comparatively rapid evolution of policy frameworks, regulatory provisions, and institutional priorities, as older documents may refer to conditions or priorities that have since been revised or superseded. Earlier documents were retained where they remained foundational and directly relevant to the analysis.

To ensure the relevance and credibility of grey literature sources, we used the AACODS (Authority, Accuracy, Coverage, Objectivity, Date, Significance) framework as a qualitative screening guide [54]. Rather than applying a rigid scoring threshold, the framework was mainly used to support structured judgement regarding the reliability, policy relevance, and analytical consistency of the analysed documents. Institutional credibility was defined as the clear attribution of a source to an identifiable and established institution or organisation with relevant scientific, technical, governmental, or regulatory expertise. Documents whose authorship or institutional provenance could not be verified, or whose content consisted primarily of unsupported opinion rather than transparent and evidence-based analysis, were excluded. No institution was excluded categorically, and no ideological criterion was applied. The remaining documents were triangulated with peer-reviewed literature to ensure coherence with academic findings and to avoid over-reliance on non-reviewed sources. Overall, grey literature was used primarily to contextualise contemporary policy developments and emerging practices, rather than to derive the core analytical categories.

To structure and guide our desk research, we defined three sequential sets of keywords, each serving a distinct analytical purpose:

a. The first set was designed to conduct a semantic mapping of how energy citizenship is framed, expressed and organised across socio-political contexts, including terms such as: {"(energy) (prosumers) behaviour", "(energy) citizen(ship)", "low-carbon lifestyle", "social aspects", "energy justice/poverty/activism", "(energy) self-sufficiency/self-consumption", "energy (citizen) community", "collective energy initiative(s)", "participatory governance", "civic engagement in energy transitions", "climate protests/solidarity", "social innovation(s) in energy systems", etc.}.
b. The second set was designed to shed light on the interface between energy citizenship and modelling practices, including- but not limited to- the following keywords: {"energy (systems) modelling", "(integrated assessment) modelling", "energy (and climate) modelling" "scenario-based simulation", "storyline-driven modelling", "supply-side/demand-side models", "agent-based models", "behavioural/lifestyle/social innovation modelling", etc.}.
c. Finally, the third set explored the interplay between different manifestations of energy citizenship and broader societal and structural developments, including economic growth, political stability, environmental policy responses, and other drivers shaping alternative future-world evolutions. It comprised keywords such as: As such, it comprised of keywords including: {"scenario-based research", "shared socio-economic pathways (SSPs)", "scenario/narrative/storyline design", "climate policy/decarbonisation pathways", "energy transition storylines/pathways", "socioeconomic inequalities and climate impact", "global development scenarios", "energy security scenarios", "climate change adaptation and mitigation scenarios", "global governance under uncertainty", "(participatory) scenario development", etc.}.

Finally, as part of the grey-literature review, we also examined publicly available outputs, particularly deliverables, from recent EC-funded projects focusing on energy citizenship (i.e., "DIALOGUES[2]", "GRETA[3]", "EnergyPROSPECTS[4]", "EC2[5]") and climate and energy modelling (i.e., "SENTINEL[6]", "openENTRANCE[7]", "Paris Reinforce[8]", and "IAM COMPACT[9]"). This allowed us to situate the present study within the current European research landscape and to identify complementarities and gaps addressed by the proposed framework.

3.2. Step 2: development of people-centred storylines

Next, the recurring trends and patterns of energy citizenship were organised into four distinct thematic categories along two intersecting dimensions, informed by the work of Dunphy et al. [55]. The first dimension distinguishes between technology-mediated expressions of energy citizenship, in which citizens engage with the energy system primarily through physical assets, digital infrastructures, and market mechanisms, and socially-mediated expressions, in which engagement operates through behavioural norms, cultural practices, governance structures, and political action. The second, contrasts individual expressions of energy citizenship, centred on personal agency and household-level decisions, with collective expressions, rooted in shared governance, community ownership, and coordinated civic action. Together, these two dimensions defined a two-by-two analytical space that structures four people-centred storylines: "Power to the People" (individual-technology-mediated), "Band Together" (collective-technology-mediated), "Habitual Creatures" (individual-socially-mediated), and "People to the Streets" (collective-socially-mediated).

To validate and refine these groupings, we elicited knowledge from relevant stakeholders via two online open-discussion workshops that took place within the "ENCLUDE" project. This allowed us to reach out

[1] https://cordis.europa.eu/project/id/101022791.
[2] https://cordis.europa.eu/project/id/101022585.
[3] https://cordis.europa.eu/project/id/101022317.
[4] https://cordis.europa.eu/project/id/101022492.
[5] https://cordis.europa.eu/project/id/101022565.
[6] https://cordis.europa.eu/project/id/837089.
[7] https://cordis.europa.eu/project/id/835896.
[8] https://cordis.europa.eu/project/id/820846.
[9] https://cordis.europa.eu/project/id/101056306.

to a larger sample of field experts, representing all parts of the quadruple helix model of innovation, which recognises four major actors in the innovation system: science, policy, industry, and society [56]. In the quadruple helix setting, actors are involved in multi-layered, dynamic, bidirectional interactions rather than unidirectional push-pull relationships [57]. The workshops took place on 18 September 2023 and 2 October 2023 and brought together more than 30 participants, including community energy practitioners, municipal utility managers, social scientists, climate and energy modellers, representatives of collective energy initiatives, and undergraduate and postgraduate students from TU Delft (The Netherlands) and the University of Piraeus (Greece). Each workshop was facilitated by at least two ENCLUDE researchers and conducted in English, using online participatory tools, such as Kialo[10] and Miro.[11] Several workshop participants were also members of the ENCLUDE "Academy for Energy Citizen Leadership" [58], an online programme for leadership development and civic engagement towards decarbonisation, which allowed members to learn and hone their individual leadership and collective organisation skills and connect to one another and to energy experts.

Participants rotated through four thematic breakout rooms corresponding to the identified categories. Within each session, participants collectively enriched draft storyline archetypes by discussing key drivers, barriers, and illustrative real-world examples. Rather than relying on formal ranking or voting procedures, emphasis was placed on deliberation and consensus-oriented discussion, allowing participants to elaborate, challenge, and refine emerging storyline elements. Following the workshops, the research team synthesised the contributions across sessions, consolidating overlapping themes and clarifying distinctions where necessary. Final consolidation and interpretation of storyline elements were undertaken by the research team, informed by workshop discussions but guided by consistency with the broader analytical framework. These people-centred storylines. Representing the spectrum of individual and collective agency within the energy system across both technology-mediated and socially-mediated registers, constitute the first axis of the two-dimensional scenario space presented in this study.

3.3. Step 3: development of future-world narratives

The third step focused on constructing the second dimension of our scenario space: future-world narratives describing alternative socioeconomic and political contexts within which energy citizenship may unfold. These narratives serve to structure the exploration of plausible futures and to contextualise the expression and effectiveness of people-centred storylines. Drawing on insights from our desk research, and particularly on major assessment and scenario resources such as the IPCC's "Special Report on Global Warming of 1.5°C" [59], the "Sixth Assessment Report" [60], and the "AR6 Scenarios Database" [61], the SSPs emerged as a coherent conceptual reference for capturing global socioeconomic, political, and environmental uncertainties.

Rather than treating each SSP as an indivisible pathway, the five SSPs were comparatively examined across structural dimensions considered particularly relevant to the conditions under which energy citizenship may unfold. These included international cooperation and geopolitical integration, governance and institutional capacity, socioeconomic development and inequality, technological progress and diffusion, and environmental policy orientation. The unit of adaptation was therefore the individual structural dimension rather than the complete SSP pathway. This allowed relevant characteristics to be selectively retained and recombined without importing the SSP framework's complete configurations of assumptions or their associated quantitative projections.

Recognising ongoing challenges in the operationalisation and applicability of the SSPs and building on limitations identified in the scientific literature, we organised an additional online co-creation workshop on 18 December 2023. This workshop followed a participatory structure similar to those described in Step 2. Based on an initial synthesis prepared through the desk research, stakeholders and field practitioners examined how the selected structural dimensions could plausibly co-evolve, identified compatible and conflicting combinations, and consolidated compatible combinations into three contrasting narrative structures. The use of three narratives sought to balance sufficient differentiation of future socioeconomic and political conditions with the interpretability and tractability required for applications across spatial scales, modelling traditions, and participatory settings.

Contemporary geopolitical and socioeconomic developments- including the COVID-19 pandemic, Russia's invasion of Ukraine, the resulting energy crisis, inflationary pressures, and shifts in European energy markets- were used to challenge and refine the plausibility of the emerging configurations. Following the workshop, the research team consolidated the contributions, resolved remaining overlaps or inconsistencies, and refined the narratives according to four criteria: internal coherence, sufficient differentiation, traceability to the SSP-derived dimensions, and relevance to the analysis of energy citizenship.

3.4. Step 4: scenario space and design of decarbonisation pathways

Finally, we combined the four people-centred storylines with the three future-world narratives to construct a transformative scenario space capable of systematically exploring socially informed decarbonisation pathways under diverse potential future evolutions. To validate the credibility and the usefulness of the developed scenario space and its potential to be operationalised for meaningful modelling applications for both near- and long-term climate and energy actions- at different scales of analysis- we elicited, once more, knowledge embedded in relevant stakeholders and field practitioners, following a two-stage user-oriented evaluation approach during the 6th ENCLUDE General Assembly meeting in Athens (23–24 May 2024):

- On the first day, during a focused session ENCLUDE researchers collectively applied the scenario space to local case studies, deriving illustrative scenarios and transition pathways aligned with the 2030 climate and energy targets and the 2050 decarbonisation goals.
- On the second day, a workshop with representatives from the C40[12] network, the REScoop.eu[13] federation of citizen energy cooperatives in Europe, the Greek energy community "Hyperion[14]", and the Municipality of Athens, also in presence of the mayor and the vice-mayor of climate governance and social economy, took place, to repeat the abovementioned exercise deriving scenarios and energy transition pathways in the cases of the municipality of Athens (local scale), the Attica regional unit (encompassing the entire Athens metropolitan area- regional scale), and Greece (national scale), taking into account the specifications and requirements of the revised National Energy and Climate Plan (NECP).

4. Results

We first present the patterns and trends of energy citizenship identified through our desk research, focusing on those most relevant to the development of decarbonisation pathways. We then introduce the people-centred storylines derived from these recurring themes. Next, we outline the future-world narratives developed through the selective adaptation of SSP-derived structural dimensions and stakeholder feedback. Finally, we present the resulting scenario space that enables the

[10] https://www.kialo.com/.
[11] https://miro.com/.
[12] https://www.c40.org/.
[13] https://www.rescoop.eu/.
[14] https://hyperion-community.gr/en/.

transformative design of decarbonisation pathways.

4.1. Patterns and trends of energy citizenship relevant to decarbonisation pathways

Drawing from our desk research and synthesising insights from both scientific and grey literature, Table 1 presents a comprehensive set of patterns and trends relevant to the development of energy transition scenarios and decarbonisation pathways. These patterns aim to capture the overarching categories of energy citizenship manifestations at both the individual and collective levels while their associated trends describe specific pathways through which these behaviours are currently enacted.

Notably, trends relating to individuals' norms, values, and perceptions are intentionally excluded from the table. This is not because they are peripheral, but because they underpin and profoundly shape all manifestations of energy citizenship. These internal dispositions influence how, and how rapidly, citizens translate intentions into low-carbon behaviours and therefore play a pivotal role in understanding energy citizenship. For instance, citizens' apprehensions about renewable energy infrastructure- often stemming from either visual and aesthetic concerns [184], potential environmental impacts (e.g., biodiversity loss), or human health implications (e.g., noise pollution) [185]- manifesting as the "Not In My BackYard (NIMBY)" movement, essentially constitute perceptions and beliefs that undermine the acceptance of renewable energy projects. Conversely, other environmentally concerned groups may view conventional technologies as inherently riskier and adopt innovative technologies as battery energy storage systems (BESS) or electric vehicles (EVs) at higher rates [186]. These opposing perceptions nonetheless represent two distinct expressions of energy citizenship.

Additionally, citizens' sense of trust in institutions, scientific authorities, and regulatory bodies constitutes another personal worldview that can either amplify or diminish support for transition policies, even when the anticipated benefits are clear [187]. Beyond institutional trust, the motivation to engage in pro-environmental behaviours is also profoundly influenced by underlying value orientations. Research indicates that individuals driven by biospheric and/or altruistic values consistently demonstrate greater propensity to invest in renewable energy technologies [188], and endorse comprehensive climate policies [189]. In contrast, individuals motivated by egoistic values typically adjust behaviour predominantly when direct personal benefits are evident [188].

Climate change anxiety, defined as the concern or distress in response to climate change, also results from individuals' mental positions [190]. While this type of anxiety is increasingly recognised as a public health issue [191] and can result in psychological and physical symptoms [190], it can also act as an emotional accelerator of energy citizenship. For example, higher levels of anxiety and climate change perceptions have been associated with a higher likelihood of adopting adaptation behaviours [192], while also enhancing one's awareness of the effects of climate change and intensify citizens' personal responsibility and moral obligation, consequently motivating their pro-environmental behaviour [193].

Moreover, citizens' literacy level, especially regarding their knowledge of financial concepts, also matters within the context of energy citizenship. For instance, a nationally representative survey showed that each one-point increase in financial literacy raises the likelihood of adopting clean energy for cooking, heating, or lighting by 14% [194]. Likewise, technology adoption and attitudes towards technological innovation can also encourage people's willingness to conform through "word-of-mouth" effects. This human tendency is shaped by people's personalities, worldviews, and the surrounding social and cultural norms. For example, analysis of approximately 60,000 solar PV installations on homes and businesses in Switzerland shows that the mere visibility of one installation can nudge surrounding households to follow suit [195]. Finally, citizens' "locus of control"- the degree to which individuals believe their actions make a difference- shapes their lifestyle choices with regards to energy use. Individuals with a strong internal locus of control are not only more inclined to install efficiency measures and monitor their own consumption, but they are also less likely to get affected by energy poverty [196].

Overall, (risk) perceptions, trust levels, value patterns and norms, emotions, and sense of control, while they stem from individuals' beliefs and mentalities, they exert influence and drive behaviours that impact the energy system in various manners. As such, they may be viewed as pillars of energy citizenship that determine who embraces environmentalism and sustainability, and who remains constrained in carbon-intensive lifestyles. Nevertheless, beyond these trends that describe internal processes that, nonetheless, directly influence external manifestations of energy citizenship, below, we focus on tangible manifestations of energy citizenship, categorising them in four overarching patterns.

4.1.1. Individual level

4.1.1.1. Technology adoption and active participation in the energy market. In the context of energy citizenship, technology adoption represents more than a technical shift: it signals a social transformation in which individuals assume greater ownership of their energy decisions and become co-producers of system change. Declining technology costs, improved performance, and supportive regulatory frameworks have enabled citizens and households to adopt advanced energy solutions at unprecedented rates [197]. The growing diffusion of smart, efficient, and renewable energy technologies is fundamentally reshaping the relationship between citizens and the energy system.

This process often begins with relatively simple energy-efficiency upgrades. For instance, replacing conventional lighting with light emitting diodes (LEDs)- particularly when paired with occupancy or daylight sensors- remains one of the fastest and most cost-effective ways for households to reduce electricity use and bills [198]. Similarly, substituting outdated white goods with high-efficiency, energy-labelled appliances constitutes a citizen-led response to EU's product standards. The "A-G" energy labelling is recognised by 93% of Europeans and has influenced the majority of recent appliance purchases [199].

Building on such measures, households increasingly adopt technologies that electrify end-uses, such as induction stoves or heat pumps. The deployment of heat pumps continues to accelerate across Europe, driven by strong user satisfaction and behavioural spillovers that promote more energy-aware practices [66]. Electrification reduces direct fossil-fuel use and enables higher integration of renewable energy assets. Comparable dynamics are observed in the transport sector, where the diffusion of EVs reduces petroleum consumption and creates opportunities for citizens to participate more actively in the energy system, particularly when EVs are integrated into home or local grids. Passive efficiency measures, including targeted or whole-building retrofits, further enhance household participation by generating cumulative energy and cost savings.

At more advanced stages, digitalisation strengthens citizen agency through smart energy management. Smart meters, adaptive thermostats, and predictive control systems allow households to monitor and optimise their consumption in real time, aligning usage with dynamic price signals or renewable availability. Evidence suggests that such feedback systems can reduce household energy consumption by 5-10% while increasing user engagement and literacy [200]. Coupling electrification, retrofits, and smart digital tools- such as pairing high-efficiency heat pumps with envelope upgrades and home energy management systems- can considerably reduce household demand [201].

In addition, recent technological advancements and declining costs of small-scale renewable systems have also created new expressions of energy citizenship, where households evolve from passive bill-payers into active energy market participants. Investments in residential rooftop PV systems or BESS enable citizens to assume multiple roles,

Table 1
Patterns and trends of energy citizenship relevant to the development of energy transition scenarios and decarbonisation pathways as derived from our desk research.

Level	Pattern	Trends	Description	Literature sources
Individual	Technology adoption & active participation in the energy market	*Electrification of heating & cooking*	The replacement of fossil-fuel boilers and gas cooktops with high-efficiency electric heat pumps and induction cookers decarbonises space/water heating and culinary energy demand.	[62–66]
		Electrification of passenger mobility	The adoption of plug-in hybrid electric vehicles, battery-electric vehicles, e-bikes, and scooters reduces transport emissions while enabling participation in smart-charging and vehicle-to-grid energy services.	[67–70]
		Building retrofits for energy efficiency	Comprehensive or targeted envelope and system upgrades (e.g., insulation, airtightness, high-performance windows, heating, ventilation, and air-conditioning systems, passive shading or lighting, deliver structural efficiency gains while also enhancing user comfort and property value.	[71–75]
		Residential prosumerism	Electricity generation via rooftop solar photovoltaic (PV) systems, self-consumption, and surplus export to the distribution grid, compensated based on different remuneration schemes, thus shifting citizens' role from passive consumers to active market actors.	[76–81]
		Smart energy management	Investments in smart, digital technologies (home energy management systems, self-learning thermostats, adaptive heating, ventilation, and air-conditioning systems, energy-tracking apps, occupancy and daylight sensors, etc.) enable citizens to monitor, optimise, and control their energy use in real time.	[62,82–85]
		Energy-label driven appliance choice & replacement	Substitution of legacy household appliances with newer high-efficiency, energy-labelled appliances secures long-term electricity savings.	[86–89]
		Peer-to-peer energy trading	Prosumers engage in energy trading, selling excess electricity directly to nearby peers and enabling the development of bottom-up and price-negotiated micro-markets through digital platforms.	[76,90–96]
		Participation in demand-response programmes	Households accept dynamic tariffs, or aggregator control to shift, shed, and shape their load in response to time-of-use electricity prices, or grid signals, lowering peak demand and earning bill credits or direct payments.	[97–103]
		Virtual power-plant aggregation	Software platforms aggregate multiple distributed energy resources, such as PV and battery systems, flexible loads, into a single market-bidding entity that sells capacity and ancillary services.	[93,104–107]
	Lifestyle changes, habits & behavioural innovations	*Modal shift to public or active transport*	Replacing private-car trips with walking, cycling, e-bikes, or using public means of transportation cuts per-capita energy consumption and emissions.	[108–111]
		Eco-tourism, staycations & vacation plans	Substitution of long-haul trips with local or regional leisure, (e.g., staycations, near-home holidays), thereby, avoiding transport emissions and/or following emission-aware itineraries with lower-carbon routes and lodgings.	[112–116]
		Eco-driving & speed moderation	Driving habits with gentle acceleration and braking, early gearshifts, and keeping to the most efficient speed band contributes to lower fuel use and carbon dioxide (CO_2) emissions.	[117–120]
		Urban agriculture for self-provisioning	Engagement in community or household food production, such as community or rooftop gardens, reduces supply-chain emissions and fosters local resilience.	[121–124]
		Sustainable diets	The adoption of plant-based diets and a gradual reduction of meat consumption through a shift towards fruits, vegetables, legumes, pulses, and plant-based proteins, supports the reduction of diet and agriculture related CO_2 emissions versus average omnivorous diets.	[125–128]
		Waste management, recycling & reusing	Correct waste-sorting (e.g., separating paper, glass, metal, plastic, and organic waste) and recycling reduces raw material demand and life-cycle energy demand for material production.	[129–132]
Collective	Collaborative & community-based initiatives	*Collective energy initiatives*	Citizens partake in collective energy initiatives such as renewable energy communities or citizen energy communities/cooperatives, in which they co-own and govern decentralised energy resources, or promote citizen-led renovation projects and initiatives, and reinvest revenue surplus locally in order to widen participation in the transition.	[133–137]
		Collective self-consumption & energy-sharing through platforms	Collective energy initiatives, such as positive energy districts and neighbourhoods form microgrids and pool their resources to engage in energy sharing and trading, collective self-consumption, or grid balancing while sharing distributed assets and settling costs/benefits via smart contracts.	[95,138–141]
		Mobility-sharing & ride-pooling	Community ride-pooling and car-/bike-sharing schemes cut vehicle kilometres travelled and embed low-carbon mobility in citizens' lifestyles.	[142–145]
		Co-housing & shared domestic services	Citizens participate in shared living arrangements where practices such as communal dining, shared laundry, and collectively used amenities lower per-capita energy demand.	[146–149]
		Crowdfunding & citizen investment platforms	Platforms and fintech portals let locals jointly fund renewable energy projects and deep-energy retrofits in housing blocks, repaid from efficiency savings.	[150–153]
	Social movements & (political) activism	*Citizen-based climate/energy assemblies & juries*	Citizen groups discuss climate and energy policies and issue binding or advisory recommendations to institutionalise citizen agenda-setting.	[154–157]
		Energy democracy & social movements	Grassroots coalitions frame the energy transition around justice, public ownership, and democratic control of energy systems, challenging officials, policymakers and politicians, and other decision-makers.	[158–162]

(*continued on next page*)

Table 1 (*continued*)

Level	Pattern	Trends	Description	Literature sources
		Decarbonisation campaigns & anti-fossil-infrastructure protests	Transnational or local civil-society coalition campaigns of students, non-governmental organisations, or fossil fuel divestment activists target institutional investors, universities, companies, and cities to cap fossil production, release fossil equities and instead reinvest in clean assets.	[163–167]
		Energy & climate change litigation	Non-governmental organisations, affected communities, and youth associations sue states and/or firms for inadequate action, green-washing, or damages, thus raising future policy ambition and reinforcing legal accountability.	[168–171]
		Just transition & energy justice advocacy	Local, affected residents, labour union, environmental organisations and energy justice groups are mobilised for equitable decarbonisation pathways, infrastructure deployment and governance in response to perceived injustices, such as exclusion, environmental degradation, or economic displacement.	[172–175]
		Participatory budgeting for climate/energy projects	Cities and municipalities dedicate portions of their capital budgets for residents to propose and vote on decarbonisation measures, e.g., rooftop PV systems, (e-)bike lanes, building-efficiency upgrades, urban greening.	[176–179]
		Participatory policy co-design workshops	Short, design-thinking sessions shown to boost creativity, legitimacy, and implementation buy-in, where diverse citizens and officials co-create draft climate/energy policy options.	[180–183]

including producer, consumer, and distributor of energy. This shift, often termed prosumerism, allows individuals to contribute to grid stability by providing demand-side flexibility [202], reduce GHG emissions [203], and support broader energy transition efforts [26]. Through self-production and self-consumption, energy citizens also benefit from decentralised generation via lower energy bills [204] and income generation [205], facilitated by remuneration schemes such as net metering, net billing, or feed-in tariffs.

Investments in PV and BESS enable participation in peer-to-peer (P2P) energy trading, where prosumers exchange surplus electricity directly with neighbours, bypassing traditional retailers. Early pilots show that P2P trading can enhance cost efficiency, local engagement, and community cohesion- provided that pricing transparency and regulatory clarity are ensured [96]. Active participation also extends to demand-response (DR) programmes, where households shift or reduce consumption in response to price signals or aggregator requests. Such participation has been shown to flatten peak demand, defer grid investments, and generate bill savings [97]. Comparable dynamics apply to vehicle-to-grid (V2G) schemes, where EVs function as mobile decentralised storage units. Studies indicate that V2G participation can foster a stronger sense of co-management among EV owners when fairness, transparency, and autonomy are upheld [68,70].

At scale, thousands of these distributed assets can be aggregated into virtual power plants (VPPs) via digital cloud-based infrastructures. Simulations and early deployments suggest that VPPs can provide reliability comparable to mid-sized thermal plants while avoiding associated emissions [104]. Overall, prosumerism, P2P trading, DR, and VPP aggregation, enabled by widespread technology adoption, empower citizens to play an increasingly central role in driving the energy transition while simultaneously benefiting economically.

4.1.1.2. Lifestyle changes, habits, and behavioural innovations. Lifestyle changes and habitual behaviours represent an important dimension of energy citizenship, in which individuals assume responsibility for how energy is consumed, saved, and managed in everyday life. Citizens exercise agency not only through one-off purchases or investments, but also through daily routines and broader lifestyle choices that, taken together, generate cumulative impacts on emissions and shape the collective trajectory of the energy transition. In this sense, small-scale actions are not isolated gestures but civic practices that embed accountability and mindfulness into ordinary routines.

Energy citizenship unfolds through a range of habitual behaviours that structure daily consumption patterns. Simple actions, such as switching off lights, adjusting thermostats, or shortening showers, may appear modest, yet collectively they contribute to noticeable reductions in energy demand and foster long-term conservation habits [206]. Other lifestyle decisions take on greater significance when repeated systematically over time. Modal shifts in everyday mobility provide a clear example: replacing a single car trip with cycling or walking can eliminate around three kilograms of CO_2 per day [207]. Motivations for such changes often combine personal health benefits, convenience, and pro-climate values, illustrating the interplay between self-interest and civic responsibility.

Leisure choices similarly carry disproportionate environmental weight. Long-distance travel is highly emission-intensive: although long trips constitute only 2.7% of journeys, they account for nearly 70% of passenger-travel emissions [114]. Alternatives such as staycations, eco-tourism, or substituting flights with rail travel therefore represent meaningful contributions at the individual level. Even the way people operate and maintain their vehicles can constitute a form of energy citizenship. Eco-driving practices, such as smoother acceleration, anticipatory braking, and maintaining efficient speeds, reduce fuel consumption and associated GHG emissions while lowering operational costs. A meta-analysis of on-board feedback systems shows an average 6.6% improvement in fuel economy, highlighting the tangible benefits of behavioural interventions [120].

Dietary choices provide another powerful sphere of engagement. Transitioning to plant-based diets can reduce diet-related GHG emissions by nearly half, while offering significant public-health co-benefits [127]. Complementary behaviours, such as selecting locally sourced foods or participating in urban agriculture initiatives, further support sustainable consumption. Rooftop gardens and urban food-production systems- when operated with recycled inputs and durable infrastructure- have been shown to outperform conventional supply chains in life-cycle assessments, while simultaneously fostering place-based environmental identities that reinforce broader pro-climate behaviours [123].

Finally, waste management practices, such as reducing waste generation, composting organic matter, and prioritising recycling or the reuse of materials, contribute to lowering emissions and supporting more circular patterns of resource use [208]. Taken together, these lifestyle choices demonstrate how behavioural innovations and everyday habits can meaningfully advance sustainable goals.

4.1.2. Collective level

4.1.2.1. Collaborative and community-based initiatives. Collective expressions of energy citizenship operate within a qualitatively different register than individual-level actions. Rather than centring on personal

technology adoption, lifestyle choices, or individual capital investments, they are rooted in shared ownership, collective governance, and cooperative decision-making. By pooling financial resources, skills, and authority, community-based initiatives redistribute control over energy infrastructure that has traditionally been managed by incumbent utilities, thereby expanding the civic domain of energy systems. In this respect, physical infrastructure often acts as the material foundation through which collective energy citizenship is enacted, as shared ownership of technologies enables collective engagement in practice. However, the depth of this technology-mediated engagement varies: while some collaborative and community-based initiatives foster enduring, value-driven relationships with shared infrastructure, others engage with technology more instrumentally, as a one-time means to a cost-saving end, with more limited transformative effects [209].

In principle, collaborative and community-based initiatives are referred to using different terms depending on regulatory and analytical contexts. Within the EU's legislative framework, Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs) constitute the two formal categories, as defined under the Directives 2018/2001 [210] and 2019/944 [211], respectively. While both models emphasise democratic participation and local benefit, RECs are limited to renewable energy generation, whereas CECs may also engage in distribution, storage, aggregation, and other energy services [212]. In practice, the most widespread organisational form embodying these principles is the citizen energy cooperative. Collectively, these models are often referred to as Collective Energy Initiatives (CEIs), an umbrella term encompassing community-led efforts across the energy transition.

CEIs represent social innovations that enable the collective production, management, and use of energy while improving resource efficiency and strengthening local economic and environmental resilience [213]. At the local level, they generate multiple co-benefits, including employment creation, enhanced social infrastructure, and environmental protection [214]. Moreover, CEIs can mitigate local conflicts, increase social acceptance of renewable energy projects, stimulate regional development, and deliver direct economic dividends through cost savings, reinvestment of revenues, and support for local enterprises [135].

Another prominent expression of collaborative energy citizenship is collective self-consumption, whereby neighbours, housing cooperatives, or co-housing blocks pool primarily rooftop PV generation and share electricity behind the meter. As highlighted by Gorbatcheva et al. [95], collective self-consumption schemes are characterised by joint asset ownership and deliberate local redistribution of benefits. These arrangements provide system-level advantages, such as improved demand-supply balancing and reduced grid losses, while also enabling more equitable sharing of energy cost savings among participants.

Community microgrids represent a further manifestation of collective energy citizenship. These localised power systems integrate distributed energy resources (e.g., PV, BESS, controllable generation) with interconnected loads and can operate in grid-connected or islanded mode [215]. Beyond enabling higher shares of renewable energy and improved resilience to outages, microgrids signify a departure from centralised energy architectures [216]. By placing operational control and benefits in the hands of local communities, they open new pathways for democratising energy systems and accelerating a just transition [217].

Citizen crowdfunding introduces an additional financial dimension to collective energy citizenship by enabling residents to act as micro-investors in local renewable energy projects. A discrete-choice experiment involving approximately 2000 respondents across ten EU countries found strong willingness to invest in solar and wind projects via online crowdfunding platforms. At the EU level, citizen investments could mobilise up to €176 billion; sufficient to meet the 2030 target of 32% renewable energy in final consumption [152]. Crowdfunding thus allows citizens to influence capital allocation and infrastructure development, reinforcing the democratic and distributive dimensions of the energy transition.

Finally, shared mobility schemes extend the principles of shared ownership and collective benefit into the transport sector. By shifting from private vehicle ownership to communally managed car- or bike-sharing systems, communities can achieve higher vehicle utilisation rates, reduce total number of vehicles and lower life-cycle energy demand [144]. Cost savings generated through lower per-trip expenses can be reinvested in local charging infrastructure and circulate within the community, consistent with the dividend-sharing logic of collaborative initiatives. In this sense, shared-mobility participants can be understood as energy citizens operating with a collective mindset, contributing simultaneously to emissions reduction, improved accessibility, and shared economic benefits.

4.1.2.2. Social movements and (political) activism. Participation in energy transition movements, such as social movements, civil society initiatives, and other forms of (political) activism that advocate for democratic and just energy systems, constitutes a central and increasingly visible expression of energy citizenship. These collective actions operate primarily within the political and institutional spheres, empowering citizens to shape energy discourse, influence governance arrangements, and redirect transition pathways. Energy democracy and just transition campaigns, for example, advocate for public or community control over energy infrastructure and for the phaseout of fossil-fuel-based projects. Beyond their emission-reduction potential, such movements advance distributional, procedural, and recognitional justice by challenging entrenched power asymmetries within energy systems [162]. Comparative case studies indicate that social movement coalitions mobilised around energy democracy agendas can shift decision-making authority towards municipalities while simultaneously accelerating renewable energy deployment [159].

Complementing these grassroot efforts, strategic climate litigation has emerged as a rapidly expanding avenue of energy citizenship. In 2024 alone, at least 226 new climate-related cases were filed globally, reflecting a growing use of legal mechanisms to hold governments and corporations accountable for inadequate climate action, reshape emissions targets, and expose climate-washing practices [168]. Similarly, anti-fossil-infrastructure protests and fossil-fuel divestment campaigns represent another- often contentious but impactful- mode of civic engagement. Evidence from a comparative dataset covering 130 mobilisations across seven carbon-intensive regions shows that campaigns opposing coal mines, pipelines, dams, and high-voltage transmission lines led to the cancellation or phaseout of proposed or existing projects in 14% of cases and triggered broader policy or regulatory reforms in an additional 15% [165].

Equally significant are the participatory governance processes that social movements help institutionalise, including policy co-design workshops, public consultations, participatory energy planning, and participatory budgeting [161]. Within this category, citizen climate assemblies and juries (CAJs) have gained prominence as deliberative forums in which randomly selected citizens engage in structured dialogue with experts and policymakers. These processes often produce recommendations perceived as both technically robust and socially legitimate, surpassing the credibility of purely top-down policy formulation [156]. Empirical reviews demonstrate that CAJs tend to generate more ambitious and justice-oriented climate policies than those previously proposed by governments, while also providing elected officials with a clear public mandate for action. This has been observed at both national scales- such as in France and the United Kingdom- and at local levels, including municipal processes in Oxford [155].

Together, social movements, legal action, and participatory institutions play a crucial role in translating diffuse public concern into politically and legally actionable commitments, such as binding fossil-fuel phase-out schedules, tighter investment mandates, and more inclusive governance frameworks. By broadening democratic oversight

and embedding justice considerations into decision-making, these collective expressions of energy citizenship strengthen both the legitimacy and the effectiveness of decarbonisation pathways.

4.2. From patterns and trends of energy citizenship to people-centred storylines

Building on stakeholder feedback, the identified patterns and trends of energy citizenship were further synthesised into four refined people-centred storyline archetypes (Fig. 2). These storylines translate abstract patterns into coherent, storyline-based representations of how energy citizenship may be enacted across different social contexts, enabling their systematic use in scenario-based research and modelling.

4.2.1. The "Power to the People" storyline

In this storyline, energy citizenship manifests through the active adoption of energy technologies and participation in energy markets, as individuals transition from passive consumers to decentralised agents of system change. Declining technology costs, performance improvements, and enabling policy frameworks accelerate the uptake of efficient appliances, building retrofits, electric vehicles, and the electrification of end-uses, contributing simultaneously to decarbonisation and demand-side flexibility. Digitalisation further strengthens citizen agency by enabling real-time monitoring, optimisation, and response to grid signals. The diffusion of rooftop PV systems, BESS, EVs, and smart devices allows citizens to become prosumers engaged in self-production and self-consumption, P2P and DR programmes, and VPP participation. Together, these practices decentralise system operation, enhance grid resilience, and embed citizens as active market participants with a measurable contribution to emissions reduction and system stability.

The extent to which this storyline unfolds is shaped by enabling regulatory frameworks, equitable access to capital and technologies, and citizens' digital and energy literacy, which together condition the speed, scale, and inclusiveness of the storyline.

4.2.2. The "Habitual Creatures" storyline

This storyline captures energy citizenship as it unfolds through everyday routines, habits, and lifestyle choices that shape how individuals consume, manage, and relate to energy. Repeated daily actions, such as adjusting thermostats, reducing travel demand, or modifying dietary choices, may appear modest in isolation but accumulate over time to produce significant system-level impacts. Modal shifts towards active or public transport, reduced reliance on high-emission travel, adoption of plant-based diets, eco-driving practices, and participation in local food systems all contribute to demand-side mitigation. Waste reduction and circular practices further extend citizens' roles in supporting sustainable energy systems. Collectively, these diffuse yet persistent behaviours form a behavioural foundation for the energy transition, fostering long-term sustainability and reinforcing bottom-up, citizen-led pathways to decarbonisation.

The effectiveness of this storyline depends on supportive infrastructures, stable social norms, and the widespread diffusion of practices across sociodemographic groups, ensuring that behavioural change is sustained rather than episodic.

4.2.3. The "Band Together" storyline

As communities increasingly recognise their collective capacity to shape sustainable futures, energy citizenship shifts towards collaborative action and shared governance. In this storyline, citizens pool resources, knowledge, and decision-making authority to reclaim control over energy systems traditionally dominated by centralised utilities. Organised through energy cooperatives, these initiatives decentralise infrastructure ownership and embed democratic principles into energy planning and operation. CEIs enable citizens to co-produce, manage, and benefit from renewable energy at the local level, enhancing resource efficiency, social acceptance, and regional resilience. Complementary models, such as collective self-consumption schemes and community microgrids, support energy autonomy, increase system reliability, and improve flexibility. Financial participation through citizen crowdfunding allows communities to influence investment flows, while shared-

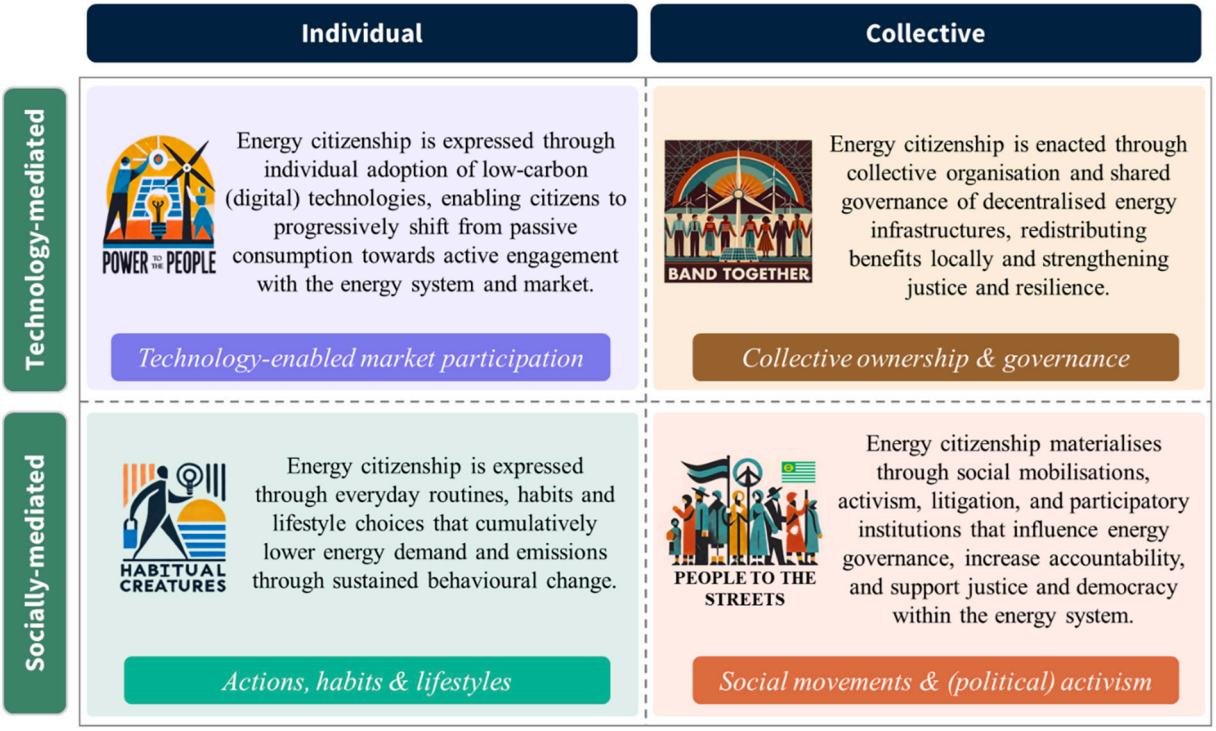


Fig. 2. People-centred storylines based on the identified patterns and trends of energy citizenship.
The images presented in the figure were created with the assistance of Generative Artificial Intelligence (GenAI).

mobility schemes extend collaborative principles into the transport sector. Together, these practices represent a socially innovative mode of system participation that promotes distributive justice, accelerates local decarbonisation, and strengthens civic engagement in the energy transition.

The transformative potential of this storyline is shaped by institutional support, legal recognition of community initiatives, and local capacity for sustained collective governance and coordination.

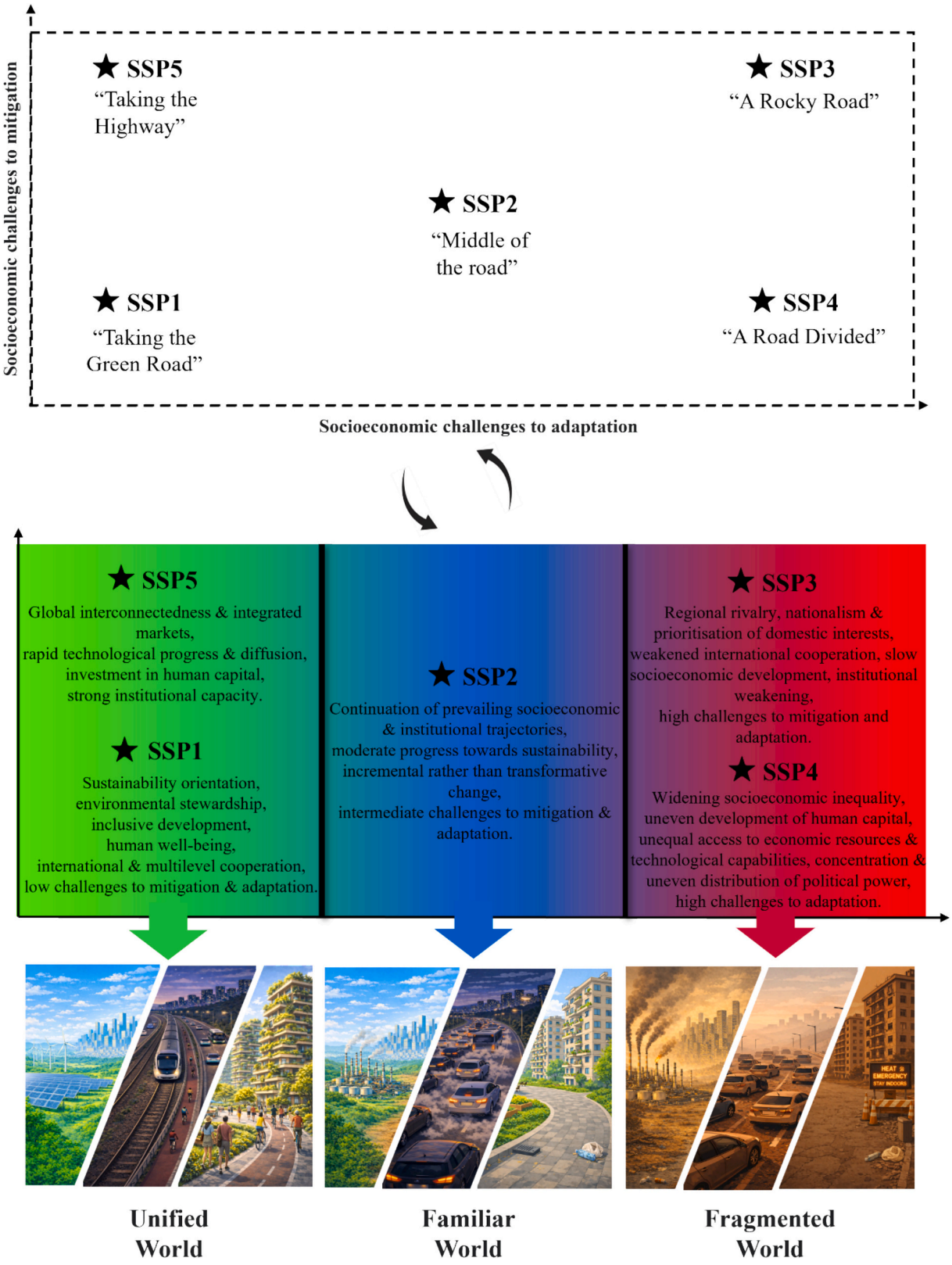


Fig. 3. Adaptation of SSP-derived structural characteristics into the three future-world narratives. Inspired by O'Neill et al. [43].
The images presented in the figure were created with the assistance of GenAI.

4.2.4. The "People to the Streets" storyline

In this storyline, energy citizenship emerges through collective mobilisation, social movements, and political activism, reflecting growing public demand for urgent and just climate action. Citizens engage in civil society initiatives that advocate for democratic, equitable, and inclusive energy transitions, amplifying public voices and challenging established power structures. Through protests, strategic litigation, citizen assemblies, and participatory governance mechanisms, energy citizens influence policy agendas, shape regulatory frameworks, and ensure that transition pathways reflect societal values of fairness and justice. These collective expressions translate public concern into political and legal pressure, reinforcing democratic accountability and accelerating systemic transformation towards sustainable energy futures.

The durability and impact of this storyline depend on political openness, legal accountability, and the ability of social mobilisation to be translated into stable institutions and long-term policy commitments.

4.3. Narratives of potential future-world evolutions

The third methodological step translates external drivers of possible futures into three internally consistent future-world narratives (Fig. 3), which define the macro-contextual conditions within which energy citizenship unfolds and decarbonisation pathways are shaped. Rather than predicting outcomes, they articulate distinct, internally consistent configurations of governance and institutional capacity, geopolitical cooperation, socioeconomic inclusion, technological development, and environmental policy ambition. Each narrative reflects how global and regional systems respond to uncertainty, external shocks, and structural change, thereby bounding the space of plausible futures against which the presented people-centred storylines can be tested.

Drawing selectively on structural dimensions derived from the SSPs, two criteria guided the construction of the future-world narratives. First, the narratives were designed to be sufficiently distinct to support comparative exploration of how contrasting socioeconomic and political conditions may enable or constrain energy citizenship, while remaining parsimonious and applicable across spatial scales and analytical approaches. Second, each narrative had to remain internally coherent, linking assumptions concerning governance, geopolitical cooperation, socioeconomic development, inequality, technological change, and environmental policy orientation in ways consistent with historical analogues and expert judgement. The narratives should therefore be understood as purpose-specific contextual configurations rather than condensed versions of the SSPs; they do not seek to reproduce the complete differentiation or quantitative architecture of the five pathways. Moreover, a narrative may be informed primarily by the broader logic of one SSP while selectively incorporating specific structural characteristics from another. Together, the narratives span continuity with prevailing trajectories, strengthened cooperation and institutional capacity, and deepening fragmentation and inequality.

4.3.1. The "Familiar World" narrative

Drawing on the continuation logic of SSP2, the "Familiar World" depicts an energy transition that unfolds incrementally through established policy frameworks and institutional arrangements. Governance remains largely technocratic and top-down, characterised by moderate ambition and conventional implementation capacity. Climate and energy policies evolve in line with existing targets and regulatory requirements, but reforms prioritise continuity, risk avoidance, and compliance rather than systemic transformation.

Within this context, citizens and households participate primarily as passive adopters, responding to government incentives, subsidies, and regulatory mandates rather than engaging proactively in shaping transition pathways. Technology uptake, such as efficiency improvements, partial electrification, or fuel switching, occurs largely through centrally designed programmes, with limited scope for citizen-led initiatives, collective experimentation, or community ownership. While local and national authorities ensure alignment with EU decarbonisation frameworks, citizen involvement remains confined to the uptake of subsidised technologies and compliance with policy signals.

In addition, external shocks, such as energy price volatility, supply disruptions, or geopolitical instability, are managed reactively within existing governance structures, reinforcing incremental adjustments rather than triggering structural change. As a result, decarbonisation progresses gradually and unevenly, achieving measurable emissions reduction but lacking the transformative momentum associated with deeper forms of energy citizenship, collective empowerment, and participatory governance.

Thus, the "Familiar World" functions as a baseline or reference narrative, capturing a policy-driven, centrally managed transition that largely preserves established patterns and against which alternative futures can be systematically assessed.

4.3.2. The "Unified World" narrative

Drawing on the sustainability orientation, inclusiveness, and multi-level cooperation of SSP1, the "Unified World" is further informed by elements of SSP5 supporting systemic low-carbon change, specifically global interconnectedness, technological dynamism, and human-capital development. Institutions prioritise human well-being, social cohesion, and long-term resilience. Climate action is recognised as a shared societal responsibility requiring coordination across governance levels.

Within this context, citizens and households are actively empowered to participate in the transition, uniting in collective efforts to address the climate crisis. Their engagement is supported by local initiatives and energy cooperatives, and multi-level policy frameworks that align local, regional, and national authorities. Targeted financial mechanisms such as renovation subsidies or co-financing schemes, systematically lower entry barriers, enabling broad participation across socioeconomic groups, including vulnerable households. Technological change accelerates through globally integrated markets, sustained innovation, and strong human and institutional capacity.

However, unlike the fossil-intensive orientation of SSP5, these enabling conditions are directed towards decentralised, renewable-based solutions that provide affordable, reliable, and low-emission energy services while enhancing system flexibility and resilience. Local and national authorities support this transformation through policy frameworks promoting shared ownership, affordability, inclusiveness, and citizen-led initiatives.

Beyond technological adoption, citizens also embrace sustainable lifestyle practices, such as energy-saving behaviours, low-carbon mobility, circular consumption patterns, etc., which often exceed national policy targets. Overall, through this alignment of institutional support and civic engagement, the "Unified World" enables rapid and socially just decarbonisation, maximising the transformative potential of energy citizenship and reinforcing trust, cooperation, and collective agency in the energy transition.

4.3.3. The "Fragmented World" narrative

Drawing on the regional rivalry, weakened international cooperation, slow socioeconomic development, and institutional weakening associated with SSP3, the "Fragmented World" is informed by the broader geopolitical and institutional logic of SSP3. This is additionally complemented by elements of SSP4, specifically widening socioeconomic inequality and the uneven distribution of human capital, economic resources, technological capabilities, and political power, while comparatively low challenges to mitigation are not incorporated into the narrative. Within this combined context, nations prioritise domestic concerns and regional interests over international collaboration, while policymaking becomes dominated by security, competitiveness, and short-term economic stability, diverting attention and resources away from long-term sustainability and climate objectives.

These socioeconomic inequalities and the resulting uneven access to

capital and clean technologies constrain participation in the energy transition. Affordability pressures, policy volatility, and declining institutional trust lead many citizens to prioritise short-term security over collective climate ambition. Conservative and risk-averse governance at the national level reinforces continued reliance on incumbent energy systems, delaying structural change and locking in fossil-fuel dependence.

Local and municipal authorities face compounded challenges, as limited funding, weak coordination mechanisms, and constrained institutional capacity restrict their ability to mobilise meaningful action. As a result, decarbonisation proceeds slowly and unevenly. Cleaner technologies, such as electric heat pumps or other renewable-based solutions, are adopted at a limited pace, often driven by necessity or regulatory compulsion rather than intrinsic commitment to climate change mitigation. Fossil fuels, including natural gas, retain a dominant role well into the medium term, while efficiency improvements and electrification advance inconsistently across regions and social groups.

Overall, the "Fragmented World" narrative reflects a delayed and poorly coordinated energy transition, in which emissions reduction occurs gradually and irregularly as traditional energy sources are phased out incrementally. The transformative potential of energy citizenship remains largely unrealised, constrained by institutional weakness, eroded trust, and the absence of coherent, long-term policy direction.

4.4. Scenario space for transformative design of decarbonisation pathways

By combining the four people-centred storylines with the three future-world narratives, a two-dimensional scenario space yielding 12 scenarios emerges (Fig. 4). The two scenario-space components constitute analytically independent dimensions of the framework: the storylines represent distinct manifestations of energy citizenship, while the narratives describe the broader structural conditions within which these manifestations unfold. Neither a storyline nor a narrative constitutes a complete scenario independently, and the four storylines are not used to derive or map individually onto the three narratives. Instead, each storyline can be situated within any of the three narratives.

Within this space, scenarios can be systematically generated, modified, and compared by varying either dimension independently or both dimensions simultaneously. Holding the future-world narrative constant allows comparison of how different manifestations of energy citizenship may shape decarbonisation under the same structural conditions. Conversely, holding the people-centred storyline constant allows examination of how alternative governance, socioeconomic, technological, and geopolitical conditions may enable, constrain, or transform the same manifestation of energy citizenship. For example, the "Power to the People" storyline can be explored within all three narratives: its focus on individual, technology-mediated participation remains unchanged, while assumptions concerning access to capital and technologies, regulatory support, institutional capacity, and technology diffusion vary across the three future-world narratives. The scenario space therefore supports systematic exploration of interactions between citizen agency and structural conditions rather than prescribing fixed correspondences between particular storylines and narratives.

From a practical perspective, scenario development can begin by selecting one or more people-centred storylines, which define the forms of energy citizenship to be examined and foreground particular social mechanisms, actor roles, and modes of engagement. The selected storylines can then be situated within a future-world narrative that specifies the broader sociopolitical, economic, technological, and governance context. The resulting combination provides a transparent basis for formulating scenario assumptions. They can then be translated into exogenous assumptions, constraints, boundary conditions, or parameter ranges, while preserving traceability between social dynamics and outcomes for a diversity of modelling approaches. As multiple forms of energy citizenship may coexist within a transition pathway, the 12 basic configurations represent the building blocks of the scenario space rather than an exhaustive set of predefined scenarios.

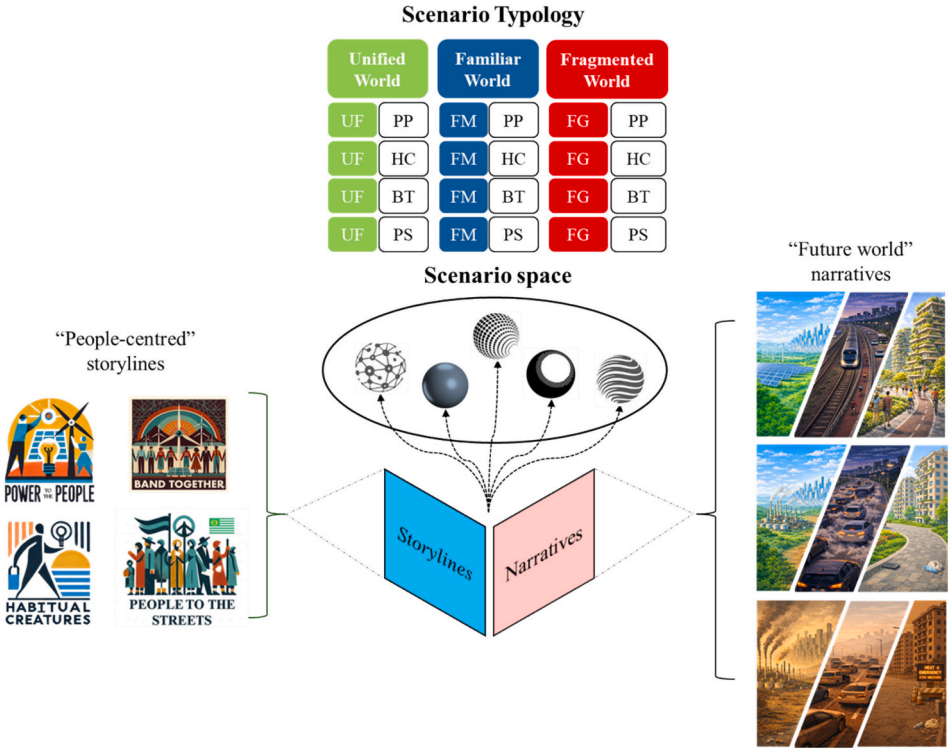


Fig. 4. Schematic illustration of the 4 × 3 scenario space generated by combining the four people-centred storylines with the three future-world narratives. Each cell of the scenario space represents a basic storyline–narrative configuration, while specific applications may incorporate multiple storylines within the same narrative (PP: Power to the People, HC: Habitual Creatures, BT: Band Together, PS: People to the Streets, UF: Unified World, FM: Familiar World, FG: Fragmented World).

Finally, the proposed scenario space is primarily designed as a descriptive and exploratory framework intended to examine how different manifestations of energy citizenship may unfold under contrasting future-world conditions. Normative elements, such as policy targets, emission constraints, or sustainability objectives, are not embedded in the structure of the scenario space itself but can be introduced when populating specific scenarios and pathways. This distinction allows the framework to support both exploratory analyses of plausible futures and normative assessments aligned with climate and energy goals, without conflating analytical description with prescriptive visioning.

5. Discussion

Our study advances scenario-based research by proposing an interdisciplinary framework for transformative and socially informed scenario design that integrates people-centred storylines of energy citizenship with narratives of potential future-world evolutions. By explicitly linking energy citizenship- often treated as a predominantly SSH construct- with scenario development and climate and energy modelling practice, the framework provides a structured way to operationalise citizen agency, social innovations, and governance dynamics within decarbonisation pathways. In doing so, the paper addresses two persistent gaps in the literature: first, research on energy citizenship has largely remained disconnected from modelling-oriented disciplines, limiting its influence on scenario construction and quantitative analysis. Second, dominant scenario approaches in climate and energy research continue to privilege top-down, technoeconomic logics that underrepresent social context, stakeholder agency, and implementation-relevant dynamics, particularly at local and sub-national scales. The framework presented here responds to both challenges by repositioning citizens as active contributors to transition pathways and by embedding social dynamics directly into the logic of scenario design.

5.1. Reframing scenario design through energy citizenship

A central contribution of this study lies in reframing scenario design by positioning energy citizenship as a core organising principle rather than as an auxiliary social layer appended to technoeconomic pathways. Conventional scenario-based research typically treats citizens implicitly- as aggregated demand profiles, representative consumers, or exogenous behavioural parameters [218], thereby constraining their role to background assumptions within optimisation-driven narratives. By contrast, the proposed framework foregrounds citizens as agents whose actions, practices, and collective organisation shape the pace, direction, and social character of decarbonisation. This shift has important implications for how scenarios are conceived. Instead of starting from predefined technology or policy targets and subsequently adjusting behavioural assumptions [219], the framework begins with people-centred storylines that capture distinct modes of energy citizenship. These storylines synthesise diverse expressions of engagement- ranging from technology adoption and lifestyle practices to collective initiatives and sociopolitical mobilisation- into analytically coherent patterns that can inform scenario construction in a systematic way. Energy citizenship thus functions not merely as a thematic lens, but as a design logic that reshapes the sequencing and priorities of scenario development.

Embedding these storylines within contrasting future-world narratives further strengthens this reframing. The narratives provide structured sociopolitical contexts that condition how energy citizenship is enabled, constrained, or transformed, recognising that citizen agency does not operate independently of governance arrangements, economic conditions, or institutional capacity. By explicitly combining people-centred storylines with alternative macro-contexts, the framework moves beyond single-path or implicitly deterministic futures and enables the exploration of interactions between agency, structure, and uncertainty. Importantly, this reframing also responds to long-standing concerns regarding the social relevance and legitimacy of scenario-based research [220]. Scenarios that explicitly reflect lived practices, collective action, and social tensions are better positioned to resonate with stakeholders and policymakers, particularly in contexts where implementation challenges dominate. By making social assumptions explicit and traceable, the framework enhances transparency and clarifies how different forms of citizen engagement contribute to, or hinder, decarbonisation outcomes.

5.2. Normative and descriptive dimensions of socially informed scenarios

A defining feature of the proposed framework is its explicit integration of normative and descriptive elements, reflecting the inherently value-laden nature of energy transitions while preserving the exploratory character of scenario-based research. Rather than treating normativity as a methodological limitation [221], the framework acknowledges that scenario design- particularly in climate and energy contexts- inevitably embeds assumptions about desirable futures, social priorities, and acceptable trade-offs.

The people-centred storylines introduce an intrinsic normative dimension. They are grounded in values such as participation, inclusiveness, justice, and democratic governance, which align with widely articulated objectives in European climate and energy policy [2]. By foregrounding these values, the framework makes explicit assumptions that are often implicit in scenario narratives, such as expectations regarding citizen engagement, behavioural change, or social acceptance. This transparency enhances interpretability and allows users to critically interrogate the social premises underpinning different decarbonisation pathways. At the same time, the framework maintains a strong descriptive and exploratory function through its future-world narratives. These narratives do not prescribe preferred outcomes; rather, they delineate plausible sociopolitical and economic contexts within which energy citizenship may unfold. By spanning contrasting conditions, from cooperative, equity-oriented governance to fragmented and inward-looking developments, they enable systematic exploration of uncertainty, constraint, and vulnerability. In this sense, the narratives function as boundary conditions that shape, but do not determine, the expression and effectiveness of energy citizenship.

By deliberately coupling normative storylines with descriptive future-world narratives, the framework navigates a longstanding tension in scenario-based research between vision-led pathways and exploratory futures [222]. Instead of separating these approaches, it integrates them within a single scenario space, allowing analysts to examine how socially desirable forms of citizen engagement interact with favourable or adverse systemic conditions. This makes it possible to assess not only which outcomes are normatively preferred, but also under what circumstances such outcomes remain feasible, resilient, or fragile. In doing so, the framework enhances epistemological clarity and supports the use of scenarios as reflective tools for decision-making rather than predictive instruments.

5.3. Implications for modelling practices

The framework also carries important implications for climate and energy modelling practice, particularly regarding how social dynamics, citizen agency, and governance contexts are represented within scenario-based analyses. Rather than prescribing specific modelling tools, it provides a structuring logic that informs model choice, coupling strategies, and interpretation of results depending on which dimensions of energy citizenship and which future-world contexts are under investigation. A key implication is that no single modelling approach can adequately capture the full spectrum of energy citizenship expressions identified in this study. Optimisation-based and equilibrium models remain well suited to analysing system-wide technology deployment and cost-efficient pathways. Their capacity to represent heterogeneous actors, behavioural diversity, and collective action depends on their

structure and resolution, and these dimensions may be represented at a higher level of aggregation than in actor-oriented approaches [223]. Where particular dynamics are not represented endogenously, they may be introduced through scenario assumptions or explored through complementary modelling approaches. The proposed scenario space instead encourages model pluralism, treating different modelling approaches as complementary rather than competing.

Storylines centred on individual decision-making, technology adoption, and demand-side flexibility align naturally with bottom-up and demand-oriented models that can represent household behaviour, investment decisions, and temporal patterns of energy use [224]. Situated within explicitly defined future-world narratives, these models allow behavioural assumptions and adoption dynamics to be interpreted in relation to broader sociopolitical conditions. Conversely, storylines emphasising collective organisation, social innovation, and political mobilisation pose different modelling challenges, as they involve network effects, peer influence, and feedback between public opinion and policy. Agent-based and other dynamic simulation approaches are particularly well suited to these contexts, as they allow system-level outcomes to emerge from interactions among heterogeneous actors.

At the same time, the presented framework remains compatible with a broad range of modelling traditions, including energy system models, IAMs, and energy-environment-economy (E3) models. How the framework informs each modelling approach depends on its scope, structure, and resolution: selected storyline and narrative elements may be represented endogenously where the model architecture permits or translated into exogenous assumptions, constraints, or parameter ranges. More disaggregated bottom-up and actor-based models can represent household heterogeneity, technology adoption, behavioural change, and collective action at a finer actor-level resolution. Recent stakeholder-informed modelling applications developed within the EC-funded Horizon 2020 project “ENCLUDE” have explored the use of the presented framework across local, national, and European scales, demonstrating how energy system models and the IMAGE IAM [225] can translate selected elements of the people-centred storylines and future-world narratives into scale-appropriate modelling assumptions to assess the decarbonisation implications of prosumer investments, the diffusion of collective energy initiatives, citizen-led building renovation and heating transitions, alternative national energy-planning pathways, and behavioural and lifestyle changes affecting residential and transport energy demand [226,227].

Subsequent peer-reviewed studies have also demonstrated the applicability of the presented framework across different analytical scales and contexts. At the local scale, Papantonis et al. used the future-world narratives to formulate differentiated trajectories for heating electrification, building renovation, behavioural change, fuel substitution, and energy costs in the residential sector of the coal- and carbon-intensive municipality of Megalopolis, Greece [228]. At the national scale, Kleanthis et al. operationalised the framework within an OSeMOSYS-based application by translating the people-centred storylines into alternative power-system planning configurations and the future-world narratives into scenario-specific boundary conditions, subsequently assessing their implications for electricity affordability across income groups in Greece [229]. In both applications, the qualitative scenario logic was translated into explicit modelling assumptions, preserving traceability between the framework's actor-centred and structural dimensions and the resulting energy, emissions, cost, and distributional outcomes.

5.4. Limitations and scope of applicability

Several limitations should be acknowledged to clarify the scope and appropriate use of the presented framework. First, the framework is intentionally conceptual and modular, designed to guide scenario construction rather than to function as a fully specified modelling methodology. It does not prescribe how individual elements of energy citizenship should be parameterised or quantified, leaving such decisions to the modeller. This flexibility enhances applicability across modelling traditions, but it also means that implementation quality depends on tool selection, data availability, and contextual expertise.

Second, the use of people-centred storylines necessarily simplifies complex and evolving social practices. In real-world settings, individuals and communities may embody multiple forms of energy citizenship simultaneously, and their engagement may change over time. The storylines should therefore be interpreted as analytical archetypes rather than exhaustive or mutually exclusive categories.

Third, while the framework accommodates multiple spatial and temporal scales through its future-world narratives, its application is most straightforward at local, regional, or national levels, where governance arrangements and social dynamics can be more clearly contextualised. At higher levels of aggregation, particularly in global modelling exercises, representing energy citizenship may require additional assumptions that may reduce granularity. In such cases, the framework's primary contribution lies in informing scenario logic and assumption-setting rather than in directly modelling micro-level behaviour.

Finally, the future-world narratives selectively translate SSP-derived structural dimensions into three internally coherent contexts designed for interpretability, modularity, and sub-national application. This parsimony necessarily reduces the differentiation of the original five-pathway framework, but it allows the structural context to be varied independently from the people-centred storylines without importing the full scenario logic of the SSPs' complete macroeconomic, demographic, and quantitative architecture. The narratives therefore constitute a purpose-specific implementation of the framework's structural axis rather than a replacement for the SSPs. Where full SSP differentiation is required, the modular design allows the people-centred storylines to be combined directly with the original five pathways.

Taken together, these limitations do not diminish the framework's contribution. Rather, they delineate its role as a structuring and interpretive tool that enhances transparency, exposes value orientations, and expands the range of socially plausible futures considered in scenario-based research. By doing so, the framework strengthens the capacity of scenarios to engage with the complexity, contestation, and unevenness that characterise real-world energy transitions.

6. Conclusions

Transitioning to decarbonised energy systems in line with the EU's climate objectives and the Paris Agreement is fundamentally a societal process that does not necessarily follow cost-optimisation logic. Accordingly, an expanding body of research calls for the integration of SSH into scenario-based research and modelling in order to better capture real-world behaviours, inform effective policy interventions, and support more inclusive decision-making, consistent with the EU's ambition to “leave no one behind”. Yet despite this growing recognition, many prevailing top-down approaches to climate and energy analysis continue to underestimate the social and cultural dynamics shaping energy use, particularly at the stage of local implementation. Against this backdrop, energy citizenship has emerged as a promising concept for advancing more democratic, equitable, and participatory forms of energy governance. However, its analytical ambiguity, together with its limited uptake in modelling-oriented research, has resulted in two persistent gaps: the lack of systematic operationalisation of energy citizenship and its insufficient integration into scenario-based research and modelling practices.

This study addresses these gaps by introducing an interdisciplinary framework for transformative scenario design that explicitly links social innovations of energy citizenship with alternative future-world evolutions. By deconstructing energy citizenship into identifiable patterns and trends and synthesising them into people-centred storylines, the framework provides a structured basis for embedding diverse forms of

citizen engagement into scenario logic. Combining these storylines with three contrasting future-world narratives enables the exploration of decarbonisation pathways under alternative sociopolitical conditions. The resulting two-dimensional scenario space allows variations in citizen agency and external context to be examined independently or jointly. To the best of our knowledge, this is the first framework that operationalises energy citizenship in a structured manner for the transformative design of socially informed scenarios while explicitly accounting for uncertainty and the dynamic character of future developments.

The flexibility of the proposed framework makes it applicable across a broad range of case studies and analytical scales. It offers insights into the evolving roles of citizens and communities in energy transitions and supports the design of socially inclusive and environmentally sustainable pathways. By enabling experimentation with different combinations of people-centred storylines and future-world narratives, the framework provides a transparent foundation for integrating social dimensions into scenario-based analyses.

Beyond its analytical contribution, the framework also responds to long-standing challenges in bridging modelling communities with policy and decision-making actors. While participatory approaches are widely recognised as valuable for incorporating SSH perspectives into scenario-based research, their implementation can remain uneven, resource-intensive, and insufficiently meaningful. The proposed framework can therefore function as a mediating platform that embeds social considerations directly into scenario design, complementing- rather than replacing- participatory processes, particularly where extensive stakeholder engagement is impractical.

Finally, energy citizenship remains a dynamic and evolving concept, shaped by societal change, technological innovation, and shifting political contexts. New forms of social innovation may therefore emerge faster than they can be captured in current classifications. Future research should test the framework in more geographically and culturally diverse contexts; examine how multiple forms of energy citizenship coexist, interact, and evolve over time; and develop transparent procedures for translating storyline-narrative combinations into model variables, boundary conditions, and parameter ranges. Further work should also assess distributional outcomes and feedbacks between citizen agency, policy responses, and broader structural change, strengthening the framework's relevance for policy implementation across local, regional, national, global, and cross-sectoral settings within and beyond the EU.

CRediT authorship contribution statement

Dimitris Fotopoulos: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis. **Nikos Kleanthis:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Formal analysis, Conceptualization. **Nicole J. van den Berg:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Bin-Bin J. Pearce:** Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition, Conceptualization. **Detlef P. van Vuuren:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition. **Alexandros Flamos:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition. **Vassilis Stavrakas:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Formal analysis, Conceptualization.

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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Data availability

No data was used for the research described in the article.

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