ENCLUDE

Energy Citizens for Inclusive Decarbonization

Impact of energy citizenship on the local level

WP5 – The impact of energy citizenship in decarbonization pathways

13/05/2023

Dimitris Fotopoulos, Nikos Manias, Nikos Kleanthis, Dimitris Papantonis, Vassilis Stavrakas, Alexandros Flamos

Technoeconomics of Energy Systems laboratory (TEESlab), University of Piraeus Research Centre (UPRC)

www.encludeproject.eu

Dimitris Fotopoulos	University of Piraeus Research Center
difoto@unipi.gr	https://teeslab.unipi.gr

Nikos Manias	University of Piraeus Research Center
manias@unipi.gr	https://teeslab.unipi.gr

Nikos Kleanthis	University of Piraeus Research Center
kleanthis@unipi.gr	https://teeslab.unipi.gr

Dimitris Papantonis	University of Piraeus Research Center
papantonis@unipi.gr	https://teeslab.unipi.gr

Vassilis Stavrakas	University of Piraeus Research Center
vasta@unipi.gr	https://teeslab.unipi.gr

Alexandros Flamos	University of Piraeus Research Center
aflamos@unipi.gr	https://teeslab.unipi.gr

Please cite as:

Fotopoulos, **D.**, **Manias**, **N.**, **Kleanthis**, **N.**, **Papantonis**, **D.**, **Stavrakas**, **V.**, **Flamos**, **A.**, **(2024).** *Impact of energy citizenship at the local level. Deliverable 5.3. Energy Citizenship for Inclusive Decarbonization (ENCLUDE) project*. European Commission. University of Piraeus Research Center (UPRC), Piraeus, Greece.

Disclaimer

The sole responsibility for the content of this publication lies with the authors. It does not necessarily reflect the opinion of the European Union. The publication has been submitted for review to the European Commission but has not yet been approved. Neither CINEA nor the European Commission is responsible for any use that may be made of the information contained therein.

Copyright Message

The ENCLUDE project has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement No 101022791.

ENCLUDE PROJECT & DELIVERABLE PROFILE

Project Acronym and Full Name:	ENCLUDE - Energy Citizens for Inclusive Decarbonization
Grant Agreement No.:	101022791
Programme:	H2020-EU.3.3.6. - Robust Decision Making and Public Engagement
Topic:	LC-SC3-CC-1-2018-2019-2020 – Social Sciences and Humanities (SSH) aspects of the Clean-Energy Transition
Funding Type:	RIA - Research and Innovation Action
Deliverable:	D5.3 - Report on the impact of energy citizenship at the local level
Work Package:	WP5
Deliverable Due Date:	30.04.2024
Actual Date of Submission:	13.05.2024
Dissemination Level:	Public
Lead Beneficiary:	University of Piraeus Research Center (UPRC)
Responsible Author:	Dimitris Fotopoulos
Contributor(s):	Nikos Manias, Nikos Kleanthis, Dimitris Papantonis, Vassilis Stavrakas, and Alexandros Flamos
Internal Reviewers:	BinBin J. Pearce (TUD) and Andreas Tuerk (JR)

Preface

The overall vision of ENCLUDE is to help the EU to fulfil its promise of a just and inclusive decarbonization pathway through sharing and co-creating new knowledge and practices that maximize the number and diversity of citizens who are willing and able to contribute to the energy transition. Motivated by achieving an equitable and sustainable future and the fulfilment of individual potential, ENCLUDE will contribute to the upcoming transformation of energy use by: (1). Assembling, aligning, and adapting disparate energy citizenship concepts for diverse communities of citizens and for different scales of policy making, lowering the barrier for action. (2). Operationalizing the energy citizenship concept at all scales of policy making for decarbonization. (3). Catalyzing a chain reaction of decarbonization actions across the EU.

1. Changes with respect to the DoA

The only deviation from the amended Grant Agreement is the extension of Deliverable 5.3 by 10 days as its due date coincided with the national holidays of the Orthodox Easter, and, thus, it was extended in agreement with the Project Coordinator.

Given the interdisciplinary nature of Deliverable 5.3, this short extension allowed for additional reviews from ENCLUDE partners with a background in social science and humanities with a view to further improving its quality and the implications derived.

This deviation impacts neither the objectives nor the successful implementation of other Tasks and WPs.

2. Dissemination and uptake

This report may easily be used both within and outside of the project, by researchers interested in the fields of energy system modeling and energy citizenship. Hence, this report will be disseminated through the usual social media channels to communicate and promote key findings and insights in an easily digestible manner. Also, it is envisaged that it will be uploaded to open research platforms (e.g., Zenodo) to reach a broader research audience.

3. Short Summary of results (<250 words)

This report is the third (3^{rd}) one out of five (5) deliverables under Work Package 5 of the ENCLUDE project and builds on the work done previously in Deliverable 5.1 and Deliverable 5.2, namely the "*people-centered*" storylines and the "*future-world*" narratives.

In this deliverable, we enhanced the ENCLUDE modeling ensemble and employed it to extract insights regarding the decarbonization potential of energy citizenship at the local level. Specifically, to simulate the different scenarios, two (2) models were employed, namely: ANIMO (grAssroot innovatioN diffusion MOdel) and DREEM (Dynamic high-Resolution dEmand-sidE Management).

More specifically, under the "*Power to the People*" storyline, we analyzed the profitability of small-scale PV systems under various policy schemes active in different Member States, and estimated their decarbonization potential, to provide incentives for citizens to actively participate in the energy transition as "*prosumers*".

Under the "*Band Together*" storyline, we tested the workings underlying the growth of Collective Energy Initiatives and their diffusion to populations with different cultural and perceptual backgrounds to project their future growth and decarbonization potential, showcasing the environmental benefits associated with collective expressions of energy citizenship.

Finally, under a combined "*Power to the People*" and "*Habitual Creatures*" storyline, we explored a "green" rebranding of the Coal and Carbon Intensive Region of Megalopolis in Greece into a city of the people, by the people, for the people, via a citizen-led transition that is based on energy efficiency investments and behavioral and lifestyle changes, towards a fair and inclusive energy transition.

4. Evidence of accomplishment

This report serves as evidence of accomplishment.

LIST OF PARTICIPANTS

	Participant Name	Short Name	Country	Logo
1	TECHNISCHE UNIVERSITEIT DELFT	TUD	Netherlands	
2	UNIVERSITY OF PIRAEUS RESEARCH CENTER	UPRC	Greece	
3	EIDGENOESSISCHE TECHNISCHE HOCHSCHULE ZUERICH	ETHZ	Switzerland	
4	UNIVERSITY COLLEGE CORK - NATIONAL UNIVERSITY OF IRELAND, CORK.	UCC	Ireland	
5	UNIVERSITY OF GLASGOW	UOG	United Kingdom	
6	JOANNEUM RESEARCH FORSCHUNGSGESELLSCHAFT MBH	JR	Austria	
7	TH!NK E	THNK	Belgium	
8	UNIVERSITEIT UTRECHT	UU	Netherlands	
9	GREEN PARTNERS SRL	GP	Romania	
10	ZDRUZENIE CENTAR ZA ISTRAZUVANJE I INFORMIRANJE ZA ZIVOTNA SREDINA EKO-SVEST	Eko-svest	North Macedonia	
11	MISSIONS PUBLIQUES	MP	France	
12	HOLISTIC IKE	HOLISTIC	Greece	
13	UNIVERSITY OF VICTORIA	Uvic	Canada	

Executive Summary

Efforts to address the contemporary climate and energy-related challenges towards a green, inclusive, and fair transition by 2050, require the empowerment and engagement of citizens and other societal actors, as has been duly acknowledged within the recent European Union's strategic and legislative frameworks. Citizens are anticipated to expand their role as self-consumers and contributors within energy communities, actively shaping alterations in the energy landscape, impacting both demand and supply.

As a result, in recent years the concept of *energy citizenship* has emerged and gained considerable attention due to its potential to bridge the gap between energy transition policies and social participation, by placing emphasis on the importance of participatory and democratic processes in decision-making and underlining the need for a more inclusive and equitable energy system.

In this context, the Horizon 2020 ENCLUDE project aims at operationalizing the concept of energy citizenship across all scales in the European Union. Within the project, Work Package 5 (WP5) has aimed to understand the multi-scale relationship between energy citizenship and decarbonization pathways across diverse contexts, with a view to provide appropriate decision-support through the application of appropriate modeling frameworks.

Building on the work done previously in WP5, in this deliverable we expand and employ different modeling frameworks of the ENCLUDE modeling ensemble to extract insights regarding the decarbonization potential of *energy citizenship* at the *local* level.

More specifically, in past deliverables a comprehensive set of "*people-centered*" storylines based on identified trends and patterns of energy citizenship was designed, highlighting citizens' perspective, and bringing them to the forefront of the energy transition:

- "*Power to the People*" (*Active participation in the energy market*).
- "*Band Together*" (*Collective initiatives and expressions of energy citizenship*).
- "*Habitual Creatures*" (*Individual behavioral and lifestyle changes*).
- "*People to the Streets*" (*Political activities*).

Additionally, a set of three (3) "*future world*" narratives was developed, describing future systemic changes of society and economy, providing a context of potential future world evolutions that may be inhabited by citizens, namely:

- "*A Familiar World*".
- "*A Unified World*".
- "*A Fragmented World*".

Set to explore the decarbonization potential of energy citizenship expressions mainly manifested at the *local* level, in this deliverable, we focus on three (3) of the four (4) outlined "*people-centered*" storylines, namely the "*Power to the People*" storyline, the "*Band Together*" storyline, and the "*Habitual Creatures*" storyline, and, combined with the "*future-world*" narratives, a scenario space to study case-specific decarbonization pathways, acknowledging the depth of complexity and diversity of the European landscape was created.

In this endeavor, we harnessed the power of existing models comprising the ENCLUDE modeling ensemble, as well as expanded it by developing a new modeling framework (i.e., ANIMO) to study the diffusion of social and grassroot innovations related to *energy citizenship*, like Collective Energy Initiatives.

Specifically, to simulate the different scenarios, two (2) of the five (5) models were employed, namely:

- ANIMO (grAssroot innovatioN diffusion MOdel).
- DREEM (Dynamic high-Resolution dEmand-sidE Management).

A brief description of the key findings for each *people-centered* storyline is provided below:

"*Power to the People*" through empowering prosumerism

Under this storyline we examined whether a *people-powered* transition based on citizen investments in small-scale PV systems can support a green transition by 2050 in the European Union's residential sector. To this end we used the DREEM model to project the annual electricity demand and electricity production from rooftop PV systems across eleven (11) cities in five (5) Member States. We then analyzed the profitability of such investments under the various policy schemes active in the countries of interest, as well as estimated their decarbonization potential in an attempt to provide incentives for citizens to actively participate in the energy transition as "*prosumers*".

"Band Together" in Collective Energy Initiatives

Through the study of three (3) Collective Energy Initiatives set in very different contexts, we strived to explore and understand the workings underlying their growth and diffusion to a larger population. Our modeling results showed that *population density* and *social connectivity* are key drivers of growth of Collective Energy Initiatives, like energy communities and ecovillages. Findings also clearly demonstrated the cascade effect of mass participation that is encouraged by densely populated areas, highlighting a "*ripple effect*" that can significantly accelerate the energy transition. On top of this, making use of ANIMO, we made projections on the future growth of the collective energy initiatives under study, based on which their emission reduction potential was estimated, showcasing the decarbonization potential associated with collective expressions of *energy citizenship*.

"Power to the People" and "Habitual Creatures" storylines towards just and inclusive transitions

Focusing on the Coal and Carbon Intensive Region of Megalopolis, in Greece, we tested whether a citizen-led transition based on energy efficiency investments and lifestyle and behavioral changes can lead to a just and inclusive transition. In this regard, we sought to find the post-lignite development trajectory of a people-powered transition in the residential sector of Megalopolis, which does not rely on traditional fossil fuels, i.e., oil and natural gas. To this end, using the DREEM modeling framework, we explored three (3) investment strategies to initiate the transition in the region according to the "*future-world*" narratives under study, and estimated the potential economic benefits for citizens. Lastly, aside from financial aspects, we assessed the related environmental benefits, as we quantified the potential for emission reduction that a reconsideration of lifestyle and behaviors along with citizen investments in energy efficiency actions in the residential sector of Megalopolis possesses.

Contents

List of Figures

List of Tables

List of Abbreviations/ Acronyms	
ANIMO	grAssroot iNnovation dIffusion MOdel
ATOM	Agent-based Technology adOption Model
CCIR	Coal and Carbon Intensive Region
CEI	Collective energy initiative
CO_2	Carbon dioxide
DREEM	Dynamic high-Resolution dEmand-sidE Management
EC	European Commission
ECCP	European Climate Change Program
EU	European Union
ETS	Emissions Trading System
FiT	Feed in Tariff
GHG	Greenhouse gas
GHI	Global Horizontal Irradiation
IAM	Integrated assessment model/modeling
ICT	Information and communication technology
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
LCOE	Levelized Cost of Electricity
NECP	National Energy and Climate Plan
NECPR	National Energy and Climate Progress Report
NPV	Net Present Value
OSeMOSYS-GR	Open-Source energy MOdeling SYStem for GReece
PV	Photovoltaic
RQ	Research Question
SDG	Sustainable Development Goal
SSP	Shared Socioeconomic Pathway
TEEM	TEESlab Modeling
TEESlab	Technoeconomics of Energy Systems laboratory
TMY	Typical Meteorological Year
WP	Work Package

1. Introduction

During the last two decades, the European Union (EU) has been a global leader in fighting climate change through its ambitious policies (Oberthür, 2011; Wurzel et al., 2016), since 1991, when the first Community Strategy was launched with the goal of reducing carbon dioxide (CO_2) emissions and increasing energy efficiency. Efforts to mitigate global warming have thus been ongoing for several years, driven not only by the EU's priorities, but also by the need to fulfill the EU's international commitments under the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and, more recently, the Paris Agreement (Stavrakas et al., 2018).

The "European Climate Change Program (ECCP)", implemented in 2000, acted as a direct strategic initiative, resulting in a combination of diverse climate change mitigation strategies. As a result, relevant EU legislation was introduced, which had to be transcribed and executed at the Member States' level. Climate and energy policies were combined in a single package of objectives for decreasing greenhouse gas (GHG) emissions, as well as measures for the further deployment of renewable energy sources (RES) and energy efficiency improvements, in the 2020 climate and energy package, enacted in 2009.

This framework is mostly preserved in the EU's 2030 package. The European Commission (EC) presented the "Winter Package" in November 2016, which covered all aspects of the energy system and shaped the policy framework for the post-2020 era (Michas et al., 2019a; Rosenow et al., 2017).

In late 2019, the EU introduced the European "Green Deal", a comprehensive strategy with the ambitious goal to attain climate neutrality by 2050, addressing the urgent challenge of climate change while fostering economic growth and safeguarding well-being (European Commission, 2019b). This initiative not only outlines the aim of achieving zero GHG emissions by 2050 but also sets an even more ambitious target of reducing GHG emissions by at least 55% by 2030 compared to the 1990 levels.

Additionally, in line with the European "Green Deal" objectives, the "Clean energy for all Europeans package" was adopted in 2019, to further support decarbonization efforts across the EU (European Commission, 2019) and yield substantial advantages for consumers, the environment, and the economy. Through the coordination of these modifications at the EU level, the legislation further reinforces the EU's role as a leader in addressing global warming, making a significant contribution to the goal of achieving carbon neutrality by 2050.

Further adding to its pledge, in March 2023, a stronger legislation to increase RES capacity was agreed, by raising its binding target to a minimum of 42.5% by 2030, up from the current 32%, with the ambition to reach 45%, doubling the existing share of renewable energy in the EU. In addition, given the fact that reducing energy consumption is crucial to bring down both emissions and energy costs for consumers and industry, a new binding was established to improve energy efficiency by 11.7% by 2030 (European Commission, 2023).

Finally, the 2022 Russia's invasion of Ukraine and the ensuing energy crisis in Europe brought about the issue of energy security of the common European energy system. Evoking the energy crises of the 1970s and late 2000s, when measures to enhance the liquidity of fossil fuel markets were perceived as the cure to these crises (Natorski & Herranz Surrallés, 2008), the current unprecedented situation calls for a different answer. The security of supply, widely understood under its geopolitical aspect, is now tightly correlated with the notion of affordability of energy, and therefore a more inclusive decarbonization strategy seems to be comprehended as the most viable long-term solution (Osička & Černoch, 2022a).

To this end, the EC presented in March of 2022 the "REPowerEU" plan, a joint European action to accelerate the clean energy transition and increase Europe's energy independence from unreliable suppliers and volatile fossil fuels (European Commission, 2022b). To achieve the goals, actions on the following areas are outlined:

- Energy savings.
- Diversifying energy imports.
- Substituting fossil fuels and accelerating Europe’s clean energy transition.
- Smart investments.

Thus, even though the diversification of gas supply and the short-term regression to the plans regarding the phase out of coal in Member States are inevitable short-term measures, energy efficiency and RES will be the main assets not only for mitigating climate change or moving to more sustainable lifestyles, but also fundamental assets to assure national and European security (Osička & Černoch, 2022b).

To move towards this direction even if the future is unclear, rapid action must be taken to put society on track for energy systems dominated by renewables by the middle of the century. This might take on a variety of forms, such as developing policies for the deployment of new generation assets, integrating various sector policies, and balancing the interests of the many actors. Therefore, a shift from fossil fuels to renewables is planned and partially underway.

So far, emphasis in the field of climate change mitigation has been put on the technical and infrastructural aspects of the energy transition. However, while technological innovations are undoubtedly needed and our understanding of them is rich, technology alone cannot stop climate change as the complex societal systems are the initial causes of the problem (Matschoss et al., 2022); how society and citizens change is less certain, as behaviors and lifestyle are constantly changing and are expected to change substantially in the future. Yet, anticipating or imagining how these will change is a challenge and generally unexplored in the field of climate change mitigation.

To help realize the vision of a green, inclusive, and fair transition by 2050, the role of citizens and other societal actors as well as their empowerment and involvement is of utmost importance and has been acknowledged within the EU’s recent strategic and legislative frameworks. A better understanding of social change, thus, is required to investigate potential future evolutions of the energy transition.

1.1. The role of societies and citizens in the European energy transition

The actions proposed by the “Green Deal” and the “REPowerEU” plan, aiming at raising the EU's climate ambition and energy independence, are projected to result in a full transformation of the present energy system by investing in practical and creative technological choices, as well as empowering citizens and involving them in the energy transition.

Furthermore, the EU's Energy Union policy emphasizes the significance of putting "*people at the center*" of the energy transition and envisions a Union where “*citizens take ownership of the energy transition, benefit from new technologies to reduce their bills, actively participate in the market, and where vulnerable consumers are protected*” (European Commission, 2021).

In this context, citizens are expected to play a much larger role as self-consumers and participants in energy communities (EU, 2018) and drive changes in the energy system, influencing both demand and supply. As a result, transitions that are not just technologically feasible, or economically possible, but also socially and politically acceptable, are required, also considering individual preferences, acceptance, and behavioral and lifestyle changes (Cherp et al., 2018). As a result of the expected increasingly participatory role of citizens and other societal actors in the future energy systems, the new concept of “*energy citizenship*” has emerged during recent years.

Energy citizenship is a term that describes how citizens are constantly engaging with the energy transition, from an economic, political, and social perspective (Campos & Marín-González, 2020) and conceives citizens and societies as active rather than passive stakeholders in the evolution of the energy system (Laakso et al., 2023). In particular, according to Campos & Marín-González (2020), energy citizenship can be broadly defined as “*a view of the public that emphasizes awareness of responsibility for climate change, equity, and justice (…), and the potential for (collective) energy actions*”.

This broad definition lends itself to be linked to various other emerging trends and patterns that can relate to: (i). the active participation of citizens to the energy market, such as through the concept of "*prosumerism*", the further diffusion of energy efficiency and smart technologies and solutions, etc., (ii). behavioral aspects of citizens and lifestyle changes in the daily lives of citizens, (iii). collective initiatives and expressions of energy citizenship, such as the formation of energy communities, co-operatives, eco-villages, or collective decision-making, such as housing association boards, etc., and (iv). political activities, such as participation in social movements and civil society initiatives advancing democratic visions of energy transition and/ or policymaking taking the form of participation in energy sector planning and decision-making, including through co-design initiatives, public consultation, and participatory design of potential future energy landscapes.

By participating in various energy-related activities and by taking an active role in the shift toward cleaner and more sustainable energy systems, citizens can collectively and individually contribute meaningfully to the fight against climate change.

1.2. Transition pathways and energy citizenship

Making decisions on climate and energy policies to achieve the desired future energy paradigms is a difficult and complicated process due to a number of internal and external variables (such as technical advancements, societal changes, behavioral aspects, economic developments, etc.) that impact the dynamics of the energy system (Haasnoot et al., 2013). Decision-makers may experience confusion or incapacity while attempting to develop strong policies, frequently as a result of a lack of information regarding the uncertainties they must take into account (Forni et al., 2016).

Policymaking under deep uncertainty, especially under long-term projections, implies that policymakers will encounter difficulties when asked to design and implement a new policy, and/ or how a particular policy instrument affects various sectors. Predicting the future and deciding on the most probable evolution before applying a policy has proven to be a difficult undertaking.

Various challenges and the way they are addressed are crucial in shaping future transition pathways in meeting the Paris Agreement "*well-below 2 degrees Celsius, while pursuing efforts to limit the increase to 1.5 degrees Celsius*" target. Five key energy sector challenges, to support basic human needs, development, and well-being are (i). energy demand growth and its coupling with demographic and economic drivers, (ii). phasing out of traditional forms of energy use and improving energy access and modernization of energy use in the context of structural economic changes, (iii). the expansion of primary energy supplies, (iv). the future of existing, and the build-up of, new energy infrastructure and innovative technological solutions, and (v). GHG emissions and other pollutants and their reduction. These challenges are related to key scientific debates on global and long-term developments in the energy sector.

In addition, the complex decisions concerning mitigation portfolios for limiting warming to 1.5°C can have both a positive and negative impact on the achievement of other societal objectives, such as sustainable development. For example, demand-side and energy efficiency measures, and lifestyle choices that limit energy, resource, and GHG-intensive food demand support sustainable development. The coupling between socioeconomic development patterns and energy demand has been identified as a fundamental issue for understanding the scale and structure of energy demand (Csereklyei & Stern, 2015; Grubler et al., 2012; Jakob et al., 2012; Schäfer, 2005).

The International Panel on Climate Change (IPCC) report indicates that on a global scale, demand-side measures are key to 1.5°C pathways. Scenarios focused on demand-side measures demonstrate the potential to reduce global GHG emissions in end-use sectors by 40-70% by 2050 compared to baseline scenarios (Calvin et al., 2023a). Demand-side mitigation encompasses changes in infrastructure use, end-use technology adoption, and sociocultural and behavioral change. Such changes can be for example the use of smart grids, the deployment and adoption of technological and social innovations, such as information and communication technologies (ICT), and the formation of energy communities, as well as habitual changes as reducing food waste or shifting to sustainable and healthy diets.

In addition, limiting global warming to 1.5°C must also be accomplished in tandem with poverty reduction and better energy security, and it can deliver significant public health benefits through improved air quality, averting millions of premature deaths. On the other hand, some transition pathways, such as bioenergy, may result in trade-offs that must be considered.

As a response to the uncertainty surrounding the different potential evolutions of the future energy system and the different pathways that could be follow to attain a green, inclusive, and fair socioeconomic system, researchers utilize the concept of "*scenario-based analysis*" to present various future development trajectories and climate-/ energy-related trends, which describe different transition pathways to a decarbonized energy system, without implying probabilities on the actual implementation of each scenario (Levesque et al., 2018a).

Such scenario-based analyses often aim to explore conditions leading to long-term objectives (e.g., 1.5°C global warming) (O'Neill et al., 2017), while providing an outline of qualitative trends and quantitative projections regarding emissions, societal futures, economic implications, and climate impacts including the evaluation of the implicit uncertainty introduced. Especially long-term global scenarios have become of particular importance to climate research and climate policy planning, since the "Special Report on Emission Scenarios" (Nakicenovic & Swart, 2000).

For more than two decades, long-term global scenarios have been critical in climate change analysis (Nakicenovic & Swart, 2000; Raskin et al., 2005; van Vuuren et al., 2012). While there are other methods for characterizing the future (Lempert et al., 2004; Webster et al., 2003), alternative scenarios are an important tool for exploring uncertainty in future conditions of the society and climate (Jones et al., 2014). Societal development scenarios frequently include both qualitative and quantitative components (Ash et al., 2010; Raskin et al., 2005; Rothman et al., 2007; van Vuuren et al., 2012).

Qualitative narratives (or storylines) describe the evolution of societal aspects that are difficult to quantify (such as the quality of institutions, political stability, environmental awareness, etc.), and provide a basis for further elaboration of the scenarios by users. Quantitative components define common assumptions for elements like population and economic growth, or rates of technological shifts that can be meaningfully quantified and used as inputs to models for modeling energy and land use, emissions, and other outcomes.

In this context, the concept of "*Shared Socioeconomic Pathways (SSPs)*" has been proposed as a new set of scenarios to be used as a basis of future climate research and present alternative futures of societal development till the end of the 21st century (O'Neill et al., 2017; O'Neill et al., 2014; van Vuuren et al., 2014). The SSPs form a set of five (5) possible future development pathways that result in fundamentally different states of human society; each SSP builds on a unique narrative and articulates the challenges on mitigation efforts and adaptation to climate change that come along with each narrative.

Despite their global scale in their original form, SSPs have been interpreted in quantitative scenarios in multiple studies, serving as the basis for long-term projections concerning different contexts, sectors, and scales to facilitate effective mitigation and adaptation planning in areas of interest.

The SSPs can also be used in combination with additional climate-specific assumptions to explore the effects, both positive and negative, of climate policies in different contexts, or to assess the overall implications of climate change. For example, SSPs have been used to account for socioeconomic uncertainties associated with changes in the world's population, economic growth, technological development, urbanization, and education from 2020 through 2100. They have also been used recently to predict long-term useful energy and final energy demands in buildings (Chakraborty et al., 2021; Levesque et al., 2018a).

By examining prospective energy futures, the need for a fair and inclusive energy transition and the advancing role of citizens in the future energy regime, are core aspects of alternative sociotechnical pathways that could lead to the vision of decarbonization, especially in the EU, which has been a front-runner in policies that foster the transition to a carbon-neutral socioeconomic environment. In this context, case-specific decarbonization pathways are typically created to accomplish a single predetermined climate target.

Reduced mitigation expenditures, rather than climate-related harm or long-term development impacts, are commonly used as the base for these paths to the desired climate target. Interactions between mitigation and other Sustainable Development Goals (SDGs), on the other hand, present both barriers and opportunities for climate policy (UN DESA., 2023). Consequently, substantial efforts are being undertaken to assess the effects of various mitigation pathways on long-term development.

There are attempts to integrate climate change mitigation as one of multiple objectives that, broadly, better reflect societal concerns and may provide benefits at a lower cost than concurrent single-objective policies (e.g., (Clarke et al., 2014)). For example, carefully chosen policies can achieve universal energy access while simultaneously diminishing air pollution and mitigating climate change (International Energy Agency, 2017; McCollum et al., 2011; Riahi et al., 2012).

It becomes apparent, thus, that the concept of "*energy citizenship*" fits well with, and possesses a significant role in, scenario-based analyses that aim to develop transition pathways to be studied towards the envisioned energy futures and the target of decarbonization.

However, the development of such scenarios and pathways, solely, is not enough, as policymakers need decision and support tools, which are able to explore the interplay of economic decision-making and behavioral heterogeneity in, for example, households' energy choices when testing common climate mitigation policies (e.g., carbon pricing), socioeconomic alternatives in a world with changing climate, etc.

1.3. Energy system modeling and energy citizenship

Energy system models have been a valuable tool towards well-informed decision- and policymaking processes in Europe over the past few decades: they have simulated multiple energy transition scenarios and pathways and have reflected on different possible evolutions of the energy systems (Süsser, Ceglarz, et al., 2021).

Energy system models are purposeful mathematical simplifications of reality- "*smaller, less detailed, less complex, or all together*", but they are also shaped by, and potentially shaping, the social world, in which they are embedded (Van Egmond & Zeiss, 2010). The same holds true for the modelers themselves, who define the model's nature-based theories, empirics, and also their ideas and mental models, respectively (Ellenbeck & Lilliestam, 2019). Thus, computer and mental models are mutually dependent.

In this regard, models can function as "*discursive*", or "*negotiation*" spaces, bringing together different social worlds- such as represented by scientists and policymakers- and enabling these worlds to create a shared understanding, work together, and negotiate knowledge and policy (Evans, 2000; Star & Griesemer, 1989). Hence, energy system models can support governmental decision-making processes (Lopion et al., 2018); however, they cannot be a "*final decision for the policy process to [be] simply implement[ed]*" (Gilbert et al., 2018).

According to Pfenninger et al. (2014) "energy system models are not only a tool for the definition of scenarios and long-term planning strategies, but also for the expression of the semantics used to formalize the "scattered knowledge" about the complex interactions of the energy sector". In this context, the field of energy system modeling is prolific, and many models have been and are currently being developed using different methodologies and working approaches. Linking social science and the concept of "energy citizenship" to modeling tools is an important topic because it can broaden the perspective on, and understanding of, the complex subject of the energy transition, the diffusion of the technological and social innovations required, and the interactions between key characteristics of citizens' behavior affecting investment decisions.

Considering the wide spectrum of activities that the concept of "*energy citizenship*" encompasses and its multi-dimensional approach to tackling climate change, it has become increasingly evident that the transition of the energy system, i.e., the established ways of producing, distributing and consuming energy in the present societies towards carbon neutrality, involves more than substituting fossil fuels with renewable energy. Instead, it implies a transformation in collective, shared practices of governing and managing the energy system and the emergence of new social roles (e.g., Bjerkan et al., 2021), and this requires the consolidation of the "*energy citizenship*" concept.

For example, when it comes to the EU, the shift to a more decentralized vision of a low-carbon energy system, where citizens take ownership of the transition, benefit from new technologies to lower their bills, and actively participate in the market, part of the required infrastructure will only be developed if citizens are willing to invest in and pursue the technological capabilities required.

However, given that it is unlikely that they will invest in new technological options with the primary goal of supporting the energy system (e.g., flexibility), it is reasonable to assume that they will only invest according to a value derived from a higher proportion of self-produced energy consumed.

In that regard, while technological infrastructure is already in place, new and innovative business models and legal frameworks are required to maximize the value of technological capabilities and to commercialize them in order to recompense citizens (Li et al., 2019; Tzani et al., 2022). Nevertheless, due to conflicts between citizens' and market actors' interests, the existing European legislative framework leads to situations where business models do not fully use demand-side capabilities, even when they exist (Wolisz et al., 2016).

Given that in modern energy systems technological innovation will continuously pose new challenges to existing regulatory frameworks, innovations in regulation should be as important as regulating innovations (Rubino, 2018). As a result, efficient policymaking around Europe should explore "*game changer*" business models that incentivize both citizens and other market actors to incorporate demand flexibility into the markets that can valorize it.

In this context, relying on demand-side modeling methods that consider citizens' behavioral characteristics is critical to determining future profile patterns of the future transformation, but it has been misused thus far. However, scientific support for climate action entails not just judging feasibility and desirability in terms of "*what*" as in policy and outcome, but also "*when*", "*where*", and, most importantly, "*whom*".

Without the essential behavioral and cultural changes, the world's response to the climate crisis will be insufficient. This might be due to a lack of adoption of low-carbon technology, the continuation of high-carbon lifestyles, or broader economic rebound effects (Nikas et al., 2020).

However, despite the increasing importance and use of energy system models, the above aspects are currently underrepresented in these models. In particular, most models take a technoeconomic and/ or cost optimization approach, which limits their ability for including social aspects and dynamics, such as policy preferences, or social acceptance (Chatterjee, Stavrakas, Oreggioni, Süsser, Staffell, Lilliestam, Molnar, et al., 2022). What is noteworthy is that social aspects can also play a significant role in accelerating or impeding processes within the energy transition, while there is a growing awareness of the importance of these dynamics.

These factors are important for the development of energy system models because societies can have a significant impact on driving or limiting the energy transition: citizens, for example, can develop and participate in community energy projects while also opposing local energy infrastructure development.

Current models tend to treat the social dimension of the energy transition as an added layer of analysis, i.e., they consider society as a larger social context, and, as a result, they overlook interactions between societal factors and other factors such as technology, economy, and even the environment (Süsser, Pickering, et al., 2021).

In this context, facilitating the energy transition towards climate neutrality in Europe by 2050 requires us to develop a new set of energy modeling tools, or further adjust the existing ones and match them with existing needs, to simulate and analyze the drivers and barriers to complete decarbonization, including decentralization, a large-scale deployment of variable RES, resulting in a greatly increased demand for system-side flexibility, sector-coupling, including electrification of transportation and heating, and the effects of alternative market designs on the behavior of different energy sector players.

1.4. Energy citizenship at the local level

According to recent literature "*there is a risk of diluting the ambition at the national level, a persistent lack of coordination of national energy policies"* and a serious *"need to strengthen common financing, policy coordination, and governance tools*" (Defard, 2023). This calls for a variety of actions by a wide range of actors at different levels of influence and for improved governance structures and collaboration across different policymaking levels (e.g., administrative levels within countries) (Intergovernmental Panel on Climate Change (IPCC), 2022; Wang et al., 2024).

Therefore, breaking transition lock-ins is inherently a political endeavor, as transition pathways are intricately linked with political decisions and policies that foster, modify, and enable changes at different policy levels, which, however, are mostly taken at the national level. This is particularly important as regional and local authorities are given more responsibility and importance in implementing climate and energy transitions (European & Regions, 2018; Kleanthis et al., 2022); when it comes to policymaking at strategic levels, though, their contribution is not always considered, and legislation does not always support the regional and/ or the local level (Aruta et al., 2023; Brandoni & Polonara, 2012).

This is not in line with Art.11 of the European Regulation on the Governance of the Energy Union and Climate Action 2018/ 1999, which states that Member States shall establish a multilevel climate and energy dialogue to deliver on the vision of climate neutrality by 2050 (European Parliament & Council of the European Union, 2018). As of now, though, the EC's assessment of National Energy and Climate Progress Reports (NECPRs), submitted in March 2023, attached to the 2023 State of the Energy Union shows that the maturity of these multilevel governance structures is currently not at the ideal level (EUROPEAN COMMISSION, 2023).

Drawing from the above, actively participating in the energy system has a range of impacts at the local level and can aid in achieving net-zero emissions. Scientific literature so far has extensively focused on ways to motivate citizens to support the concept of "prosumerism". For example, Egert et al. (2021) presented several theoretical frameworks and approaches, drawn from multiple disciplines (e.g., pedagogy, behavioral economics, and psychology), for motivating users to choose certain options for action or to show specific behaviors concerning their behavior in the energy system (Egert et al., 2021).

Prosumerism typically refers to RES generation at the local level, such as through rooftop photovoltaic (PV) systems, or small wind turbines, while it aids in reducing dependence on the central energy system and therefore enhances resilience by providing back-up power during outages (Egert et al., 2021).

This in turn reduces the need for grid expansion and lowers electricity costs for residents and businesses while relieving grid congestion. It can also help reduce energy needs and require less energy from traditional power plants, which can, in turn, help reduce GHG emissions and other pollutants, causing less environmental harm (Ruggeri, 2021).

Another study pointed out the economic benefits prosumers enjoy, as producing one's own energy stimulates local economies and creates jobs, since prosumers can provide excess electricity back to the grid (or even sell it in some cases), generating savings, or even income for households (Gautier et al., 2017).

In addition, collective expressions of energy citizenship at the local level, as energy communities, are already widely spread, with over 3,500 active energy communities throughout Europe currently (Caramizaru et al., 2020). Gjorgievski et al. (2021) reviewed scientific works on the multifaceted impacts of energy communities and identified indicators to evaluate their economic, environmental, technical, and social benefits. They found that positive influence was noted across the different indicators when scenarios with local collective energy projects were compared to scenarios in which no energy communities were formed.

Since energy communities have been considered as a significant tool against climate change, besides their impacts research has also focused on the specific circumstances that favor and promote citizen participation. Systematic literature reviews have identified trust, environmental awareness, community identity, and social norms as deciding factors that facilitate the creation of local energy communities (Soeiro & Ferreira Dias, 2020; Young & Brans, 2017; Seebauer et al., 2022).

In a study by Fina & Monsberger (2023), energy communities in Austria were investigated to specify gaps that hinder their diffusion on a large scale. To close these gaps, ideas, and measures to help their uptake and full integration were discussed and business model approaches as well as policy recommendations were developed.

Finally, extensive research has also been conducted in the field of citizen behavior and lifestyle changes and its impact on decarbonization pathways. In a study using an integrated assessment model (IAM), it was found that lifestyle changes can potentially achieve about 13% of emission reduction by 2030 (van Sluisveld et al., 2016).

Williamson et al. (2018) formed a set of 30 measures for citizens or households, which were based on altering patterns of human consumption, spanning from the food sector to the transportation and energy sector. They found that a GHG emission reduction in the range of 19.9-36.8% is to be expected when these measures are implemented, confirming the fact that individual actions and lifestyle choices play a crucial role in addressing decarbonization and climate change mitigation.

Yet, there remains a significant gap in understanding the enablers and success factors of energy-related behavior change initiatives (Feola & Nunes, 2014; Steg et al., 2015). Axon et al. (2018) addressed this gap by identifying and characterizing a sample of 50 cases of energy-related behavior change initiatives, selected across five European countries, and provided insight into the success factors and commonly encountered barriers to energy-related behavior change initiatives.

1.5. Objectives and scope of this deliverable

Since energy citizenship has such a large variety of expressions, it is obvious that it can greatly influence decarbonization processes on multiple fronts and scales. Especially at the local scale, though, it is crucial to better understand how the impacts of the different aspects of energy citizenship have been studied so far.

A recurring challenge noticed in recent literature is the lack of using quantitative methods, such as energy system models; most research is based on either field studies or surveys and interviews. Such methods, while they do offer benefits and can pave the way for further research on the subject, can only derive general trends and implications that may not be adequate for policymaking.

ENCLUDE addresses this gap by using the strengths of energy system and integrated assessment models, aiming at a more holistic modeling of the different aspects of energy citizenship, exploring the multi-scale relationship between its various forms and the decarbonization of the energy system. As part of this deliverable ("*D5.3: Report on the impact of energy citizenship at the local level*"), the ENCLUDE modeling suite, including two (2) agent-based models (ABMs), a demand-side management (DSM) model, an energy planning optimization and capacity expansion model (CEM), and an integrated assessment model (IAM), adds a quantitative dimension to the research on the matter of energy citizenship and its expressions at the local level.

More specifically, our work builds on the previous ENCLUDE work under "*WP5: The impact of energy citizenship in decarbonization pathways*", namely: Deliverable 5.1 ("*D5.1: Report on models' adjustments and modifications to match emerging energy citizenship trends and patterns*") and Deliverable 5.2 ("*D5.2: Report on the development of decarbonization pathways based on social innovations of energy citizenship*"), as follows:

"*D5.1: Report on models' adjustments and modifications to match emerging energy citizenship trends and patterns*" in a nutshell (Tsopelas et al., 2022):

In this deliverable, different aspects of energy citizenship were identified and articulated through desk research, which were then categorized in distinct patterns and trends, each one describing a key aspect of energy citizenship, as follows:

- Active participation in the energy market.
- Actions towards energy efficiency.
- Behavioral aspects.
- Collective expressions of energy citizenship.
- Political activities.

The ENCLUDE modeling ensemble and its capabilities were also presented.

"*D5.2: Report on the development of decarbonization pathways based on social innovations of energy citizenship*" in a nutshell (Tsopelas et al., 2023):

As part of the ENCLUDE Deliverable 5.2, the identified trends and patterns of energy citizenship served as guidelines for the development of four (4) "***people-centered***" storylines, a short description of which is provided below:

"*Power to the People*": This storyline explores a decentralized energy system where citizens become more actively participating in the energy transition, investing in relevant green infrastructure as small-scale PV systems (prosumerism) and energy efficiency and smart technologies.

"*Band Together*": This storyline focuses on citizens' collective actions in the energy system, such as the formation of energy communities, where optimized and localized energy production and resource utilization can take place.

"*Habitual Creatures*": This storyline revolves around daily habits of citizens and how small changes in everyday life and their lifestyle can impact the energy transition and contribute to the decarbonization of the energy system.

"*People to the Streets*": This storyline emphasizes political activism surrounding climate change and citizen participation in social movements and civil society initiatives advancing democratic visions of energy transition.

In addition, and by expanding the concept of SSPs, as presented above, a set of three (3) "***future-world***" narratives referring to different potential evolutions of the future in terms of external systemic factors that are related to institutions and organizations were also formulated- a short description is presented below:

- **"*A Familiar World*":** This narrative simulates the future-world evolution in its present state, with the current rates of decarbonization and the baseline scenario specifications as foreseen by current policy documents, relevant announcements, and political decisions made at the EU level.
- **"*A Unified World*":** This narrative simulates a future-world evolution in which society, governments, and nations around the EU, but also at the global level, come together and unite against climate change, as the biggest crisis of our age. Policymaking processes all around the world promote acceleration of decarbonization through transnational collaboration and investments in green solutions as soon as possible.
- **"*A Fragmented World*":** This narrative simulates potential future-world evolutions of undesired societies, which tend more and more to "dystopia" in the sense of extreme or even exaggerated worst-case scenarios, e.g., more totalitarian regimes arise, more social inequalities, more control over people through the usage of propaganda, censoring of information or denial of free thought, the gradual loss of individuality, enforcement of conformity, rise of individualism and anti-collectivism, more (war) conflicts at the regional and transnational level. This narrative assumes that policymaking processes emphasize more regional and national security rather than combating the climate crisis.

By combining the work conducted under the previous WP5 deliverables, and by following the overarching design of WP5, in this report we proceed with the next step; designing transition scenarios and decarbonization pathways in different real-world case studies, as selected from the extensive and well-detailed case study pool developed as part of the work conducted under the ENCLUDE Work Package 3 (WP3) (Brenner-Fliesser et al., 2023).

For example, recognizing the importance of the "Power to the People" storyline, we appraise the potential impacts of prosumerism at the local level, towards greener futures, while we also assess the decarbonization potential of investing in energy efficiency solutions and adopting energy-related lifestyle changes at the local level of municipalities and the value of collective citizen activities in contributing to meaningful changes over time.

To do so, the ENCLUDE modeling ensemble (**Table 1**) is employed to provide quantified results on the decarbonization potential of these different variations of energy citizenship at the local level. To adjust our work and match it to the case-specific characteristics of the analyzed case studies and to the needs of the patterns and trends of energy citizenship identified, the previously modeling ensemble, as presented in the context of Deliverable 5.1, is further expanded with two (2) new additions.

In this report, we introduce one of these new entries, the ANIMO modeling framework, a new modeling framework further enhancing the ENCLUDE modeling ensemble's capabilities towards a broader and, at the same time, deeper (more holistic) exploration of the different energy citizenship expressions.

Case studies across different geographical contexts and socioeconomic environments are modeled, with our aim being, eventually, and combining the work under this deliverable, with the work that will be presented in the next WP5 deliverable ("***D5.4 Report on the decarbonization potential of energy citizenship at national, regional, and EU level***"), a sound understanding of the multi-scale relationship between the different energy citizenship expressions and decarbonization pathways, not only theoretically, but also through real-life practical implementations. In this deliverable we focus on the local level.

Furthermore, more information on the workings and capabilities of the models is provided. As such, this report may easily be used both within and outside of the project, by policymakers and other relevant end-users from the field of policy and practice using our findings to derive interesting and policy-relevant implications and recommendations, and by researchers and other end-users from the field of academia that are interested in the ways that different patterns and trends of energy citizenship at the local level can be integrated into the design of decarbonization pathways and simulated through the use of energy system models.

Based on the specifications of the case studies and the capabilities of each modeling tool (i.e., local spatial resolution), in this deliverable we present results from the application of the DREEM and the ANIMO models.

Table 1. The enhanced ENCLUDE modeling ensemble.

Modeling framework	Description
grAssroot iNnovation dIffusion MOdel (ANIMO)	**ANIMO** is an agent-based model capable of simulating the diffusion of social innovations, such as the creation of, and participation in, energy community projects, and investigating how envisioned social improvements are embraced by, and distributed throughout, households and individuals with various socioeconomic, behavioral, and lifestyle profiles.
Agent-based Technology adOption Model (ATOM)	**ATOM** is an agent-based model, which based on the plausibility of its results compared to historical data and observations, simulates the expected effectiveness of various policy schemes on technology adoption (e.g., small-scale solar PV, battery energy storage systems, heat pumps, electric vehicles, etc.) in the residential sector, for the geographical and socioeconomic context under study. Apart from exploring the expected effectiveness of technology adoption under policy schemes of interest, the model allows us to consider and explicitly quantify the uncertainties that are related to agents' preferences and decision-making criteria (i.e., behavioral uncertainty). As agents in the model, we refer to citizens and households.
Dynamic high-Resolution dEmand-sidE Management (DREEM)	**DREEM** is a fully-integrated energy demand and demand-side management simulation model, focusing on the building sector, which expands the computational capabilities of existing Building Energy System and demand-side models, by not only calculating energy demand, but by also assessing the benefits and limitations of demand flexibility, primarily for the main end-users (consumers/citizens), and, then for other energy system actors involved (e.g., suppliers, retailers).
Integrated Model to Assess the Global Environment (IMAGE)	**IMAGE** is an integrated assessment model (IAM) suited to large scale and long-term assessments of interactions between human development and the natural environment, and integrates a range of sectors, ecosystems, and indicators. The model identifies socioeconomic pathways and projects the implications for energy, land, water, and other natural resources, subject to resource availability and quality.
Open-Source energy MOdeling SYStem for GReece (OSeMOSYS-GR)	**OSeMOSYS** is an energy system optimization and capacity expansion model generator that follows a dynamic, deterministic, technology-rich, bottom-up, linear-programming approach for medium-to-long-term energy planning. It is utilized to determine the most economically efficient pathway by minimizing the discounted

	cost of the system and by optimizing the capacity and electricity generation of each technology to meet the predefined final energy demand. **OSeMOSYS-GR** is a country-specific implementation of OSeMOSYS that has been developed as part of the ENCLUDE modeling ensemble and adjusted to accurately model the unique characteristics of the Greek power system for the period 2021-2050.

1.6. Structure of this deliverable

The remainder of this deliverable is structured as follows:

- **Section 2** includes an overview of the working approach followed.
- **Section 3** match the identified patterns and trends of energy citizenship to the individual modeling tools of the ENCLUDE ensemble, based on their capabilities.
- **Section 4** provides a description of the modeling tools' limitations and capabilities as well as the further modifications and adjustments that took place for model application.
- **Section 5** presents an overview of the final scenario space designed and to be modeled by the ENCLUDE modeling ensemble, based on the "*people-centered*" storylines and the "*future-world*" narratives developed.
- **Section 6** presents the specification of the analyzed case studies, along with respective parameters that were used, the data collection and treatment process followed, etc.
- **Section 7** presents the results of the model application to the case studies.
- **Section 8** provides conclusions and recommendations of our work, summarizes limitations, and highlights next steps and further research topics.

2. Working approach

We follow a multi-method approach, coupling the strengths of energy system modeling with qualitative and semi-quantitative techniques. As depicted in **Figure 1**, our working approach consists of five (5) methodological steps to reach from the initial set of the patterns and trends of energy citizenship (as derived in **Deliverable 5.1**[1]) and the ENCLUDE "people-centered" storylines and "future-world" narratives (as derived in **Deliverable 5.2**[2]), to the final ENCLUDE scenario space and the case-specific decarbonization pathways to be modeled in the context of the real-life applications presented in this report.

2.1. Step 1: Matching patterns and trends of energy citizenship to the ENCLUDE modeling ensemble

As part of the ENCLUDE Deliverable 5.1 (Tsopelas et al., 2022), desk research on patterns and trends of energy citizenship was conducted, also based on insights and preliminary findings on typologies of energy citizenship that were developed as part of the work conducted in the context of the ENCLUDE WP2 (Dunphy et al., 2023).

In parallel, a detailed documentation of the ENCLUDE modeling ensemble took place, entailing the current state of the models, their capabilities and limitations, their input and output variables, and their technical characteristics, e.g., spatial, temporal, and sectoral coverage and resolution. A data collection process enabled us to also develop a matching matrix, optimizing the connections between the models and their ability to address the identified patterns and trends of energy citizenship. Moreover, various interface protocols for the soft linkage of the models, where necessary, were developed, concerning data transfer and model communication and interoperability. Based on this work, we summarized the "*status-quo*" of the ENCLUDE modeling ensemble.

The above allowed us to cluster the identified patterns and trends of energy citizenship in a matching matrix, optimizing the connections between the ENCLUDE modeling ensemble and their ability to address the different aspects of energy citizenship. More specifically, during the period March-June 2023, the identified patterns and trends were mapped again onto the ENCLUDE models to redefine the model capacities for addressing various aspects of energy citizenship both at the individual and collective level and potential model developments, modifications, and adjustments required.

2.2. Step 2: Further model developments, modifications, and adjustments

After matching the identified patterns and trends of energy citizenship to the ENCLUDE modeling ensemble, two (2) inter-WP online workshops were organized, during the period September-October 2023, to discuss model capacities in terms of addressing the different aspects of energy citizenship. During these internal ENCLUDE workshops, partners discussed required model inputs and expected outcomes as well as the selection of potential case studies. Partners also provided feedback on the consideration of important variables and assumptions and the acquisition of data necessary for the calibration and the parameterization of the modeling ensemble.

This gap analysis highlighted specific patterns and trends of energy citizenship that were not adequately addressed by the ENCLUDE modeling ensemble. This allowed further model developments, modifications, and adjustments required so that the modeling ensemble is able to simulate the decarbonization pathways developed as part of the work under this deliverable. In this context, a new modeling framework, ANIMO, was developed, while the original modeling framework of DREEM was modified. Furthermore, the models' documentation was also updated.

[1] https://doi.org/10.5281/zenodo.7094196
[2] https://zenodo.org/records/7638854

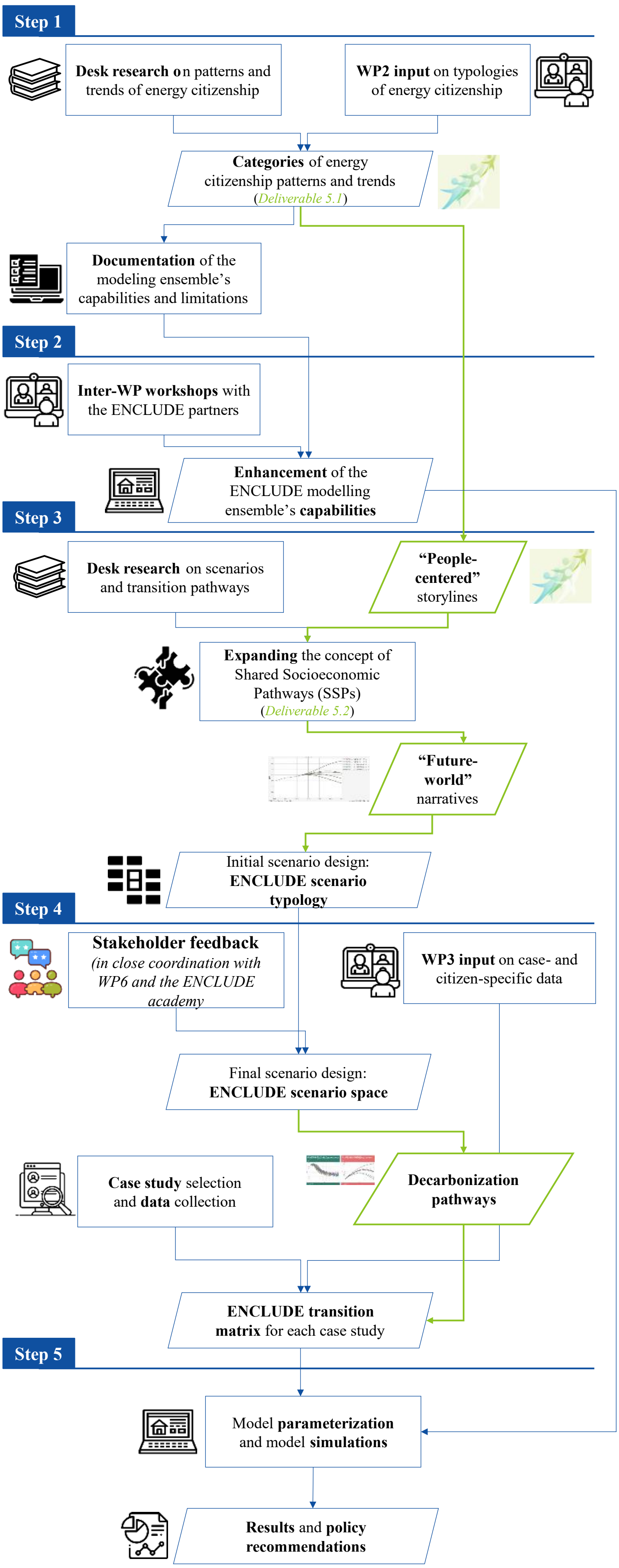

Step 1
Desk research on patterns and trends of energy citizenship
WP2 input on typologies of energy citizenship
Categories of energy citizenship patterns and trends (Deliverable 5.1)
Documentation of the modeling ensemble's capabilities and limitations
Step 2
Inter-WP workshops with the ENCLUDE partners
Enhancement of the ENCLUDE modelling ensemble's capabilities
Step 3
Desk research on scenarios and transition pathways
"People-centered" storylines
Expanding the concept of Shared Socioeconomic Pathways (SSPs) (Deliverable 5.2)
"Future-world" narratives
Initial scenario design: ENCLUDE scenario typology
Step 4
Stakeholder feedback (in close coordination with WP6 and the ENCLUDE academy)
WP3 input on case- and citizen-specific data
Final scenario design: ENCLUDE scenario space
Case study selection and data collection
Decarbonization pathways
ENCLUDE transition matrix for each case study
Step 5
Model parameterization and model simulations
Results and policy recommendations

Figure 1. Multi-method working approach as followed in the context of the ENCLUDE WP5 to quantify the decarbonization impact of energy citizenship at the local level.

2.3. Step 3: Scenario design, storylines, and narratives

This next step aimed at the design of the initial scenario space inside of which case study-specific decarbonization pathways, are, eventually, developed. Starting point for the initial design of the scenario space was the work implemented in the context of the ENCLUDE Deliverable 5.2 (Tsopelas et al., 2023) and the desk research on scenario-based analysis around the concept of energy citizenship, focusing on the IPCC's SR1.5 and the accompanying database (IPCC SR1.5 Scenario Explorer)(Masson-Delmotte et al., 2019; Daniel Huppmann et al., 2019)

To ensure that the final set of the decarbonization pathways developed for the ENCLUDE applications are based on the most up-to-date and policy-relevant evidence on the contribution of energy citizenship in contributing to the visions of decarbonization and climate neutrality, we also used as a basis of our desk research the IPCC Special Report 6 (Calvin et al., 2023b).

In parallel, we expanded the work under Step 1 by further elaborating on the categories of the energy citizenship patterns and trends identified under Deliverable 5.1 (Tsopelas et al., 2022) to produce a set of "people-centered" storylines that best describe the different citizen-specific aspects of energy citizenship in terms of citizens' active participation to the energy transition. This work has also been presented as part of Deliverable 5.2.

By combining the insights of our desk research on scenario-based analysis around the concept of energy citizenship with the final set of the *ENCLUDE "people-centered" storylines*, our next goal was to further expand our scenario space with alternative scenarios that explore uncertainty in future conditions of the society and climate and describe the evolution of societal aspects that are difficult to quantify (such as the quality of institutions, political stability, environmental awareness, etc.), and provide a basis for further elaboration of the scenarios by users.

This allowed us to also capture the effect of the different types of "environments" that could potentially surround citizens and citizen-specific expressions of energy citizenship, as external systemic changes that can potentially occur in future developments regarding governmental institutions, organizations, and nation-wide societal changes, etc.

To do so, we built on the concept of SSPs, which are a collection of five (5) qualitative descriptions of future changes in demographics, human development, economy and lifestyle, policies and institutions, technology, and environment and natural resources (Liu et al., 2024). The conceptual framework for the design and use of SSPs typically calls for the creation of global pathways that describe the future evolution of key societal aspects.

As part of Deliverable 5.2, we further expanded and adjusted this set of qualitative descriptions to develop a set of three (3) qualitative descriptions, the ENCLUDE *"future-world" narratives*, that could supplement the "people-centered" storylines in developing the ENCLUDE scenario typology.

As part of this report, our focus was to design the scenario space, based on the work already conducted under WP5, so that we can apply it to the different case studies, to which the ENCLUDE modeling ensemble would be applied to. The initial design of the scenario space started with the combination of the "people-centered" storylines with the "future-world" narratives and the design of the ENCLUDE scenario typology (**Figure 2**).

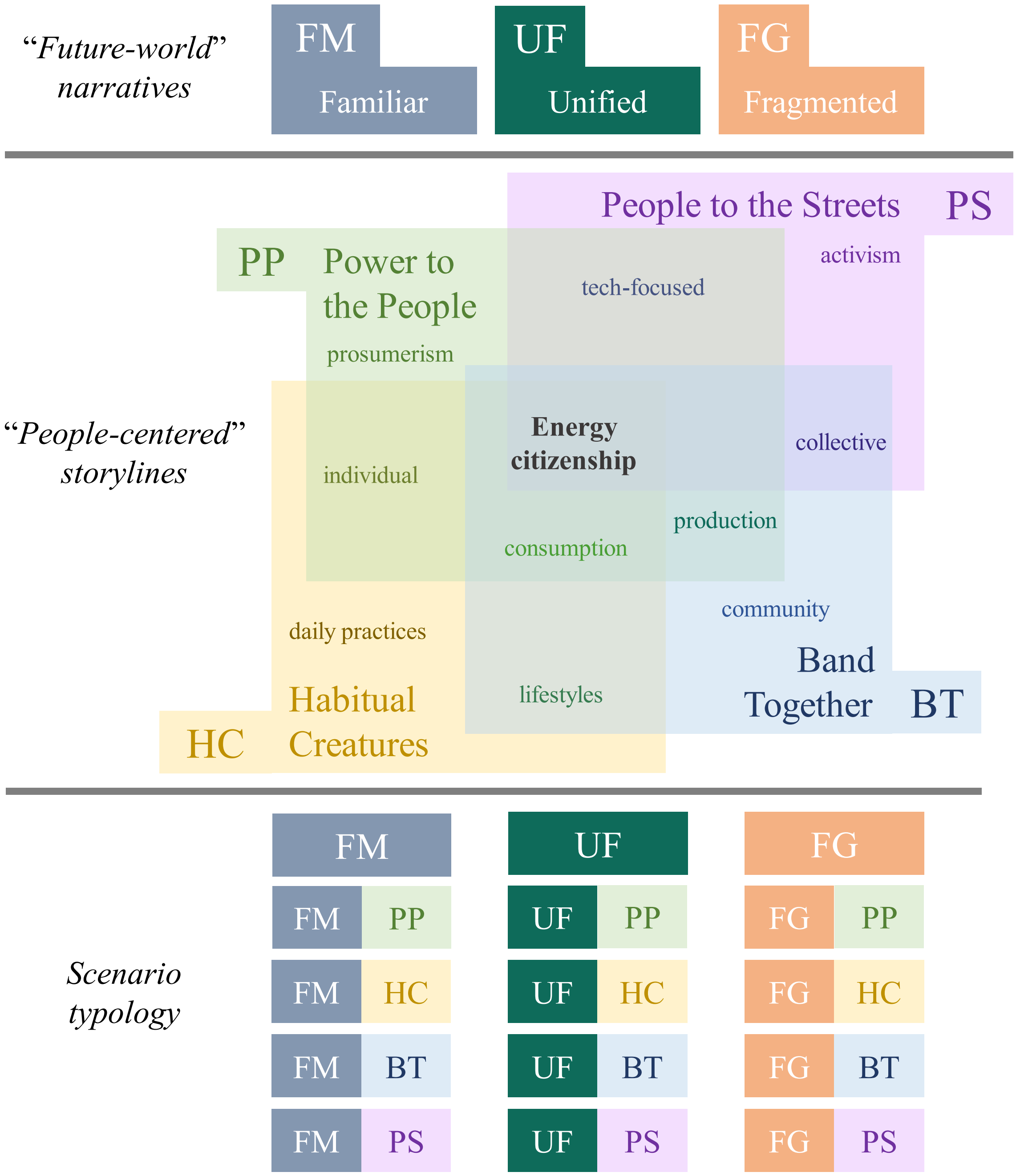


Figure 2. The ENCLUDE scenario typology showcasing all the potential combinations of the ENCLUDE "*people-centered*" storylines and "*future-world*" narratives towards the development of the ENCLUDE scenario space.

2.4. Step 4: Case study specification and decarbonization pathways

As Carlsen et al. (2016) pointed out, a broad and balanced scenario space is typically needed in order to implement scenario-based research correctly and effectively. By crafting diverse sets of storylines and narratives that encompass varying degrees of climate- and energy-related actions, technological advancements, societal shifts, and behavior adoption rates, a better coverage of future possibilities is attained. This offers a nuanced perspective on what the future may hold and aids in not only preparing for potential challenges but also illuminates the pathways toward sustainable and resilient solutions.

On the contrary, creating a limited and ill-defined scenario space may lead to failing to anticipate certain developments or underestimating the complexities of societal transitions which in turn can result in the implementation of insufficient or misguided policies and biased decision-making. For instance, an overly optimistic scenario that neglects the challenges of transitioning to RES and assumes rapid global cooperation without accounting for geopolitical challenges could result in delayed or ineffective policy responses. By anchoring decisions solely on best-case scenarios, a misleading perception of security and a failure to adequately prepare for contingencies can be created. Similarly, an excessively conservative scenario space- one that underestimates the pace of technological advancements, policy changes, or societal shifts- can stifle innovation and hinder progress.

If policymakers are on the side of caution, overly conservative scenario space may perpetuate reliance on outdated technologies and impede the transition to more sustainable practices. For example, envisioning a future where the status quo prevails without accounting for breakthroughs in renewable energy or shifts in citizens' behavior might discourage investments in cutting-edge technologies.

This can lead to missed opportunities for transformative change and result in inadequate preparations for a rapidly evolving climate landscape. All things considered, in both cases, the potential ripple effects of oversights and misjudges extend to economic repercussions, social disruptions, and exacerbation of climate-related vulnerabilities.

It is imperative, thus, to design a scenario space which encompasses a broad spectrum of possible futures, acknowledging uncertainties and embracing the depth of complexity of the European landscape, at the local, the national, and the transnational level.

Considering these literature insights, the ENCLUDE scenario typology is the starting point for the development of the ENCLUDE scenario space (Figure 3), which, applied to specific case studies, will lead to the final ENCLUDE transition matrix and real-life decarbonization pathways of energy citizenship.

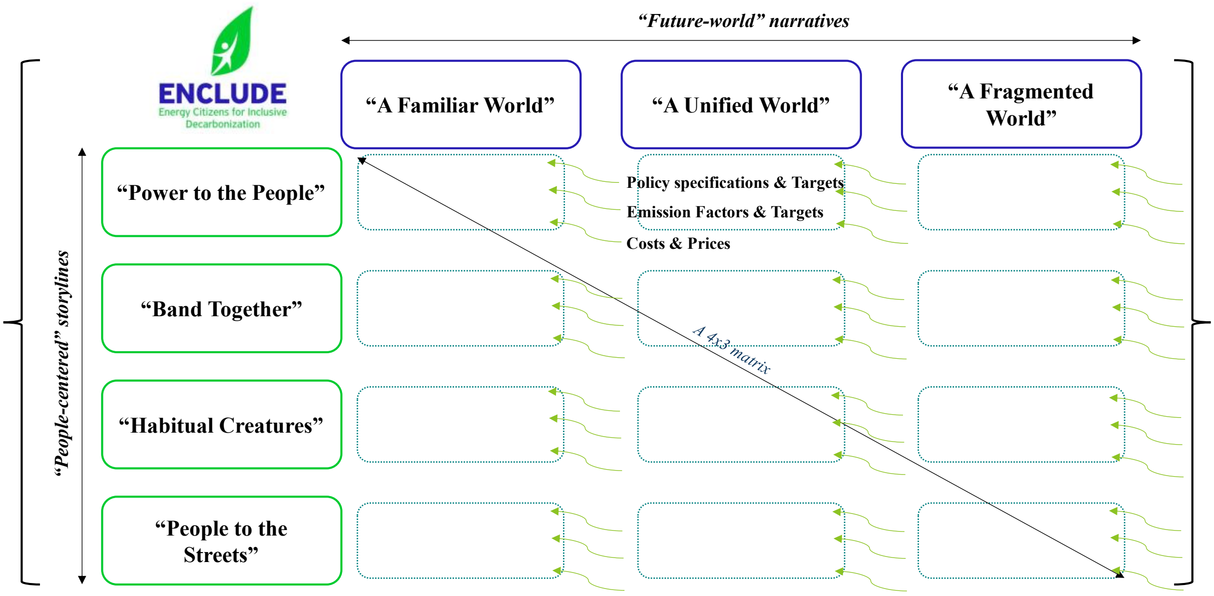


Figure 3. The ENCLUDE scenario space to be applied to specific case studies for the development of real-life decarbonization pathways.

As a next step thus, we selected a set of case studies, which the enhanced ENCLUDE modeling ensemble will be applied to. To do so, we explored diverse cases across Europe to illuminate the full range of differences and demonstrate cross-cutting themes. Geographical dimension adds an important value to quantifying the impact of energy citizenship, in terms of the decarbonization potential of its various expressions, at the local level and to better understanding the several important implications of geographies in the EU's policymaking landscape.

Our selection focused on the spatial variation across contexts and the emphasis on cross-case differences of political, social, cultural, economic, demographic, and technological particularities of energy systems.

The main source of information and data for the selection and specification of the case studies was the case study pool developed and maintained in WP3 (Brenner-Fliesser et al., 2023). This way, we were able to collect data provided in the questionnaire developed by WP3 and filter the case studies to select those that we would delve deeper into based on their policy relevance and according to enhanced capabilities of the ENCLUDE modeling ensemble.

By applying the ENCLUDE scenario space to each case study, and by considering case-specific characteristics and citizen-specific data, the ENCLUDE three-dimension transition matrix is produced for each one of the case studies, comprising a final case-specific set of decarbonization pathways (**Figure 4**).

To further supplement our work and ensure that the ENCLUDE transition matrix is designed in a policy-relevant way, we also made sure to include insights and specifications form the most recent policy documents, in accordance with the emission caps of the updated mitigation targets by 2030 and 2050 in the context of the "Fit for 55" package and the European Green Deal strategy. Based on the latter, an indicative modeling time horizon, i.e., reference year (simulation start year), interim milestone years (where and if necessary), and the target year (simulation end year), were specified, to be adjusted, though, each time, based on the case-specific characteristics of the application under study.

Finally, to also make sure that the ENCLUDE transition matrix is not only policy relevant, but also helpful and supportive of the different potential end-users' needs, relevant stakeholders' and practitioners' feedback (in close coordination with the work conducted as part of WP6 and the ENCLUDE Academy) was also considered to diversify and expand the decarbonization pathways developed, and eventually account for possible uncertainties and different potential evolutions of the future energy system (Pearce et al., 2022).

Based on stakeholders' feedback, our scenario space and transition matrix were further populated with the evolution of different exogenous variables, e.g., emission factors, evolution of relevant energy prices and costs, technological costs and relevant updated configurations, benefits for citizens and/ or other power actors involved, always in accordance with the specifications of the "*people-centered*" storylines and "*future-world*" narratives.

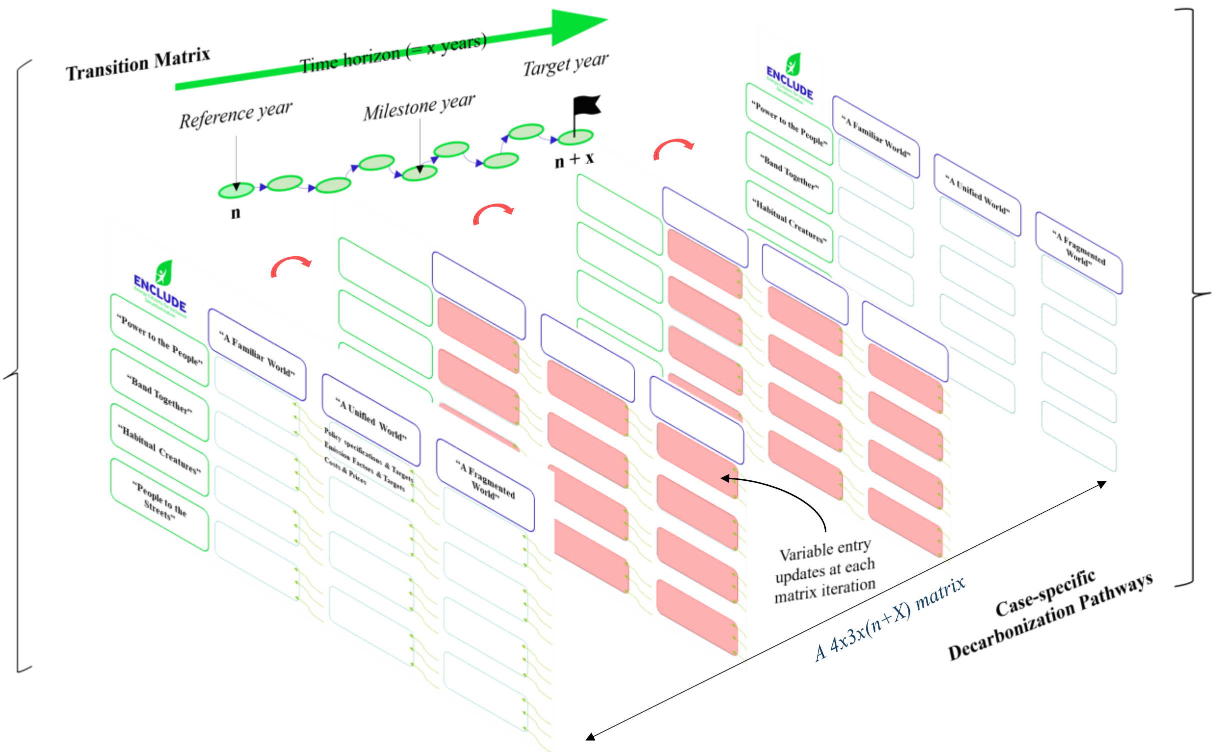


Figure 4. The ENCLUDE three-dimension transition matrix to develop case-specific decarbonization pathways in each application under study.

2.5. Step 5: Model application and policy recommendations

As a final step, we used the enhanced ENCLUDE modeling ensemble to simulate the matrix of the case-specific decarbonization pathways derived, for the time horizon (e.g., 2030, 2040, 2050) and the time interval (e.g., one hour, one year, five years) of interest in each application at hand. Modeling results were further analyzed, presented to the rest of the ENCLUDE partners, and discussed to co-create robust recommendations for citizens, end-users from the fields of policy and practice, and other relevant stakeholders, to trigger actions at the local level.

3. Matching "people-centered" storylines to the ENCLUDE modeling ensemble

A preliminary matching of the identified patterns and trends of energy citizenship to the ENCLUDE modeling ensemble, based on the detailed documentation of its "status-quo", capabilities, limitations, input and output variables, and technical characteristics, e.g., spatial, temporal, and sectoral coverage and resolution, took place as part of Deliverable 5.1 (Tsopelas et al., 2022).

A data collection process also enabled us to develop a matching matrix, optimizing the connections between the models and their ability to address the identified patterns and trends. Moreover, various interface protocols for the soft linkage of the models, where necessary, were developed, concerning data transfer and model communication and interoperability.

As part of the work presented in this deliverable, and in view of the application of the ENCLUDE modeling ensemble to the case-specific decarbonization pathways developed at the micro scale (local level), an updated gap analysis was conducted to identify new patterns and trends of energy citizenship that were not still addressed by the ENCLUDE modeling ensemble, considering the new directions derived from the development of the "people-centered" storylines and the "future-world" narratives, the insights from the work conducted under WP3 and WP6 (and the ENCLUDE Academy), and relevant end-users' and other stakeholders' feedback.

This allowed not only the identification of further model developments, modifications, and adjustments required, but also a holistic understanding of the multi-scale relationship between patterns and trends of energy citizenship (both at the individual and the collective level), transition pathways towards decarbonization, and the ENCLUDE modeling ensemble. Based on this work, we revised and further updated the "*status-quo*" of the ENCLUDE modeling ensemble (**Figure 5** and **Figure 6**).

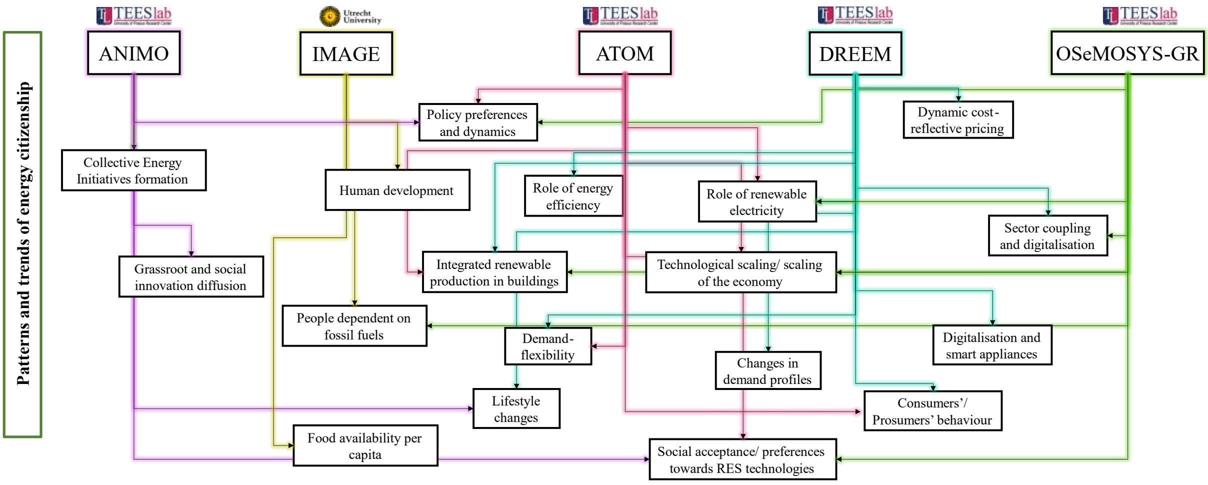


Figure 5. Updated "status-quo" of the ENCLUDE modeling ensemble: Mapping of the patterns and trends of energy citizenship that each model has been designed and further developed and modified to address.

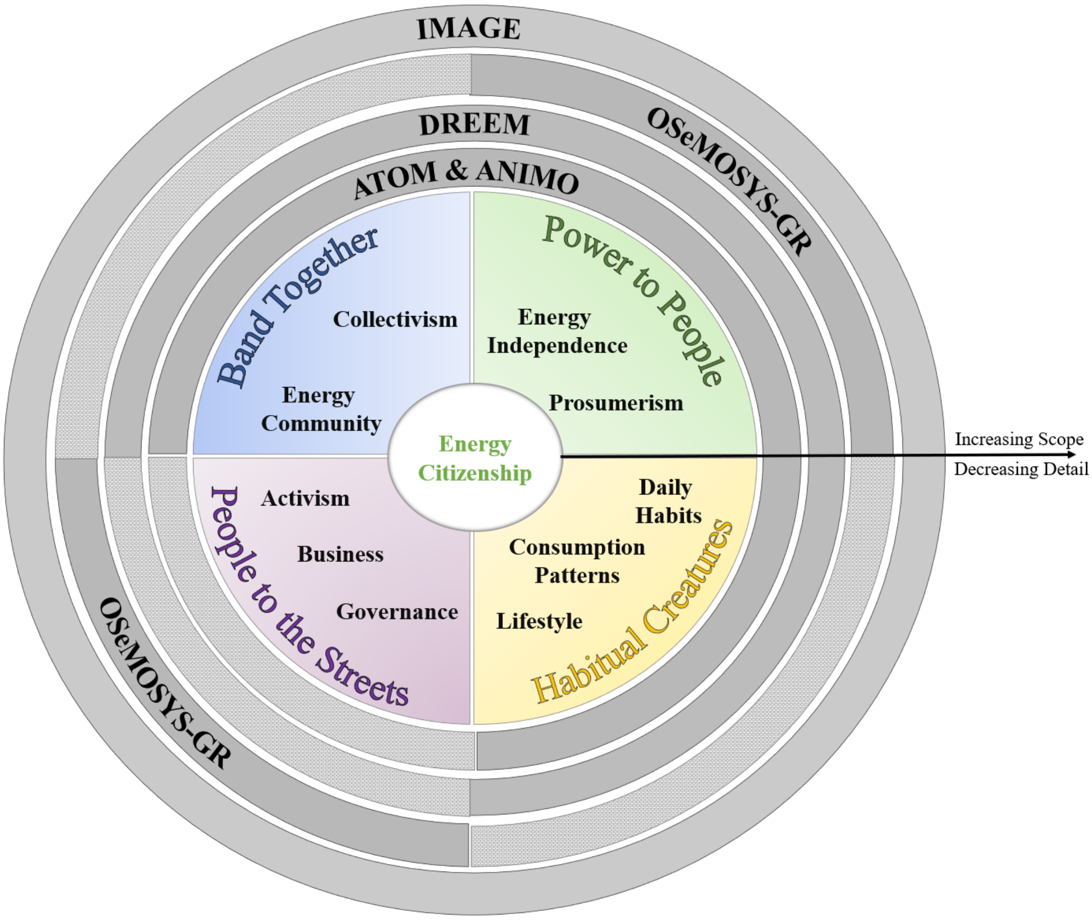


Figure 6. Summary of the "people-centered" storylines that the enhanced ENCLUDE modeling ensemble is capable to address post further developments, modifications, and adjustments.

3.1. Model matching to "people-centered" storylines at the local level

Since an important issue to address in the context of this work is "*scale*" there was a need to capture nuances of energy citizenship at the local level. Starting from the micro scale, our work recognizes the need to enhance comprehension of both individual and collective factors that are relevant to the decision-making processes underlying the emergence of energy citizenship.

This entails an exploration of the particular social innovations and technological capabilities that engage citizens and encourage changes at both the household (individual) and the community (collective) level. Figure 7 showcases the multi-scale relationship of the ENCLUDE modeling ensemble, also indicating the scale of analysis in which the individual models will be utilized.

To that end, we further expanded the architecture of the ATOM model- whose original scale of analysis is at the national level (meso scale), as presented under Deliverable 5.1- to develop a new modeling framework, ANIMO, which aims at an exploration of the methods through which envisaged social innovations of energy citizenship and respective technological infrastructure can be embraced and diffused within households and communities of different profiles, and in different contexts, as a basis for supporting better-informed decision-making (Stavrakas et al., 2019a). In this deliverable, since the focus of our work is on the decarbonization potential of energy citizenship at the micro scale (local level), the ANIMO and DREEM models are employed.

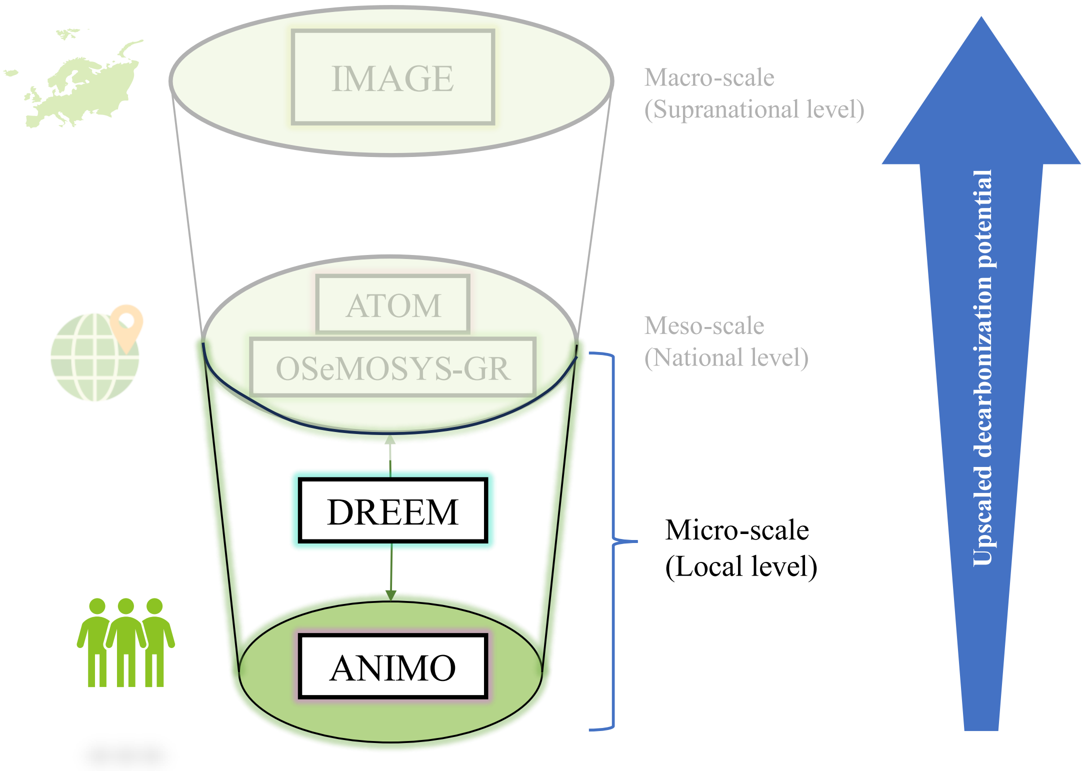


Figure 7. Different scales of analysis of the decarbonization potential of the identified patterns and trends of energy citizenship based on the current "status-quo" of the ENCLUDE modeling ensemble.

3.1.1. The grassroot innovation diffusion model (ANIMO)

The gr**A**ssroot i**N**novation d**I**ffusion **MO**del (**ANIMO**) is a new modeling framework designed and developed in the context of the ENCLUDE project to simulate the spread of social and grassroot innovations, including the establishment and involvement in energy community projects. It delves into how envisaged social advancements are adopted and disseminated among a network of individuals, with diverse socioeconomic, behavioral, and lifestyle profiles.

ANIMO was explicitly developed to address the "*Band Together*" storyline (**Figure 8**) by delving into the dynamics of citizens' decisions within a structured social system, concerning the decision to join, or abstain from participating, in an energy community (or a similar structure like an ecovillage). Additionally, it aims to explore inter-community collective decision-making processes and how these processes potentially impact the community's external perception and, to some extent, interactions between current and prospective community members.

The main premise behind the model's development is that the main ways that grassroot innovations as energy communities and/ or ecovillages tend to typically influence larger society are through ***(1). replication***, ***(2). growth in scale***, and ***(3). translation*** (Boyer, 2018a).

Our ambition is that ANIMO is further developed to the point that it can address all these three (3) ways; addressing "*replication*" as the growth of the number of energy communities, "*growth in scale*" as, either the growth of specific communities, or the growth of their influence through partnerships and funding programs, and "*translation*" as the adoption of community-relevant policies and practices by mainstream society and institutions.

With the aim of performing socially well-informed modeling activities, an extensive database is required so that the model can accurately represent and simulate the adoption of social innovations of energy citizenship, also considering specifications on the energy communities' structure and their context under study. Therefore, the ANIMO framework is also supplemented with a complete framework for parameter estimation as well as quantification of the uncertainty that governs its ability to replicate real-life processes and make future projections. Leveraging data gathered from the ENCLUDE case studies, ANIMO is enhanced to analyze the decision-making processes of distinct citizen profiles, a crucial aspect in the effective development and execution of socio-technically informed modeling exercises.

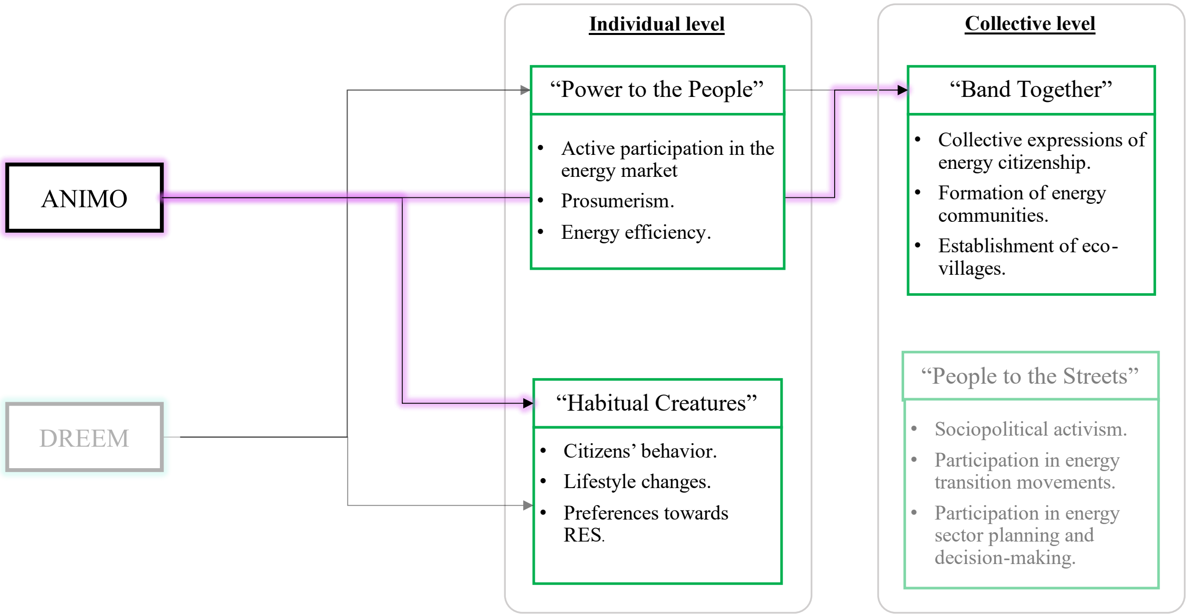


Figure 8. "People-centered" storylines that the ANIMO modeling framework was developed to address in the context of the real-life applications under study at the local level.

3.1.2. The dynamic high-resolution demand-side management model (DREEM)

The **D**ynamic high-**R**esolution d**E**mand-sid**E** **M**anagement (**DREEM**) model is a fully-integrated energy demand and demand-side management simulation model, focusing on the building sector, which expands the computational capabilities of existing Building Energy System and demand-side models, by not only calculating energy demand, but by also assessing the benefits and limitations of demand flexibility, primarily for citizens, and, then for other energy system actors involved (e.g., suppliers, retailers, distribution system operators) (Stavrakas & Flamos, 2020).

The main premise behind the development and the use of the DREEM model has been that in order for citizens to have a more active and positive participation to the energy transition, they first need to become more aware of the benefits from investing in new energy products and services.

In this context, the novelty of the model lies in its potential to be used in a wide range of applications, not only to assess the existing technological infrastructure, but also to support the development of business models and regulatory innovations, which maximize the value of energy products and services, and monetize them, to fairly compensate citizens and other relevant energy market actors.

In the context of the work presented in this report, the DREEM model will be employed to quantify the decarbonization potential of the "*Power to the People*" and the "*Habitual Creatures*" storylines by simulating case-specific transition pathways that envision patterns and trends of energy citizenship as citizens' active participation to the energy market and actions towards increasing energy autonomy and achieving energy savings (**Figure 9**).

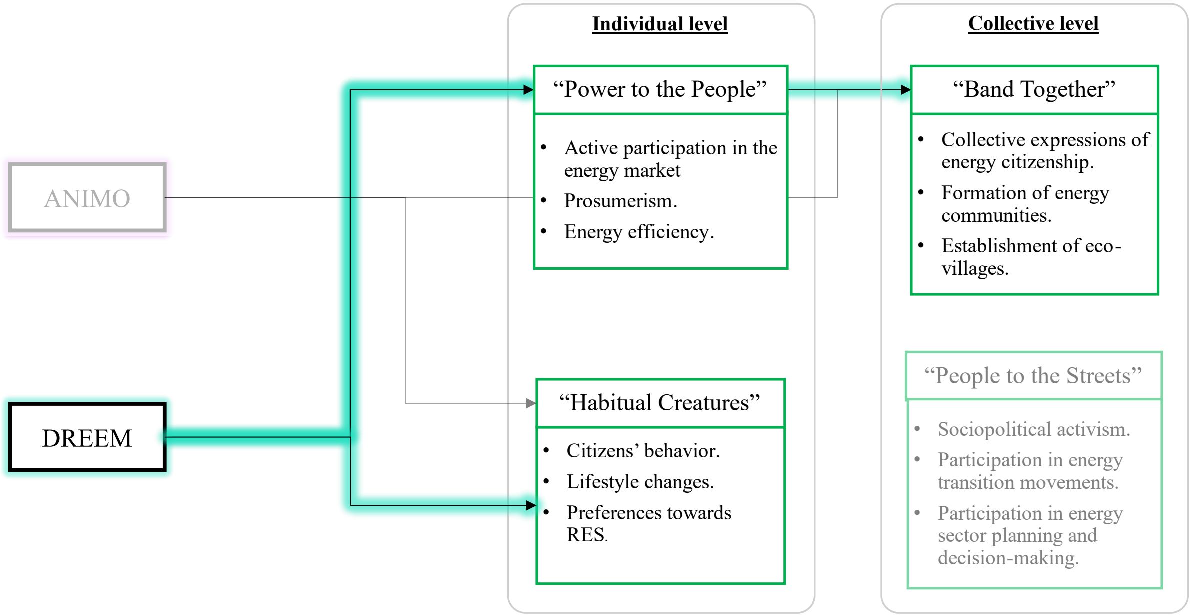


Figure 9. "People-centered" storylines that the DREEM modeling framework was further developed, modified, and adjusted to address in the context of the real-life applications under study at the local level.

For the "*Power to the People*" and the "*Habitual Creatures*" storylines, the DREEM model will be utilized to address multiple facets of prosumerism within the EU's residential sector. It will assess potential costs and benefits at the household (individual) level, while examining regulatory schemes and business models that could encourage citizens to invest in the necessary technological infrastructure (i.e., small-scale PV and residential storage systems), enabling them to actively participate to the energy market.

In addition, by scaling up from the individual to the collective level and by modeling a group of households making investments and actively participating to the energy transition, the DREEM model will be employed to quantify the benefits of a citizen-centered energy transition by 2050 with investments in energy efficiency actions, also considering behavioral and lifestyle changes and the adoption of sustainable daily habits in terms of energy consumption. Numerous daily activities, such as the use of household appliances, heating, and washing, play a crucial role in determining a household's energy consumption levels and are fundamental aspects of being an energy citizen.

In this context, the DREEM model will also address specific rebound effects resulting from specific behavioral consumption patterns; for instance, the direct rebound effects associated with the transition from incandescent or halogen bulbs to more energy efficient compact fluorescent lamps or light-emitting diodes, will also be considered. These changes in lighting technologies represent external outcomes influenced by the internal behavioral characteristics that define the energy behavior of citizens. This can be of value since the heightened awareness of one's own energy consumption can lead to individual energy conservation measures, contributing to a reduction in energy usage and significant energy savings.

Finally, in the context of the "*Band Together*" storyline, the DREEM will be employed to demonstrate the energy autonomy and the energy saving potential (and respective benefits for citizens) of collective actions. Energy communities and various other collective energy initiatives, including energy collectives, cooperatives, and eco-villages that focus on communal and localized energy production and resource optimization, will be modeled using DREEM.

This modeling exercise will illustrate the substantial decarbonization potential associated with energy communities. Such insights can prove valuable to stakeholders, including policymakers, as they can inform the development of appropriate legislation that encourages the establishment of energy projects and increased participation.

Since an important aspect of ENCLUDE is the combination of citizen and policymaker engagement with research analysis and modeling iterations, this last application of the DREEM model will specifically be designed to provide relevant end-users with useful insights regarding the conditions and the contexts within which collective actions of energy citizenship can lead to decarbonization, through several "*what if*" scenarios. To this end, the model will also feed in strategic citizen clusters developed under the work conducted in the context of the ENCLUDE WP4.

Results from this application will be thus presented in the context of the final WP5 deliverable ("*D5.5 Report on the decarbonization potential of strategic energy citizens' clusters*").

3.2. Model matching to "people-centered" narratives at the meso and the macro scale

Finally, an important gap highlighted in the context of updating and further enhancing the ENCLUDE modeling ensemble to address the ENCLUDE "people-centered" storylines, is current computational tools', and existing energy system models' capabilities to particularly address the "*People to the Streets*" storyline. Political activism and citizen participation in sociopolitical movements in favor or against green transitions is a cornerstone of civic engagement, which empowers individuals and collectives to voice their concerns, advocate for (or against) sustainable policies, and contribute to the collective effort to combat (or not) climate change and protect the environment for future generations.

Nonetheless, the majority of the existing energy system models predominantly concentrate on evaluating the technoeconomic facets of the energy transition, often overlooking the intrinsic social, cultural, and sociopolitical dimensions. Addressing such a nuanced aspect of energy citizenship led to the development of the OSEMOSYS-GR modeling framework.

The addition of the OSEMOSYS-GR framework signals the completion of the ENCLUDE modeling ensemble, which is now capable of exploring the complex relationship between the various forms of energy citizenship and their impact on the decarbonization of the energy system at different scales of analysis.

However, the perspective of the OSEMOSYS-GR framework concerns the meso-scale of analysis (**Figure 7**) which will be subject of study in the follow-up WP5 deliverable ("*D5.4 Report on the decarbonization potential of energy citizenship at national, regional, and EU level*").

4. Further model developments, modifications, and adjustments of the ENCLUDE modeling ensemble

After matching the ENCLUDE "people-centered" storylines to the ENCLUDE modeling ensemble, further model developments, modifications, and adjustments took place so that the ANIMO and the DREEM models are able to simulate the case-specific decarbonization pathways developed as part of the work under this deliverable.

In this section we present these model advancements, which will also be used to update earlier versions of the models' documentation in the ENCLUDE Policy Interactive Policy Platform (as part of the word conducted in the context of the ENCLUDE **WP7**).

4.1. The ANIMO modeling framework

The gr**A**ssroot i**N**novation d**I**ffusion **MO**del (**ANIMO**) is a new modeling framework designed and developed in the context of the ENCLUDE project to simulate the spread of social and grassroot innovations, including the establishment and involvement in energy community projects. It delves into how envisaged social advancements are adopted and disseminated among a network of individuals, with diverse socioeconomic, behavioral, and lifestyle profiles.

The ANIMO framework was explicitly developed to address the "*Band Together*" storyline by delving into the dynamics of citizens' decisions within a structured social system, concerning the decision to join, or abstain from participating, in an energy community (or a similar structure like an ecovillage). Additionally, it aims to explore inter-community collective decision-making processes and how these processes potentially impact the community's external perception and, to some extent, interactions between current and prospective community members.

The main premise behind the model's development is that the main ways that grassroot innovations as energy communities and/ or ecovillages tend to typically influence larger society are through (**1**)**. *replication***, (**2**)**. *growth in scale***, and (**3**)**. *translation*** (Boyer, 2018b).

Our ambition is that ANIMO is further developed to the point that it can address all these three (3) ways; addressing "*replication*" as the growth of the number of energy communities, "*growth in scale*" as, either the growth of specific communities, or the growth of their influence through partnerships and funding programs, and "*translation*" as the adoption of community-relevant policies and practices by mainstream society and institutions.

The origin of ANIMO can be traced back to a notable shortcoming that was identified during the matching exercise in the original modeling architecture (as has already been presented in Deliverable 5.1) of ATOM (Michas et al., 2020; Stavrakas et al., 2019). ATOM was found to be insufficient when it came to simulating the diffusion of social and grassroot innovations; this limitation emerged because ATOM primarily focuses on simulating the dynamics of technological innovation diffusion among citizens and various types of agencies, including collective actions like citizen communities, eco-village structures, etc.

Originating from ATOM, the ANIMO modeling framework exhibits certain resemblances to its predecessor; ANIMO still remains an ABM, possessing the respective advantages. As such, it has the ability to simulate the decision-making process of the members of a heterogeneous society and to comprehend a system as a collection of independent decision-making entities, the so-called "*agents*".

ABM is a flexible modeling method as it can describe the micro-level behavior/ behavioral tendencies and the individual preferences of citizens, and their interaction within a social network (Ringler et al., 2016; MacAl & North, 2010), while it allows the inclusion of considerable detail and nuance about their decision-making process, capturing real-world complexity more accurately compared to traditional analytical or statistical models.

The versatility of ABMs is evident by their use in various fields including, social influence and opinion formation (Mäs et al., 2010), group dynamics (Bradshaw et al., 2003), social cooperation (Bowles & Gintis, 2004), urban and regional development (Stephan et al., 2010), and collective intelligence (Bonabeau et al., 2000).

In general ABM possesses a significant advantage as far the exploration of emergent and self-organized phenomena is concerned, as it provides a dynamic and realistic way to explore complex systems, uncover unexpected patterns, and gain insights into how simple agent-level interactions can lead to complex and surprising system-level behaviors (Helbing, 2012). In the intersection of the above-mentioned fields is where the development of grassroot innovations lies, such as emergence and expansion of Collective Energy Initiatives (CEIs).

However, there are also distinctions between the two (2) models that needed to be addressed during the transition from ATOM to ANIMO. Firstly, ATOM is used for assessing technology adoption rates and impacts that different policy schemes attain when it comes to projections of technology diffusion. This essentially acts as an input which outlines a set of rules and directives for the agents in the model to operate within. Each of the policy schemes analyzed in ATOM provides distinct incentives for adopting a certain technology and influence agents in a variety of manners.

Nevertheless, such a type of influence is usually absent when it comes to modeling of social and grassroot innovations. This divergence arises because in the case of social and grassroot innovations, the approach is fundamentally different from the government-directed policies and the market driven incentives. On the contrary, social and grassroot innovations generate novel bottom-up solutions that respond to the context, interests, and values of the involved communities (Dana et al., 2021).

Social transformations and grassroot initiatives are typically centered on the complex interaction between various categories of stakeholders including citizens, local community members, committed activists, practitioners, and researchers, experimenting with social innovations. The absence of policy and governmental regulations, and the lack of market incentives, significantly alters the interaction dynamics among agents, presenting a dimension of the simulation process that ATOM was not capable of effectively handling.

Conversely, ANIMO is better suited to explore such self-organization processes and novel behaviors. By adjusting agents’ rules, parameters, or initial conditions, the ANIMO framework is able to investigate a wide range of scenarios to discover emergent patterns and understand how they might evolve over time.

Furthermore, ATOM primarily focuses on the dynamics of technology diffusion, such as solar PV and residential battery energy storage systems, which essentially represent investments in equipment, products, and infrastructure. Therefore, economic factors play a crucial role in each agent's ultimate decision, encompassing considerations such as resistance to investing, associated risks, investment costs, pay-off period, and household income. While economic considerations are also integrated in the ANIMO model and partly influence whether an individual will participate in a citizen collective action, in this case, the issue is considerably more intricate.

This complexity arises from the presence of additional and somewhat different factors that intertwine with social values, orientations, and perspectives. These factors include sensitivity to, and perception of environmental and climate issues, preferences regarding being an independent (autonomous) energy producer (i.e., prosumer), or a traditional grid user, and most importantly, the level of cooperation and altruism inherent in the individuals within a particular area.

To address this complexity, ANIMO introduces a set of new agent-related parameters, thus, to capture these attributes. Note that these attributes are each time case specific, as they depend on the nature and the structure of the real-life application under study, as the process of selecting and designing these agent-related parameters, as well as informing them based on real-life data can very much affect the plausibility and the accuracy of the modeling results derived.

Lastly, a difference in the scale of operation exists between ATOM and ANIMO. While ATOM predominantly functions at the national level, providing insights and policy recommendations on a meso scale, the establishment of CEIs represents a grassroot social phenomenon primarily occurring at the local level. Consequently, ANIMO emerges as a tailored solution, designed to address the intricacies and dynamics inherent to local community engagement in energy initiatives.

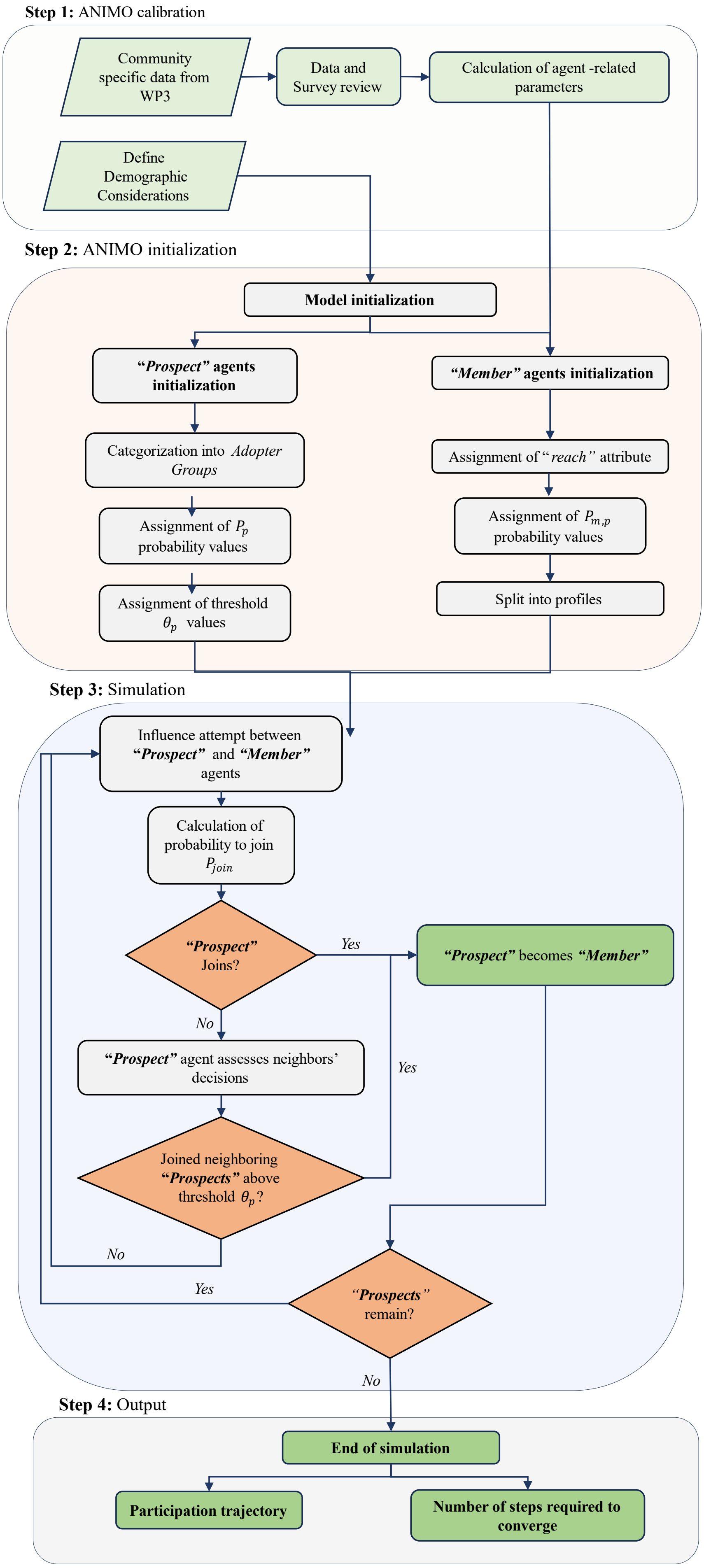
This localized focus allows ANIMO to delve deeper into the nuanced interactions and dynamics within communities, providing a platform for modeling and understanding the complexities of energy citizenship at the grassroot level. By complementing the macro-level perspective offered by ATOM with a micro-level analysis provided by ANIMO, a more comprehensive understanding of energy citizenship can be attained, facilitating the formulation of effective policies and strategies that resonate with diverse community contexts and scales.

Figure 10 presents the modeling architecture and methodological flowchart followed to develop the ANIMO framework. The modeling architecture of ANIMO is based on the adapted combination of two opinion diffusion models, namely the *Independent Cascade Model* and *Linear Threshold Model* (Shakarian et al., 2015).

However, these models are limited in terms of their approach in the depiction of social networks, simplifying them to a mere sum of nodes and edges (Rychtár, 2008). Following a logic-programming approach, which was first introduced by P. Shakarian et al., (2010), for this particular instance of information diffusion process in the energy communities under study, we developed a richer, more realistic model.

Moving past these limitations, in ANIMO there are assigned labeled attributes, that endow agents and their interactions with meaningful and natural properties. This approach aligns with other diffusion models employed across diverse fields including business (Jackson & Yariv, 2006), economics (Zhang & Marbach, 2012), and epidemiology (Shakarian et al., 2013), where such models have been utilized to capture the dynamics of adoption, spread, and diffusion of innovations, behaviors, or diseases.

By not only adhering to, but also expanding established principles and methodologies within diffusion modeling, ANIMO contributes to a broader framework of interdisciplinary research aimed at understanding and predicting complex social phenomena across different contexts and disciplines. In this preliminary version of ANIMO, designed to address the ENCLUDE “Band Together” storyline, the model is structured around *three (3) layers*: *(1)*. “*agent classes*”, *(2)*. “*spatial & demographic considerations*” (e.g., population), and *(3)*. “*time dimension*” (temporal resolution).



Step 1: ANIMO calibration
Community specific data from WP3
Data and Survey review
Calculation of agent -related parameters
Define Demographic Considerations
Step 2: ANIMO initialization
Model initialization
"Prospect" agents initialization
"Member" agents initialization
Categorization into Adopter Groups
Assignment of "reach" attribute
Assignment of P_p probability values
Assignment of $P_{m,p}$ probability values
Assignment of threshold θ_p values
Split into profiles
Step 3: Simulation
Influence attempt between "Prospect" and "Member" agents
Calculation of probability to join P_{join}
"Prospect" Joins?
Yes
"Prospect" becomes "Member"
No
"Prospect" agent assesses neighbors' decisions
Yes
Joined neighboring "Prospects" above threshold θ_p?
No
Yes
"Prospects" remain?
No
Step 4: Output
End of simulation
Participation trajectory
Number of steps required to converge

Figure 10. Current modeling architecture and methodological flowchart of the ANIMO framework as it has been developed in the context of the ENCLUDE project.

4.1.1. First layer: Agent classes

There are two agent classes in ANIMO, "***Members***" and "***Prospects***".

"Members" (m) refer to the current members of the CEI under study, while "*Prospects*" *(p)* refer to the population in the area surrounding the CEI under study that are yet to join, i.e., prospective members. Similarly to the *Independent Cascade Model*, "*Members*" are assigned a probability factor, $P_{m,p}$, that reflects their ability to positively influence a "*Prospect*", convincing them to join the community. Typically, this probability is assigned based on data such as frequency of interactions, geographic proximity, or historical infection traces, depending each time on the specific application.

However, in the case of ANIMO, the probability distribution for "*Members*" is informed by the values of the agent-related parameters that characterize all agents of the class, which are informed by survey/census data available. This probability varies for every agent, and therefore, certain "*Members*" possess greater influence than others, reflecting the inherent diversity in individuals' capacity to persuade. In addition, "*Members*" also possess an attribute describing their "*reach*" related to the number of "*Prospects*" upon which they can exert influence.

The "*reach*" attribute ranges for all "*Members*", representing various profiles of individuals, from high influential "*Members*" with expansive social networks capable of disseminating information through "word-of-mouth", to more low profile "*Members*", avoiding attention and opting for a more isolated lifestyle with limited social interactions.

What differs from the original *Independent Cascade Model* is the fact that the "*reach*" attribute of "*Members*" in the ANIMO model, changes dynamically as the simulation time progresses. This means that not only the number of connections to "*Prospects*" but also the specific "*Prospects*" to whom the community member connects to, are subject to change during the simulation period.

This represents real-life processes more accurately as social connections are either temporary and tend to fade away with time passing, or new ones are established. This constitutes an expansion of the *Independent Cascade Model*, where the degree of connectedness (i.e. number of connections) as well the specific connections among agents, remain constant. Lastly, it is noteworthy to mention that the "*reach*" attribute can be adjusted to reflect different societal trends and evolutions, according to each "world" narrative that will be explored.

On the other hand, "*Prospects*" are characterized by a different set of agent-related parameters. More specifically, in the beginning of the simulation they are assigned an "*adopter group*" to which they belong to. The different "*adopter groups*" are drawn from Diffusion of Innovations theory, conceived by sociologist Everett M. Rogers (Rogers, 1983) . This theory provides a framework for comprehending the dissemination and adoption of novel ideas, technologies, and practices within societies and has found wide application across various disciplines.

The highlight of the study is the notion of the adoption curve, which is a graphical representation of the process of innovation adoption across distinct groups within a social system, each characterized by varying levels of readiness to embrace new innovations.

More specifically, the curve, provided in **Figure 11**, identifies *five (5) different adopter groups/ categories* in which individuals fall into and describe their attitude towards adopting new technologies or behaviors, namely:

- ***Innovators*** are risk takers who have the resources and desire to try new things, even if they fail.
- ***Early Adopters*** are selective about which innovations they adopt. They are considered the "one to check in with" for new information and reduce others' uncertainty about a new innovation by adopting it.

- ***Early Majority*** take their time before adopting a new idea. They are willing to embrace a new technology as long as they understand how it fits with their lives.
- ***Late Majority*** adopt in reaction to peer pressure, emerging norms, or economic necessity. Most of the uncertainty around an idea must be resolved before adoption.
- ***Laggards*** are traditional and make decisions based on past experience. They are often economically unable to take risks on new ideas.

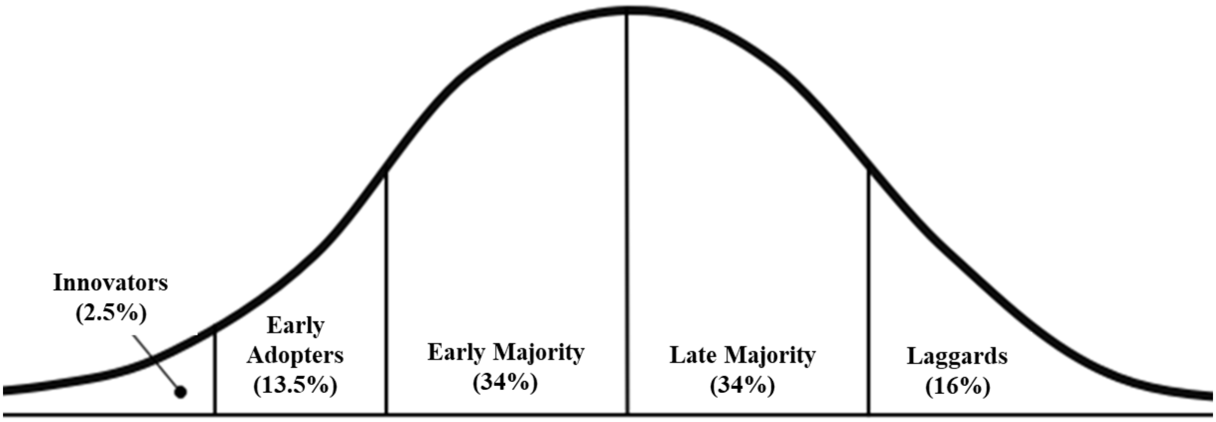


Figure 11. Adoption of innovation curve (Rogers, 1983).

Similarly to the probability factor that characterizes "*Members*", the *receptivity towards innovations* is incorporated into ANIMO as a probability P_p, the value of which depends on the group that the "*Prospect*" belongs to. Consequently, "*Innovators*" are the easiest to mobilize while "*Laggards*" pose the greatest resistance, with all other groups occupying intermediate positions.

The probability P_p of "*Prospects*" is combined along with the probability factor $P_{m,p}$ of "*Members*", to create the final probability to join, P_{join}, which takes into account both the influencing capabilities of existing community "*Members*", as well as the preferences and attitudes of prospective community members (i.e. "*Prospects*"). Concluding, through this process, the probability that a *"Prospect"* will join the community and become *"Member"* at an interaction between agents of the two classes is calculated as:

$$P_{join} = P_{m,p} \times P_p$$

To further refine the model's representation of influencing, social pressure phenomena are also incorporated. Similarly to the "*reach*" attribute of "*Members*", each "*Prospect*" is respectively endowed with a social circle, denoted as $\eta(p)$, the size of which varies, portraying both well socially connected as well as isolated individuals. As the simulation time (t) progresses, certain "*Prospects*" are more likely to be deciding in favor of joining the CEI under study and transitioning into the role of a "*Member*".

The set of "*Prospects*" that have turned into "*Members*" in earlier time than the current time t of the simulation is symbolized as H_{t-1}. This phenomenon is tracked by the model, thereby influencing "*Prospects*'" subsequent decisions regarding joining the CEI under study.

For this reason, inspired by dynamics of the *Linear Threshold Model*, "*Prospects*" are lastly characterized by a threshold θ_p in the interval [0,1], representative of the percentage of individuals within their social circle that need to become "*Members*", in order for the "*Prospects*" in question to consider joining.

As expected, there exists inherent variability in threshold values for each "*Prospect*", reflecting differences in susceptibility to peer pressure and adding an additional layer of sophistication and realism to the model.

However, in contrast to the *Linear Threshold Model*, where the threshold θ_p is selected uniformly at random due to lack of knowledge of the tendency of agents to adopt an idea or innovation, the approach in ANIMO differs, since we can further inform the threshold values, by having "*Prospects*" categorized into the adopter groups mentioned earlier. Therefore, θ_p values are assigned through distinct normal distributions, for each of the adopter groups.

Furthermore, the mean and median of each of the distributions can be modified to create skewed distributions, allowing for the model dynamics to be appropriately adapted, with a view to adding further nuance when simulating and exploring various "world" narratives and scenarios. In general, a "*Prospect*" (p_i) becomes a *"Member"* at time t of the simulation if:

$$\sum p \in \eta(p_i) \cap H_{t-1} \geq \theta_{p_i}$$

4.1.2. Second layer: Spatial & Demographic considerations

Achieving realistic modeling representations necessitates informing the model about different spatial and demographic considerations of the social group under study. It is important to know, for example, the population density of the area in which the CEI under study exists. This serves two primary purposes: firstly, it is evident that the potential for growth of a CEI is constrained by the population residing in the area.

By incorporating population density data sourced from real-life region-specific data and determining the size of the geographical scope that will be taken into consideration, the total number of "*Prospects"* can be derived. Secondly, densely populated areas facilitate increased social interactions, thereby enhancing the likelihood of information dissemination and propagation of influence.

Thus, by considering the population density, the model can better capture the dynamics of social interaction and its impact on the spread of information within and without the community under study. In addition, another demographic consideration that was integrated into ANIMO is the rate of population growth, based on which the population of agents can be updated, depending also on the time horizon of the simulation, further enhancing the model's realism by capturing real-world trends and potential fluctuations in population over time.

Moreover, agents from both *agent classes* in the model possess a geographical attribute, pertaining to their spatial positions within the simulated environment. Therefore, "*Members*" are typically clustered in proximity to one another to emulate a cohesive community, while "*Prospects*" are situated in surrounding areas.

However, ANIMO further expands upon the traditional *Linear Threshold* and *Independent Cascade* models by incorporating the possibility for both "*Members*" and "*Prospects*" to reposition themselves within the simulation environment.

Consequently, they can rewire their social connections, altering existing ties and establishing new ones with agents that are now in proximity. This added modeling aspect is important to capturing the dynamics of community formation and is thought to enhance the model's sophistication and realism by more accurately reflecting real-life processes of spatial mobility and social network formation.

Lastly, similar to the variability observed in the "reach" attribute, where "*Prospects*" exhibit differing degrees of sociability, the propensity for movement in ANIMO also spans a spectrum, in order to capture the diverse range of mobility patterns observed in real-world contexts. As a result, some agents may prefer to remain stationary or limit their movements to their immediate vicinity, while others may exhibit a higher degree of mobility, traversing larger distances within the simulated world.

4.1.3. Third layer: Time dimension

As far as the time dimension of the model is concerned, the simulation progresses in discreet time steps t. In each time step, the processes outlined previously unfold, potentially leading to a subset of

"*Prospects*" transitioning into "*Members*". In this stage, in order to fully utilize the output of ANIMO's application, it is important to calibrate the model's time step duration to match the observed real-world phenomena.

This means establishing a meaningful correlation between simulation time and the actual temporal dynamics observed in the growth of energy communities. Therefore, in the context of this particular application of the model, we turned to sourcing empirical data pertaining to the evolution of CEIs. By inquiring into the growth patterns exhibited by CEIs, insights can be extracted regarding the growth rate and trajectory of community development over a time frame.

Such insights can be used to inform the calibration of the model's time scale and validate the ANIMO framework against historical data, allowing for a more accurate representation of the target system. However, in the case of CEIs, growth data has been scarce. Nonetheless, this may not pose a considerable limiting factor, as in some cases, and particularly within the scope of our work, where we delve into the exploration of speculative "future world" narratives, it has been argued that strict validation with external data may not be necessary (Heppenstall et al., 2021).

Besides, the interdependencies and interactions between agent classes and their environments coupled with the emergence of phenomena at different spatial and temporal scales mean that many aspects of the model are impossible to observe in reality, and even if it were possible to observe certain aspects of the simulated system, it is unlikely that detailed, granular spatiotemporal data would be available to validate the behaviors of the agents directly (Batty & Torrens, 2005).

Lastly, it is also important to emphasize that ANIMO belongs to a category of models often described as "*progressive*" or "*monotonic*". This means that once a "*Prospect*" becomes a "*Member*" during the simulation, there is no provision for reverting to their initial state, differentiating it from other non-progressive models.

Moving forward with ANIMO's specific application in ENCLUDE, with the aim of performing socially well-informed modeling activities, an extensive database is required so that the model can accurately represent and simulate the adoption of social and grassroot innovations, also considering specifications on the communities' structures and their context under study.

Therefore, the ANIMO framework is also supplemented with a complete framework for parameter estimation as well as quantification of the uncertainty that governs its ability to replicate real-life processes and make future projections. Leveraging data gathered from the ENCLUDE case studies, ANIMO is enhanced to analyze the decision-making processes of distinct citizen profiles, a crucial aspect in the effective development and execution of socio-technically informed modeling exercises.

In this context, and after careful evaluation and communication with the ENCLUDE WP3, the best documented and data-rich case studies were selected; in the surveys conducted by WP3, questionnaires providing information about key aspects of the community members' life situation, such as income, education, and environmental awareness, were answered (Brenner-Fliesser et al., 2023).

Based on that, insights concerning the key beliefs of the members were extracted, and a profiling of the population was created. This is provided as input into ANIMO, calibrating each time the case-specific agent-related parameters, which were designed and selected to capture the main drivers of human behavior and decision-making concerning the decision to join an energy community.

Having defined the geographic and socioeconomic contexts, the application of the ANIMO framework will simulate the expansion of specific energy community projects, projecting the anticipated growth rate of the community over a predetermined time frame. This process holds significant importance since it allows for a comparison of growth rates across various communities, essentially examining different populations.

This analysis can shed light on and pinpoint social values and beliefs that are more likely to result in favorable decisions; in this case supporting the further expansion of energy communities. These insights can, in turn, assist policymakers in designing tailored legislation aimed at enhancing the incentives that are genuinely impactful and propel such social and grassroot innovations forward.

Finally, the ANIMO framework is part of the Technoeconomics of Energy Systems laboratory (TEESlab[3]) Modeling suite (TEEM). All of the model's modules have been developed in Python source code. Supporting efforts around Europe towards open model development, ANIMO will become open-access and publicly available for all the relevant end-users.

To increase transparency, associate source code, datasets, and detailed documentations, along with suitable open licenses (where possible) to enable the models' use, modification, and republication, will be uploaded on the TEESlab UPRC's GitHub page[4], while case study results will be made available on the ENCLUDE Interactive Policy Platform (as developed in the context of the ENCLUDE WP7).

4.2. The DREEM modeling framework

The **D**ynamic high-**R**esolution d**E**mand-sid**E** **M**anagement (**DREEM**) model is a fully-integrated energy demand and demand-side management simulation model, focusing on the building sector, which expands the computational capabilities of existing Building Energy System and demand-side models, by not only calculating energy demand, but by also assessing the benefits and limitations of demand flexibility, primarily for the main end-users (consumers/ citizens), and, then for other energy system actors involved (e.g., suppliers, retailers, distribution system operators) (Stavrakas & Flamos, 2020).

The main premise behind the development and the use of the DREEM model has been that in order for citizens to have a more active and positive participation to the energy transition, they first need to become more aware of the benefits from investing in new energy products and services.

In this context, the novelty of the model lies in its potential to be used in a wide range of applications, not only to assess the existing technological infrastructure, but also to support the development of business models and regulatory innovations, which maximize the value of energy products and services, and monetize them, to fairly compensate citizens and other relevant energy market actors. Overall, the DREEM model:

- Embodies key features towards the simulation of renewable energy, energy efficiency, and other demand-flexibility actions, like demand response, in the building sector.
- Builds on the concept of modularity consisting of multiple components, each of which is composed of additional modules, allowing for more flexibility in terms of possible system configurations and computational efficiency (high time resolution and quick simulations) towards a wide range of scenarios, to study different aspects of end-use and energy transition (**Figure 12**).
- Provides the ability to incorporate technological breakthroughs in a detailed manner, such as the inclusion of heat pumps, or electric vehicles, in view of energy transitions envisioning the full electrification of the heating and transport sectors.
- Produces outputs for a group of buildings, for example a neighborhood, a district, a municipality, or an energy community.
- Serves as a basis for modeling energy demand in the building sector, within the broader field of local, regional, and national energy systems, in different geographical/ climate and socioeconomic contexts of interest.

[3] https://teeslab.unipi.gr/
[4] https://github.com/TEESlab-UPRC

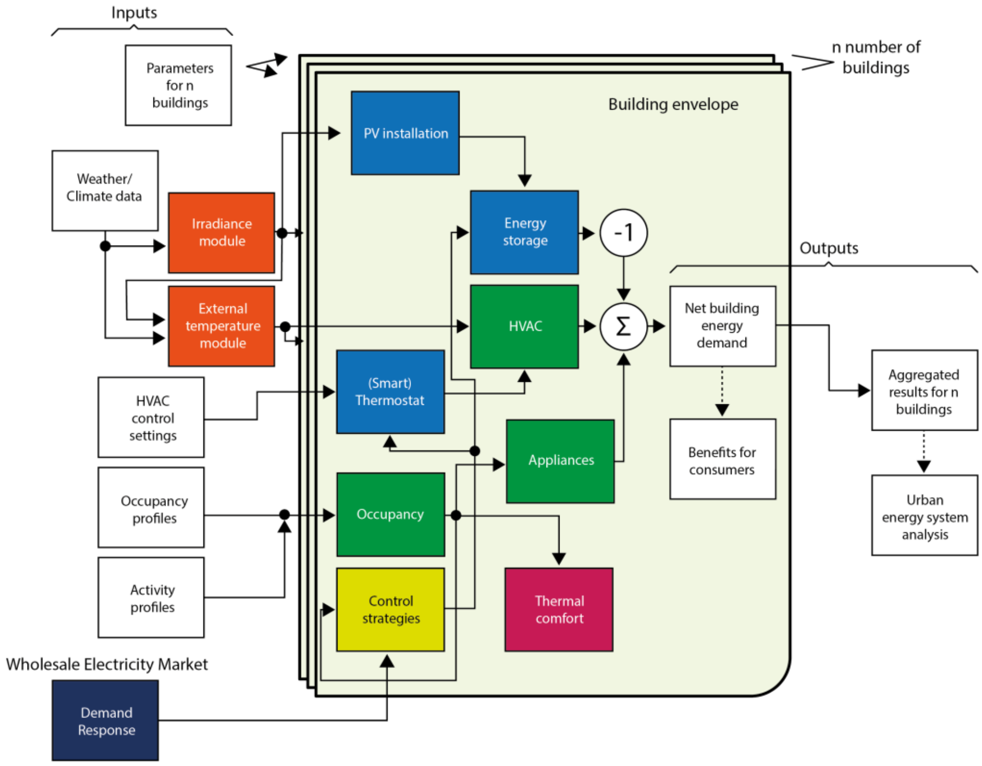


Figure 12. The original architecture of the DREEM model as presented by Stavrakas & Flamos (2020).

All the model's modules have been developed using the "Buildings" library, an open-source, freely available Modelica library for building energy and control systems (Wetter, 2011; Bünning et al., 2017); Zuo et al., 2016). Alongside the Modelica models, Python scripts have been developed to model parts of the model's components and to enable the interface with the Dymola simulation environment. DREEM is also part of the TEEM; the model is open access[5] under the "GNU Affero General Public License".

The updated ENCLUDE version of the model, including associate source code, datasets, and detailed documentations to enable the models' use, modification, and republication, will be distributed through the TEESlab UPRC's GitHub page, while case study results will be made available in the ENCLUDE Interactive Policy Platform (as developed in the context of the ENCLUDE WP7).

To address the modeling needs of the work presented in this report and in order for the model to become capable of quantifying the decarbonization potential of the "*Power to the People*" and the "*Habitual Creatures*" storylines and simulating case-specific transition pathways that envision patterns and trends of energy citizenship as citizens' active participation to the energy market and actions towards increasing energy autonomy and achieving energy savings, the model's original architecture and capacities, as originally introduced by Stavrakas & Flamos (2020), have been expanded.

The updated modeling structure of DREEM is presented in **Figure 13**. Below, we provide a description of the new components and respective modules that have been developed and integrated to the original model's structure, along with the components and modules that have been used for the application at hand, based on **Table 2**.

[5] https://github.com/TEESlab-UPRC/DREEM

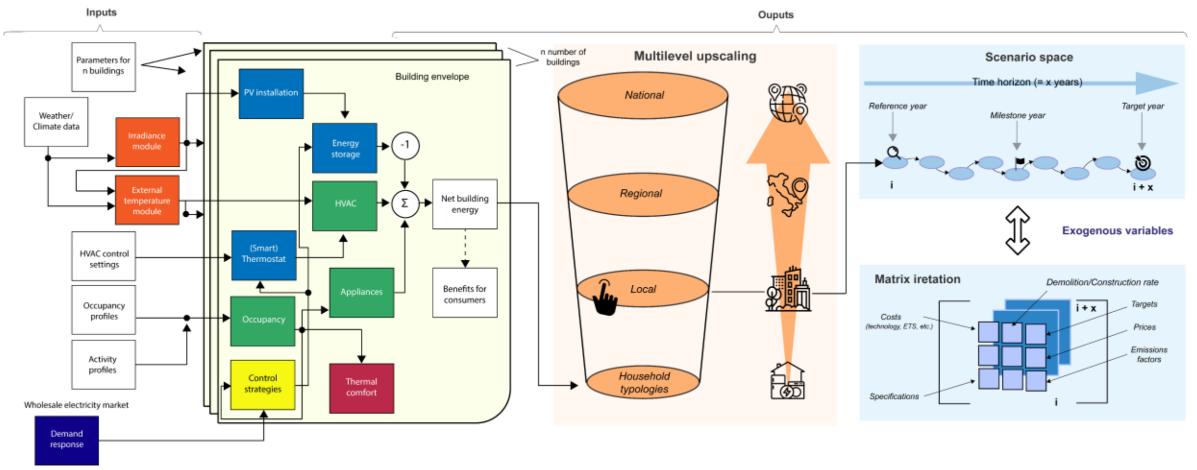


Figure 13. Expanded architecture of the DREEM model as further developed, modified, and adjusted in the context of the ENCLUDE project.

Table 2. Hierarchical structure of the expanded version of the DREEM model as used in this study: Short description of the main components and modules.

Components	Modules	Description	Developed
C_1: Weather/ Climate data	-	This single-module component is responsible for generating climatic boundary conditions. It reads weather data from the respective files and then provides them to the other components, where and when necessary.	Modelica
C_2: Building envelope	-	This single-module component models different building typologies with the corresponding characteristics, properties, and heat conduction elements.	Modelica Python
C_3: Energy demand	*C_3M_1: Occupancy*	This module defines and sets the parameters for the behavior and the activities of the occupants by generating and storing default patterns.	Modelica
	C_3M_2: Appliances	This module is responsible for generating energy demand profiles from appliances, using statistics describing their mean total daily energy demand and associated power use characteristics, including steady-state consumption, or typical use cycles, based on occupancy patterns.	
	C_3M_3: Heating, ventilation, and air conditioning	This module is responsible for heating, ventilation, and air conditioning inside the building.	

C_4: Thermal comfort	-	This single-module component is responsible for determining, based on international standards, appropriate conditions and temperature ranges that result in occupants' thermal satisfaction.	Modelica Python
C_5: Flexibility management	*C_5M_1: PV installation*	This module contains information about the orientation of the roof to determine the PV generation based on the position of the sun and recorded irradiation data for the location of interest.	Modelica
	C_5M_2: Energy storage	This module contains models that represent different energy storages. It takes as an input the power that should be stored in/ extracted from the storage. The "C_7: Control strategies" component is responsible so that only a reasonable amount of power is exchanged, and that the state of charge remains between the appropriate ranges.	
	C_5M_3: (Smart) Thermostat	This module is responsible for the operation of the HVAC control system. By receiving the indoor temperature as a measured signal and based on the difference of set and measured temperature, it sends signals to the "*C_3M_3: Heating, ventilation, and air conditioning*" module to yield the heat and ventilation flows inside the building.	
C_6: Demand-Response	-	This single module component simulates Demand-Response mechanisms that motivate citizens to respond to real-time price signals.	Python
C_7: Control strategies	*C_7M_1: Momentary Control Algorithm*	This single module component is responsible for the energy management supervision strategy that, given the time-shifting events of demand and the citizen occupancy signals received, aims at achieving energy savings and cost effectiveness.	Modelica Python
C_8: Multilevel upscaling	-	This new single-module component is responsible for applying an upscaling approach to compute cumulative energy consumption patterns in the building sector, at the scale of interest, using parameters and statistics obtained from survey and/ or census data. It receives inputs from the "C_2: Building envelope" and the "C_3: Energy demand" components.	Python

C_9: **Transition matrix**	*C_9M_1: Scenario space*	This module is responsible for designing the scenario space (in terms of the transition pathways and the respective exogenous variables) inside of which the transition matrix is initiated and updated, based on relevant policy documents' specifications and practical experts' feedback.	Python
	C_9M_2: Matrix iteration	This module is responsible for initializing the transition matrix and updating it at each time interval (i.e., iteration), following the scenario space's specifications (i.e., targets and constraints) derived from the "*C_9M_1: Scenario space*" module.	

4.2.1. C_1: Weather/ Climate data

Seasonal variability to reflect the changing level of demand between winter and summer is an important aspect, which is often omitted or addressed in an oversimplified manner by existing demand-side models in the field. In the DREEM model we address this issue through the inclusion of a single module component dedicated to generating accurate climatic boundary conditions based on historical weather data.

To do so, the component uses Typical Meteorological Year (TMY) weather data format, and particularly the TMY3 format, while it is then configured to provide a common set of irradiance and temperature data for the geography under study, with the respective irradiance and temperature profiles having appropriate time-diversity to enable higher resolution (Cebecauer & Suri, 2015; Wilcox & Marion, 2008).

4.2.2. C_2: Building envelope

The DREEM model builds on the concept of "reduced (low)-order" thermal network modeling, which represents a thermal zone by thermal resistances and capacities (RC-network), using the electrical circuit analogy, in which voltage is analogous to temperature and current is analogous to convective and radiative heat transfer (McKenna & Thomson, 2016; Harish & Kumar, 2016). The respective module represents all main thermal masses of the building under study as four elements, accompanied with supportive features for consideration of solar radiation (as visualized by Stavrakas & Flamos, 2020)).

The parameters for heat transfer coefficients, and thermal resistances and capacities, are determined using historical data and standards for the geographical context of interest. In this work, we present the detailed mathematical representation and equations used to further develop the RC-network methodology in DREEM.

Thermal network models generally focus on one-dimensional heat transfer calculations. A geometrically correct representation of all the walls of a thermal zone is thus not possible. To reduce simulation effort, it is, thus, reasonable to aggregate walls to represent elements with similar thermal behavior. The number of a wall's elements depends on the thermal properties of the walls and their excitation (e.g., through solar radiation), on the excitation frequencies.

The same applies for the number of RC-elements per wall. There is the option between models with one to four wall elements, and to define the number of RC-elements per wall for each wall. The latter can be done by setting n_k, which is the length of the vectors for resistances R_k and capacities C_k. Each wall element uses reduced-order models to describe heat conduction and storage within the wall, depending on if the wall contributes to heat transfer to the outdoor environment (exterior walls), or it can be considered as simple heat storage elements (interior walls). All the exterior walls and windows provide a heat port to the outside. All the wall elements (exterior walls, windows, and interior walls) are connected.

This component's modeling architecture is defined in the German Guideline VDI 6007 Part 1, which describes a dynamic thermal building model for calculations of indoor air temperatures and heating/cooling power (German Association of Engineers, 2012). The important modeling parameters that are used to parameterize the "C_2: Building envelope" component in the DREEM model are as follows:

- n... defines the length of chain of RC-elements per wall.
- R...[n] is the vector of resistances for the wall element. It moves from indoor to outdoor.
- C...[n] is the vector of capacities for the wall element. It moves from indoor to outdoor.
- $R..._{Rem}$ is the remaining resistance between C[end] and outdoor surface of the wall element. This resistance can be used to ensure that the sum of all the resistances and coefficients of heat transfer is equal to the U-value. It represents the part of the wall that cannot be activated and thus does not take part at heat storage.

The thermal behavior of a homogeneous wall layer v of arbitrary thickness s, for one-dimensional heat flow and periodic case problem, is illustrated by the following matrix notation (Figure 14):

$$\begin{pmatrix} \underline{\theta}(x=0) \\ \underline{q}(x=0) \end{pmatrix}_V = \boldsymbol{A_V} \cdot \begin{pmatrix} \underline{\theta}(x) \\ \underline{q}(x) \end{pmatrix}_V$$

where x is the coordination towards the normal wall.

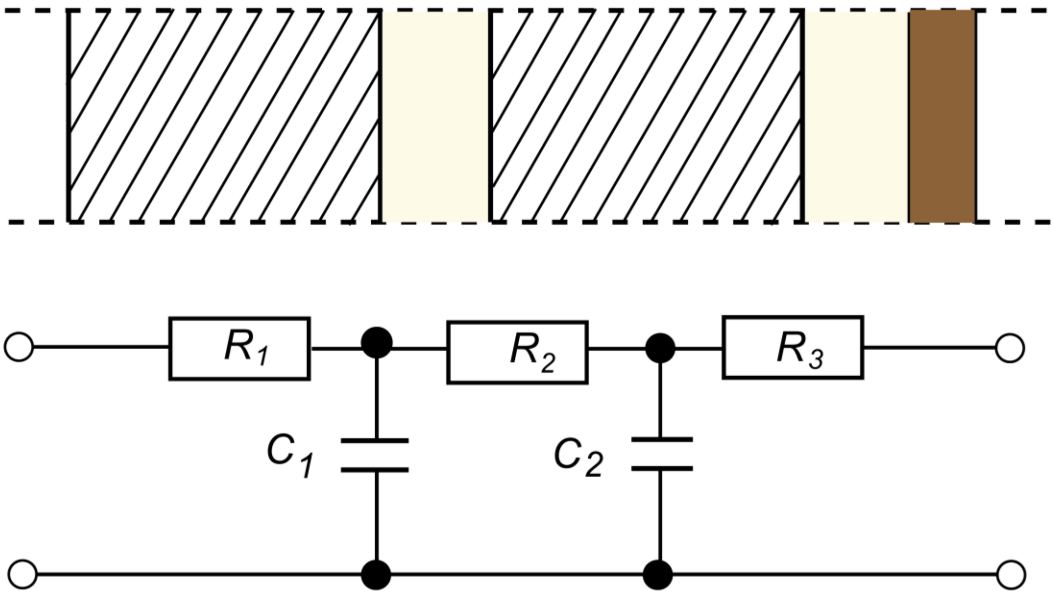


Figure 14. Graphical representation of the thermodynamic model used in DREEM for one wall element.

The chain matrix $\boldsymbol{A_V}$ for a wall layer can be written:

$$\boldsymbol{A_V} = \begin{Vmatrix} \underline{a}_{11} & \underline{a}_{12} \\ \underline{a}_{21} & \underline{a}_{22} \end{Vmatrix}_V = \begin{Vmatrix} Re\underline{a}_{11} & Im\underline{a}_{11} & Re\underline{a}_{12} & Im\underline{a}_{12} \\ -Im\underline{a}_{21} & Re\underline{a}_{11} & -Im\underline{a}_{12} & Re\underline{a}_{12} \\ Re\underline{a}_{21} & Im\underline{a}_{21} & Re\underline{a}_{22} & Im\underline{a}_{22} \\ -Im\underline{a}_{21} & Re\underline{a}_{21} & -Im\underline{a}_{22} & Re\underline{a}_{22} \end{Vmatrix}_v$$

while the elements of the chain matrix for a wall of layer v are obtained as:

$$Re\underline{a}_{11} = Re\underline{a}_{22} = \cosh\sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \cos\sqrt{\frac{1}{2}\omega_{BT}RC}$$

$$Im\underline{a}_{11} = Im\underline{a}_{22} = \sinh\sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \sin\sqrt{\frac{1}{2}\omega_{BT}RC}$$

$$Re\underline{a}_{12} = \mathrm{R} \cdot \sqrt{\frac{1}{2\omega_{BT}RC}} \cdot \left(\cosh\sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \sin\sqrt{\frac{1}{2}\omega_{BT}RC} + \sinh\sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \cos\sqrt{\frac{1}{2}\omega_{BT}RC}\right)$$

$$Im\underline{a}_{12} = \mathrm{R} \cdot \sqrt{\frac{1}{2\omega_{BT}RC}} \cdot \left(\cosh\sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \sin\sqrt{\frac{1}{2}\omega_{BT}RC} - \sinh\sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \cos\sqrt{\frac{1}{2}\omega_{BT}RC}\right)$$

$$Re\underline{a}_{21} = \frac{-1}{R} \cdot \sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \left(\cosh\sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \sin\sqrt{\frac{1}{2}\omega_{BT}RC} - \sinh\sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \cos\sqrt{\frac{1}{2}\omega_{BT}RC}\right)$$

$$Im\underline{a}_{21} = \frac{-1}{R} \cdot \sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \left(\cosh\sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \sin\sqrt{\frac{1}{2}\omega_{BT}RC} + \sinh\sqrt{\frac{1}{2}\omega_{BT}RC} \cdot \cos\sqrt{\frac{1}{2}\omega_{BT}RC}\right)$$

where:

- R is the thermal resistance of the wall's layer per unit area in $\frac{\mathrm{m}^2 \cdot \mathrm{K}}{\mathrm{W}}$ with $\mathrm{R} = \frac{\mathrm{s}}{\lambda}$,
- C is the heat capacity of the wall's layer per unit area in $\frac{\mathrm{J}}{\mathrm{m}^2 \cdot \mathrm{K}}$, $\mathrm{C} = \mathrm{c} \cdot \rho \cdot \mathrm{s}$,
- ω is the angular frequency in $\frac{1}{\mathrm{s}}$, $\omega = \frac{2 \cdot \pi}{86{,}400 \cdot \mathrm{T}}$,
- T is the period of the fundamental in days. For the calculations we select a period time of T=7 days, based on ISO 13786 - Thermal performance of building components - Dynamic thermal characteristics - Calculation methods,
- s is the thickness of the wall's layer in m,
- λ is the thermal conductivity of the wall's layer in $\frac{\mathrm{W}}{\mathrm{m}^2 \cdot \mathrm{K}}$,
- $\mathrm{c} \cdot \rho$ is the heat storage capacity of the wall layer in $\frac{\mathrm{J}}{\mathrm{m}^2 \cdot \mathrm{K}}$.

The chain matrix $A_{1,n}$ of the total wall is calculated by multiplying the matrices A_ν of the individual wall's layers (ν = 1,…, n). as:

$$\mathrm{A}_{1,\mathrm{n}} = \mathrm{A}_1 \cdot \mathrm{A}_2 \cdot \mathrm{A}_3 \cdot \ldots \cdot \mathrm{A}_{\mathrm{n}-1} \cdot \mathrm{A}_\mathrm{n}$$

Based on the chain matrix $A_{1,n}$ of the total wall, the resistances and capacities of the replacement model are estimated as:

$$R_1 = \frac{1}{A} \cdot \frac{(Re\underline{a}_{22} - 1) \cdot Re\underline{a}_{12} + Im\underline{a}_{22} \cdot Im\underline{a}_{12}}{(Re\underline{a}_{22} - 1)^2 + Im\underline{a}_{22}{}^2}$$

$$R_2 = \frac{1}{A} \cdot \frac{(Re\underline{a}_{11} - 1) \cdot Re\underline{a}_{12} + Im\underline{a}_{11} \cdot Im\underline{a}_{12}}{(Re\underline{a}_{11} - 1)^2 + Im\underline{a}_{11}{}^2}$$

$$C_1 = A \cdot \frac{1}{\omega_{BT}} \cdot \frac{(Re\underline{a}_{22} - 1)^2 + Im\underline{a}_{22}{}^2}{Re\underline{a}_{12} \cdot Im\underline{a}_{22} - (Re\underline{a}_{22} - 1) \cdot Im\underline{a}_{12}}$$

$$C_2 = A \cdot \frac{1}{\omega_{BT}} \cdot \frac{(Re\underline{a}_{11} - 1)^2 + Im\underline{a}_{11}{}^2}{Re\underline{a}_{12} \cdot Im\underline{a}_{11} - (Re\underline{a}_{11} - 1) \cdot Im\underline{a}_{12}}$$

Where A is the total area of the wall in m^2. The resistance R_3 is then calculated as the difference between the total heat transfer resistance of the wall and the sum of the equivalent model resistors R_2 and R_1, as:

$$R_3 = \left(\frac{1}{A} \cdot \sum_{v=1}^{n} \frac{S_V}{\lambda_V}\right) - R_2 - R_1$$

The model can now be reduced to a simplified model (Figure 15) that comprises of a total resistance R_w and heat capacity $C_{1,korr}$. For one-sided thermal stress, the replacement model simplifies the case of thermal load accordingly. The total resistance R_w is equal to:

$$R_w = R_3 + R_2 + R_1 = R_{REM} + R_1,$$

while the corrected heat storage capacity $C_{1,korr}$ is equal to:

$$C_{1,korr} = A \cdot \frac{1}{R_1 \cdot \omega_{BT}} \cdot \frac{R_w - Rea_{12} \cdot Rea_{22} - Ima_{12} \cdot Ima_{22}}{Rea_{22} \cdot Ima_{12} - Rea_{12} \cdot Ima_{22}}$$

An external window is a special case of the replacement model and in this case, the heat storage capacity $C_{1,korr}$ should practically be set to zero.

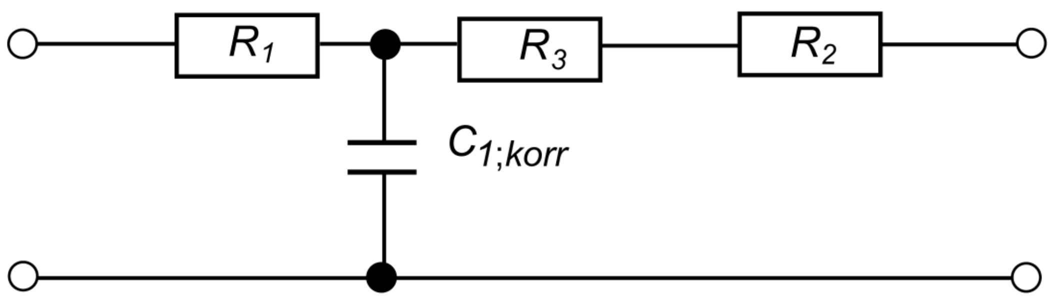


Figure 15. Graphical representation of a simplified model for the thermal behavior of components under asymmetrical loading**.**

4.2.3. C3: Energy demand

The DREEM model aims to generate accurate and realistic energy demand profiles, avoiding unnecessary computational complexity, by building on the concept of stochastic modeling and providing simulated data about households' energy demand, with statistics suitable for the task at hand. This component uses a bottom-up approach to simulate energy consumption considering households' occupancy, use of appliances, and heating, cooling, and ventilation options.

The component's individual modules use many simplified assumptions to simulate various aspects of energy demand (occupancy and citizens' activity/ behavior profiles, sharing of appliances, etc.) and focuses on parameters and statistics obtained from survey and/ or census data.

4.2.4. C4: Thermal comfort

The model focuses on addressing the- often overlooked by other models in the field- aspect of occupants' thermal comfort, by utilizing an individual component that aligns with international standards (DIN EN ISO 7730, ASHRAE 55, EN 15251). Built upon the Fanger approach, it employs the characteristic Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfaction (PPD) indices (P.O. Fanger, 1970).

To determine optimal indoor thermal conditions for occupants, DREEM calculates PMV and PPD, by considering weather and other parameters, such as dynamic metabolic rates and clothing insulation, adjusted based on seasonal variations. By doing so, it offers a comprehensive approach to accurately model thermal comfort and fill existing gaps. The acceptable ranges of the PMV and PPD indices are presented in Table 3.

Table 3. Expectation levels of the PMV and PPD indices according to the EN 15251 standard (Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings-Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics, 2006).

PPD (%)	PMV	Description
< 6	- 0.2 < PMV < + 0.2	Increased expectation level: recommended for spaces inhabited by highly vulnerable individuals with specific needs, like sick children, elderly persons, etc.
< 10	- 0.5 < PMV < + 0.5	Standard expectation level: new and renovated buildings.
< 15	- 0.7 < PMV < + 0.7	Moderate expectation level (acceptable range): existing buildings.
< 20	- 1 < PMV < + 1	Minimum expectation levels: values acceptable only for limited parts of the day.
> 20	PMV < -1 or PMV > + 1	Unacceptable expectation levels: values deviating acceptable criteria, deemed tolerable only for a very limited part of the year.

4.2.5. C_5: Flexibility management

This component uses a bottom-up approach that initially specifies for each building under study the available flexible devices and technologies, synchronizing their operation with the configurations of the occupants, where necessary, as obtained from the "*C_3M_1: Occupancy*" module. The "*C_3M_1: Occupancy*" module is used to create consistent profiles for the devices, meaning that devices requiring user interaction can only change their state when a person is at home.

For flexible devices the usage patterns are generated using the household configuration and it is guaranteed that the start/ end times are synchronized with the occupancy profiles. This updated version of the DREEM model focuses on the inclusion of technologies such as small-scale PV installations and electricity storage (i.e., batteries), and smart devices, as smart thermostats, etc.

4.2.6. C_8: Multilevel upscaling

This newly developed single-module component allows the DREEM model to serve as a modeling tool of accurate energy demand profiles in the building sector, within the broader field of local, regional, and national energy systems, in different geographical/ climate and socioeconomic contexts of interest. It uses an upscaling approach, building on parameters and statistics obtained from survey and/ or census data, to calculate cumulative energy consumption in the building sector, at the local, the regional, or the national level, according to the needs of each application at hand.

After having specified the individual building typologies of interest under the "C_2: Building envelope" component and simulating their individual energy consumption patterns, based on the specifications and the parameterization of the "C_3: Energy demand" component, this component computes cumulative energy consumption patterns at the scale under study as the product of each individual building typology's energy consumption and the number of the respective households per typology and number of citizens (as extracted by the available statistical data).

4.2.7. C_9: Transition matrix

The DREEM model has been developed to allow for producing outputs at a high resolution (i.e., one minute), also accounting for seasonal variability to reflect the changing level of demand between winter and summer, while its modular structure provides the necessary computational efficiency to simulate large numbers of buildings for the long-term transition with the appropriate demand diversity and accuracy (due to its bottom-up structure), also reducing the simulation complexity owing to the multidisciplinary nature of energy demand models and their input data requirements (Süsser et al., 2022; Chatterjee et al., 2022).

In this context, this newly developed component creates a scenario space, based on the policy specifications of each application at hand, which is further updated based on the evolution of exogenous variables (e.g., costs, prices, technological specifications) and is stored in a matrix to provide detailed information on the energy transition in the building sector for the time horizon (e.g., 2030, 2040, 2050) and the time interval (e.g., one hour, one year, five years) of interest.

5. The ENCLUDE scenario space and transition matrix at the local level

Considering all the insights from the sections above, the ENCLUDE scenario space to be applied to the selected set of case studies is presented in Figure 16.

Note that since the present deliverable addresses the impact of energy citizenship at the local level and based on the capabilities of the ENCLUDE modeling ensemble and their scale of analysis the "*People to the Streets*" storyline is not part of the final scenario space.

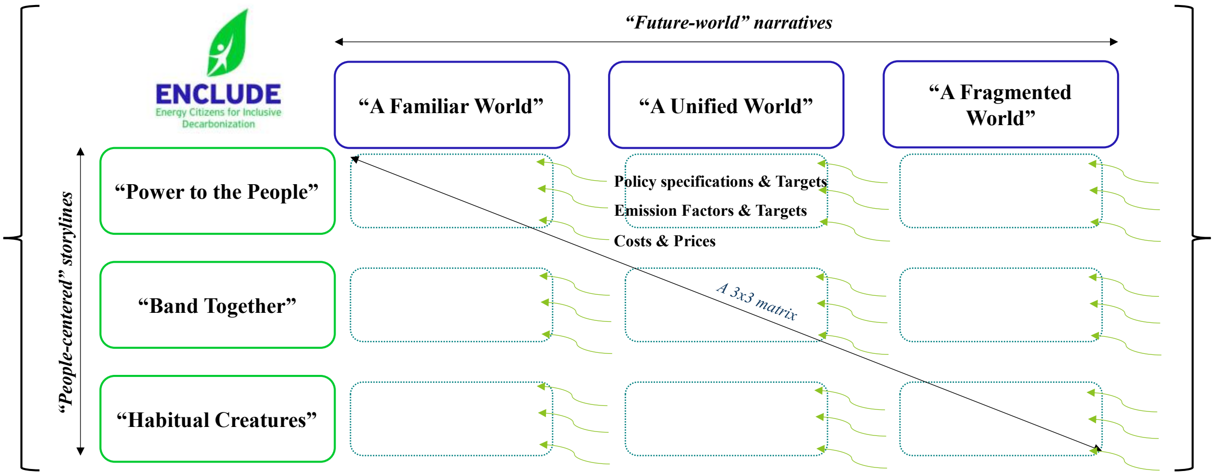


Figure 16. The final ENCLUDE scenario space to be applied to specific case studies for the development of real-life decarbonization pathways at the local level.

As we progress and finalize the scenario space, this will play a pivotal role in facilitating the subsequent phases related to the formulation of the different transition pathways to be simulated in the selected case studies.

The ENCLUDE scenario space to be employed in the real-life case studies will help to address a variety of questions, spanning from the decarbonization potential of the different aspects of energy citizenship at the local level to how to optimally realize and introduce to the public the relevant social innovations as well as the evaluation of specific policies and proposition of novel ones.

In the following sections, this scenario space is quantitatively transformed into the final ENCLUDE transition matrix so that it can be fed into the individual tools of the ENCLUDE modeling ensemble.

The final ENCLUDE transition matrix (Figure 17) is further populated with the evolution of different exogenous variables, e.g., emission factors, evolution of relevant energy prices and costs, technological costs and relevant updated configurations, benefits for citizens and/ or other power actors involved, always in accordance with the specifications of the ENCLUDE "*people-centered*" storylines and "*future-world*" narratives.

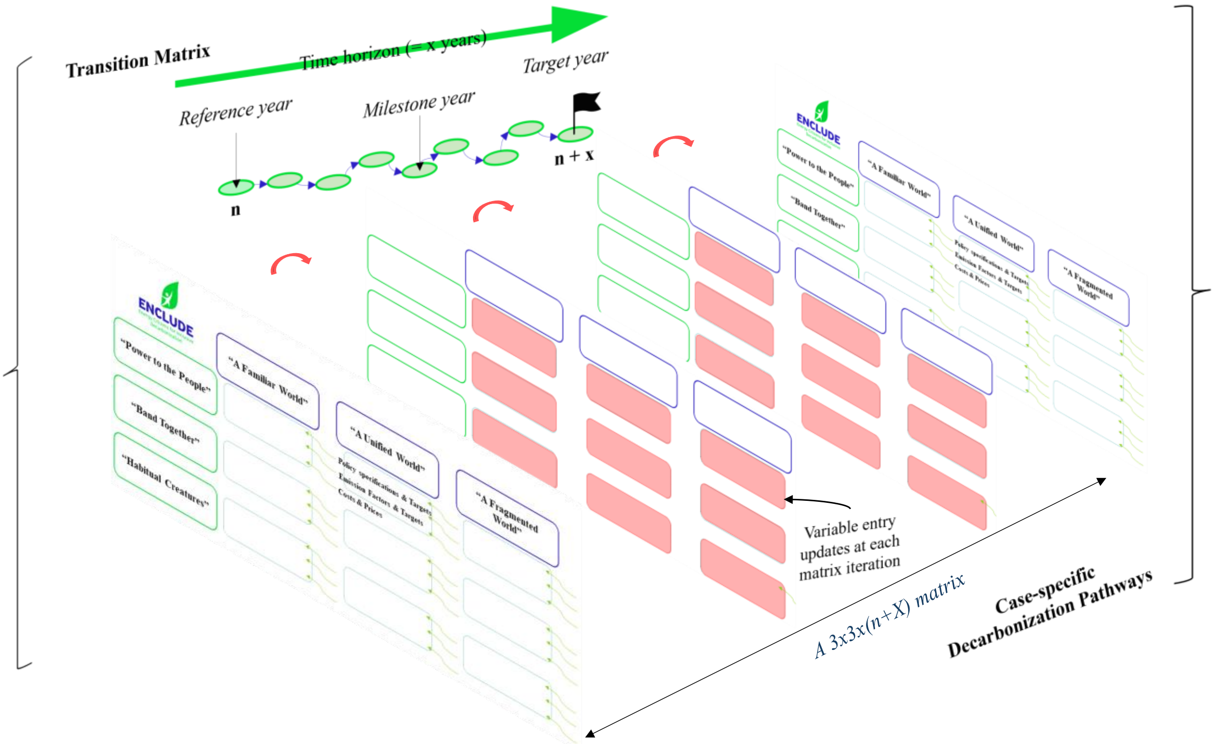


Figure 17. The final ENCLUDE transition matrix for the development of real-life decarbonization pathways at the local level.

6. Decarbonization pathways in real-life case studies based on "people-centered" storylines

In this section, we present the case studies selected for each one of the ENCLUDE storylines under study to be analyzed by the ENCLUDE modeling ensemble and the rationale behind their selection. In addition, we also present the case-specific scenario space and transition pathways that are integrated into the modeling tools.

As mentioned above, the "*People to the Streets*" storyline is excluded, as it concerns an expression of energy citizenship which is primarily considered to operate and have impacts on a macro scale. Consequently, this particular storyline is subject for exploration in the in the follow-up WP5 deliverable ("***D5.4 Report on the decarbonization potential of energy citizenship at national, regional, and EU level***").

6.1. Case study selection and specification

Geographical dimension adds an important value to quantifying the impact of energy citizenship- in terms of the decarbonization potential of its various expressions- at the local level and to better understanding the several important implications of geographies in the EU's policymaking landscape. To this end, we selected and explored a set of diverse case studies across Europe to illuminate the full range of differences and demonstrate cross-cutting themes (**Table 4**).

The main source of information and data for the selection and specification of the case studies was the case study pool developed and maintained in the context of WP3. Our selection focused on the spatial variation across contexts and the emphasis on cross-case differences of political, social, cultural, economic, demographic, and technological particularities of different energy systems across the EU.

Finally, we were able to collect data provided in the questionnaire developed by WP3 and filter the case studies to select those that we would delve deeper into based on their policy relevance and according to enhanced capabilities of the ENCLUDE modeling ensemble.

Table 4. List of the selected case studies to which the ENCLUDE modeling ensemble is applied.

"People-centered" storyline	Scale of analysis	Trend/ Pattern of energy citizenship	Model	Sectoral coverage & Geography	Time Horizon
"*Power to the People*"	Household	Prosumerism	DREEM	*Building (Residential) sector* Aalborg, Copenhagen (Denmark) Marseille, Paris (France) Athens, Thessaloniki (Greece) Lisbon, Porto (Portugal) Bilbao, Madrid, Malaga (Spain)	2023 - 2050
"*Band Together*"	Community	Collective Energy Initiatives (CEIs)	ANIMO	*Collective structures in the Building (Residential) sector*	2023 - 2030

				"Belica Energy Community[6]" (North Macedonia) "Cloughjordan Ecovillage[7]" (Ireland) "EnergieC Midden-Delfland[8]" (The Netherlands)	
"*Power to the People*" & "*Habitual Creatures*"	Municipality	Energy efficiency & Lifestyle/ Behavioral changes	DREEM	*Building (Residential) sector* Municipality of Megalopolis[9] (Greece)	2023 - 2050

Our set of case studies comprises seven (7) EU member states and one (1) Western Balkan country, which is currently in accession negotiations with the EU as a potential Member State. Figure 18 shows the geographical diversity of our case studies, along with their variance in the local scale of analysis, using the Nomenclature of territorial units for statistics "NUTS3" classification. In particular, the NUTS3 codes selected in each country, representing the region of each case study, are:

- **Denmark:** Aalborg ("*DK050*"), Copenhagen ("*DK011*" and "*DK012*").
- **France:** Marseille ("*FRL04*"), Paris ("*FR101-FR108*").
- **Greece:** Athens ("*EL301-EL306*"), Municipality of Megalopolis ("*EL651*"), Thessaloniki ("*EL522*").
- **Ireland:** County Tipperary ("*IE051*").
- **North Macedonia:** Municipality of Makedonski Brod ("*MK003*").
- **Portugal:** Lisbon ("*PT1B0*"), Porto ("*PT11A*").
- **Spain:** Bilbao ("*ES213*"), Madrid ("*ES300*"), Malaga ("*ES617*").

In addition, our case study selection showcases a great diversity of climate conditions, from "Temperate" (mesothermal climate, Köppen classification represented as "C") to "Continental" (microthermal climate, Köppen classification represented as "D"), and from "Oceanic" (Köppen classification represented as "Cfb") to "Mediterranean" (Köppen classification represented as "Cs") (Arnfield, 2023).

It also showcases a set of different cases when it comes to local and regional energy-related challenges for the transition to a greener future, spanning from the issue of "just and inclusive" transition in Megalopolis, the issue of prosumerism in Aalborg, the establishment of energy communities in the Northern Macedonia to the difficulties posed by the rapid urbanization and the need for infrastructure development as seen in cities such as Athens, Paris, Bilbao and Madrid.

The selected case studies also vary significantly in terms of their socioeconomic contexts. For instance, case studies situated in nations such as North Macedonia, Greece, and Portugal, where instances of energy poverty are more likely to occur, offer a unique opportunity to investigate the implications of energy citizenship amidst socioeconomic disparities, (lower incomes, higher unemployment rates, etc.).

These considerations are pivotal in ensuring an equitable and inclusive transition towards sustainable practices, with regard for vulnerable populations, including low-income households and marginalized communities.

[6] https://transitiongroups.org/group/green-commune-belica/
[7] https://www.thevillage.ie/
[8] https://www.energiecmiddendelfland.nl/
[9] https://megalopoli.gov.gr/

Finally, our case study selection spans across different policy landscapes concerning the frameworks in place to address energy-related challenges, ranging from cases such as in North Macedonia, which may face challenges in developing comprehensive energy policies due to its status as a transitioning economy, to Denmark, a global leader in renewable energy, possessing a robust and well-established policy framework supporting the transition to clean energy.

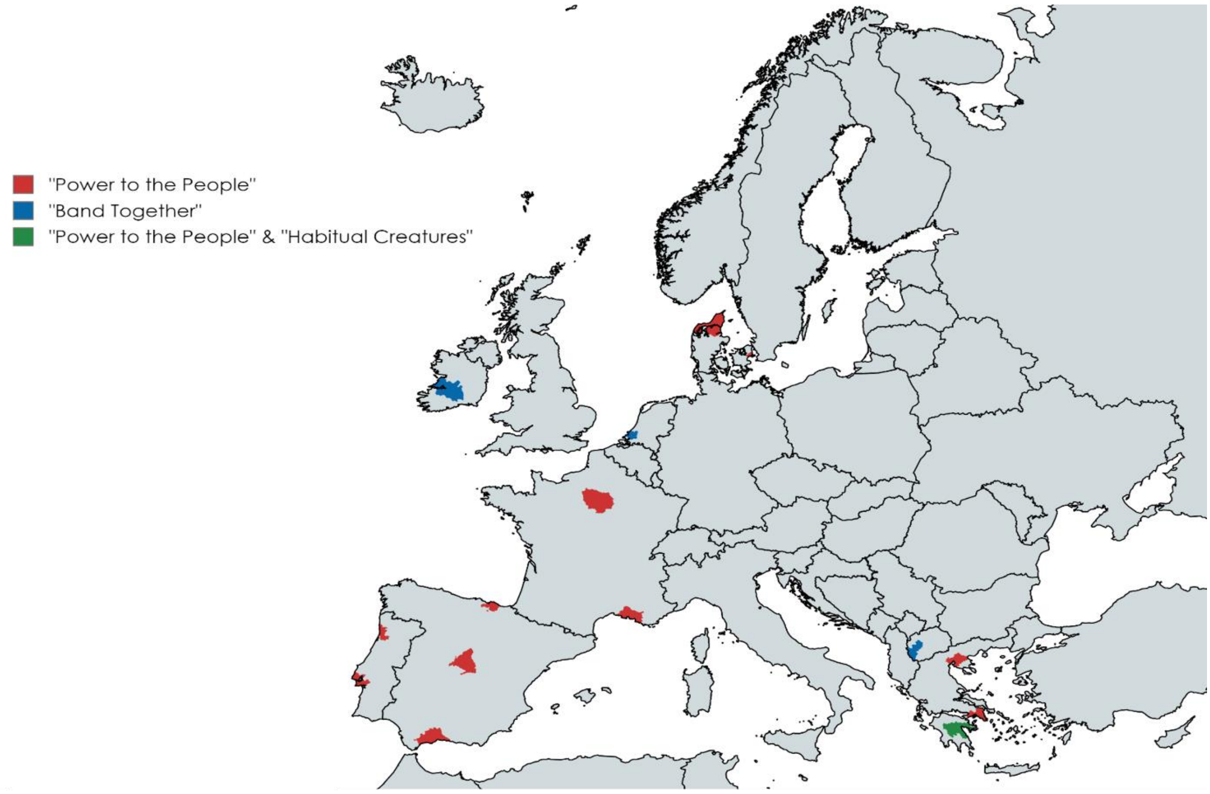


Figure 18. Selected case studies to be modeled using the ENCLUDE modeling ensemble across Europe: Geographical diversity and variance in the local scale of analysis (visualization developed using the online map-making tool "MapChart[10]").

6.1.1. *"Power to the People" through empowering prosumerism*

Under the *"Power to the People"* narrative the notion of the citizens' active participation in the energy market is further explored. Citizens are increasingly becoming individual owners, thus, consuming their own electricity, and playing a facilitating and supportive role in driving the energy transition (Krumm et al., 2022; Trutnevyte et al., 2019).

"*Prosumerism*" is the concept that refers to the act of citizens investing in energy infrastructure that will transform them from simple consumers of energy to producers and self-consumers of energy (or as the term has been established in the relevant literature the past decade, "*prosumers*") through small-scale RES technologies installed in their residence, being able to provide flexibility to the grid by adjusting their consumption patterns (Kühnbach et al., 2022).

Considering the EU's strategic visions towards climate neutrality by 2050, solar PV systems have been considered a viable substitute for conventional energy sources (Koumparou et al., 2017). In this context, PV self-consumption is becoming extremely important, especially in the residential sector, where consumers take the role of prosumers, producing and consuming energy at the local (household) level. Typically, self-consumption encompasses the adoption and further diffusion of a wide range of technologies and systems such as small-scale PV, battery storage, and smart-grid devices, which bring demand flexibility into the market.

[10] https://www.mapchart.net/

A growing number of recent studies in the literature, though, have been assessing PV self-consumption and its economics, focusing on systems that only use PV or on PV systems coupled with battery energy storage systems (Stavrakas et al., 2019a). The findings show that if PV self-consumption at the residential level becomes economically competitive soon, citizens will be willing to self-consume electricity instead of buying it from the grid. Such a massive and radical change could impact national power systems around the world, especially if the necessary regulatory framework is not in place and influence the interests of the electricity market stakeholders (Yu, 2018).

In addition, regulatory and financial challenges related to the need for novel market business models and supporting mechanisms are the main obstacles to the sustained exponential growth of PV technology (Michas et al., 2019a). Therefore, policymakers should focus on an optimal mix of PV power and other RES technologies; they should also anticipate the risks and uncertainties related to further PV adoption.

Considering all the above, under the ENCLUDE "*Power to the People*" storyline, and in the context of the modeling work presented in this report, we intend to explore transition pathways based on the concept of prosumerism through the further citizen adoption of small-scale PV systems in the residential sector of five (5) different Member States of different geographical and climate conditions and of diverse socioeconomic contexts.

Since the scale of our analysis is the local level, we selected different cities to analyze transition pathways at the household level and explore the economic viability and the decarbonization potential of prosumerism under different potential evolutions of the future, i.e., the three (3) ENCLUDE "*future-world*" narratives. Below we provide a short policy background of prosumerism in the five (5) selected countries' residential sector.

Denmark

Denmark stands out as a pioneering Member State in the integration of RES within its power sector. A staggering 57.72% of Denmark's electricity generation is derived by wind energy, showcasing the nation's remarkable commitment to harnessing this abundant and clean energy resource (Rövekamp et al., 2021; Statista, 2024a). Additionally, approximately 20.58% of the remaining electricity generation is attributed to bioenergy, further underscoring Denmark's diversified approach to renewable energy utilization (Statista, 2024a).

Despite its impressive achievements in wind energy, Denmark's adoption of solar energy remains in a nascent stage since solar energy contributes only with 9.28% in the power generation at the national level (Statista, 2024a). With a per capita solar energy generation of 340 kWh (Our World In Data, 2024a), Denmark currently ranks twelfth (12th) among the 27 Member States in this regard.

In the residential sector, the total capacity of small-scale solar PV systems grew significantly from 39 MW to 526 MW with the most recent available relevant data spanning from 2012 to 2018 (IEA, 2018). While Denmark leads the EU in wind energy per capita with 3,218 kWh (Our World In Data, 2024b), there is significant room for growth and development in the solar energy sector. This presents an opportunity for Denmark to further diversify its renewable energy portfolio and strengthen its position as a global leader in sustainable energy transition.

Hence, with regards to the potential role that the Danish residential sector could play towards the climate visions at the national level, it is useful to make a deeper dive in the decentralization potential at the local level through the utilization of small-scale solar PV systems (Hansen et al., 2022).

Denmark aims to promote the integration of solar energy in the residential sector mainly through net metering, while prosumers are able to choose also to be remunerated through a feed-in tariff policy scheme but with a significant low fixed price of around 62 €/MWh (compared to the amount that citizens are called to pay for the electricity consumption- around 381 €/MWh including taxes, according to Country Economy (2024a)), applicable for ten (10) years after the connection with the grid (Wikberg, 2019).

It is noteworthy that Denmark aims to gradually abolish this fixed price remuneration scheme and keep net metering as the main solar energy supporting policy scheme through the application of the legislative framework "BEK no. 999 of 29/06/2016", which allows every electricity production technology to participate in the net metering policy scheme, apart from geothermal (Danish Government Gazette, 2016). All residential solar PV installations (under or equal to 10 kW_p) are exempted from the obligation to pay the so-called Public Service Obligation tariff, while from 2012 and onwards the netting period changed from annual-based to hourly-based (Hansen et al., 2022; Wikberg, 2019; Ziras et al., 2021). Finally, according to Ziras et al. (2021), the application of a supportive hourly-based net metering policy scheme in Denmark led from 2010 up to now, an important tax relief of Danish citizens.

France

In contrast with the other case studies of this deliverable, France is the leader globally in the share of nuclear power in the electricity generation with 63.29% (Ritchie & Rosado, 2020) and has the second (2^{nd}) largest nuclear installed capacity in the world with 61.37 GW after the United States (Pata & Samour, 2022). However, France is in a growing stage yet in terms of solar energy with only 310 kWh of solar energy per capita which ranks France fourteenth (14^{th}) among Member States, despite the high potential it has for the integration of solar energy in the power sector.

More specifically, according to a relevant research conducted by Bódis et al. (2019), France could be able to cover around 28.5% of its final electricity consumption (around 441 TWh) with 125.58 TWh produced by solar PV, if rooftop solar PV systems were to be installed in every rooftop available area in the country (estimated around 1,346 km^2), and moreover, in an economically feasible way, since it is estimated that around 88.5 TWh from this potential electricity production would have Levelized Cost of Electricity (LCOE)[11] in the range of 0.06-0.12 €/kWh (the rest 37 TWh would have LCOE in the range of 0.12-0.15 €/kWh).

It is worthy to mention that numerous studies indicate that, although nuclear power is considered as a "clean" technology, it involves serious environmental and security risks (Ayoub & Sornette, 2023; Lamnatou et al., 2024; Zeraibi et al., 2023). Furthermore, in the context of harmonization with the European Green Deal, France will have to improve its RES penetration in the power generation mix since only around 28.5% of the electricity production comes from RES (Statista, 2024c).

In this regard, prosumerism in the residential sector could play a prominent role for the further penetration of solar energy in the energy mix of France. According to the most recent available data, the installed capacity of residential solar PV installations is estimated around 1,800 MW (IEA, 2022); France aims to promote the diffusion of small-scale solar PV installations in the residential sector mainly through the application of a feed-in tariff (FiT) scheme according to "Art. 14/Order of May 9 for solar/2017" with a contract duration of 20 years (French Government Gazette, 2017). Today (2024), the fixed price based on which prosumers are able to be remunerated is equal to 147.4 €/MWh (Bellini, 2024). It is noted that net metering is not allowed in France (Fröding & Gasne, 2024; Oriol, 2018).

Greece

Located in Southern Europe, Greece is a transcontinental country, strategically located at the crossroads of Europe, Asia, and Africa, with a diverse geographical landscape and a large potential in RES (i.e., high solar irradiation levels), which makes it an attractive market choice for both small-scale PV owners and suppliers (Michas et al., 2020). Furthermore, due to its numerous islands, electricity interconnection of the islands with the mainland in Greece remains a continuous challenge, with the non-interconnected islands depending mainly on conventional generation units. As a result, Greece makes a reasonable selection for a decarbonized vision of a power sector, that relies also on decentralized generation and storage.

[11] Levelized Cost of Electricity (LCOE) is an economic measure used to compare the lifetime costs of generating electricity across various generation technologies.

More specifically, the average Global Horizontal Irradiation (GHI) of Greece is around 1,639 kWh/m^2 (on an annual basis) which ranks Greece in the third (3rd) position among Member States (according to data retrieved by Global Solar Atlas (*Global Solar Atlas*, 2024)). Greece used to traditionally depend on lignite for power generation (IEA, 2023; Karamaneas et al., 2023) up to now where natural gas contributes with 31.73% in the electricity generation of the country (Statista, 2024b), while despite its abundant solar potential, Greece has not utilized the full potential of solar power integration (Chatzisideris et al., 2017) since solar energy contributes with only 18.93% in total power generation at the national level (Statista, 2024b).

It is noteworthy that if rooftop solar PVs would be installed in every available rooftop area (estimated around 128 km^2), around 17 TWh could be generated on an annual base, which means that almost 32% of the final electricity consumption (around 53.46 TWh/year) could be covered by small-scale solar PV systems (Bódis et al., 2019). The latter highlight the significant potential for Greece to leverage its enormous solar resources and significantly enhance its contribution to RES, thus making progress towards a more sustainable and resilient energy landscape in the context of the concept of energy citizenship.

Up to now, according to the most recent official available data, Greece's rooftop solar PV installed capacity (under or equal to 10 kW_p) is around 352 MW (DAPEEP SA, 2022). The largest rooftop solar PV adoption was achieved from 2009 to 2013 when the most generous FiT policy scheme was operational with the fixed price ranged from 450 €/MWh in 2009 to 294 €/MWh in 2013 (Kërçi et al., 2022; Stavrakas & Flamos, 2022).

Today (2024), prosumers in Greece are able to choose how they will be remunerated between a FiT policy scheme with a fixed price equal to 87€/MWh according to "Article 4/L.4414/2016.A'149", and a net metering policy scheme without remuneration for prosumers according to "Law 5037/2023.OFG 78/28.03.2023" with a four-month netting period (Greek Government Gazette, 2016) (Greek Government Gazette, 2023). It is noted that the final settlement takes place after nine (9) four-month periods and any excess energy that has not been remunerated until then is cleared.

Portugal

Portugal is located in Southern Europe, more specifically in the Iberian Peninsula. According to data retrieved by Global Solar Atlas, Portugal has an abundant solar potential with an average GHI equal to 1,551 kWh/m^2 annually, which ranks it fifth (5th) among the Member States (*Global Solar Atlas*, 2024).

Moreover, according to Bódis et al. (2019), who conducted research for geospatial assessment of rooftop solar PV potential among the Member States, Portugal has a significant technical potential of 24,26 TWh/year if solar PV systems would be installed in every available rooftop area (for Portugal is estimated around 170 km^2). This technical potential could be able to cover 52.3% of the electricity consumption at a national scale and in an economically feasible way since all the electricity that could be generated would have a LCOE in the range of 0.06-0.12 €/kWh (Bódis et al., 2019).

However, Portugal is in a nascent stage yet about the deployment of solar PV systems. Its energy mix of the power sector is mainly based on fossil fuels since 40.42% of the electricity production comes from natural gas, oil, and coal, with natural gas being a dominator in the energy mix since it contributes with 37.14% to the electricity production (3.15% for oil, and 0.13% for coal), according to data retrieved from Our World In Data (2024).

Furthermore, the main renewable energy source for power generation of Portugal is wind energy. Wind energy contributes with 28.3% to power generation, ranking Portugal seventh (7th) among Member States in terms of electricity produced by wind energy per capita with 1,293 kWh per capita (Our World In Data, 2024b). The third (3rd) largest energy source for the electricity production of Portugal is hydropower with 16.17% and then bioenergy follows with 8.23%.

As a result, it becomes obvious that Portugal has not taken advantage of its solar potential since solar energy contributes only with 6.5% to the power generation which ranks Portugal fifteenth (15th) among

Member States, far from the average electricity generation from solar energy per capita in the EU. More accurately, the electricity generation from solar energy per capita of Portugal is 297 kWh per capita, while the average in the EU is 463 kWh per capita (Our World In Data, 2024a).

Finally, Portugal aims to promote rooftop solar PV installations through a net billing policy scheme after the abolition of the previous FiT policy scheme in 2022. According to Climate Action Network (2024), the legislation applicable in Portugal for rooftop solar PV installations is Decree-Law 15/2022, which defines that excess of electricity generation from the PV system is sold at the wholesale market price, which wholesale market price is announced on a daily basis by OMIE (the nominated electricity market operator for managing the Iberian Peninsula countries' day-ahead and intraday electricity market (Portuguese Government Gazette, 2022; Climate Action Network, 2024b)).

Spain

Bordering on Portugal, Spain is another Member State located in the Iberian Peninsula of Southern Europe. Similar to Greece and Portugal, Spain has also a significant solar potential with an average annual GHI equal to 1,588 kWh/m^2.

This potential ranks Spain on the fourth (4th) position among Member States (between Greece and Portugal). According to Bódis et al. (2019), Spain has also a very high technical potential which is resulting through its rooftop available area, as well as through its abovementioned solar potential. More specifically, Spain's technical potential for electricity production through the utilization of rooftop solar PV systems is equal to 65.24 TWh/year with rooftop available area estimated to be equal to 462 km^2.

This technical potential could be able to cover approximately 28% of the total electricity consumption, and moreover, around 55 TWh from the 65.24 TWh could be produced in an economically effective way with a LCOE spanned from 0.06 €/kWh to 0.12 €/kWh, while the rest electricity (around 10 TWh) would be produced with LCOE ranged from 0.12 €/kWh to 0.18 €/kWh (Bódis et al., 2019).

Spain is one of the leaders in solar PV deployment since it is ranked third (3rd) among Member States in terms of electricity generation from solar energy per capita with 690 kWh per capita (behind from Netherlands and Germany), according to Our World In Data (2024a). However, even if Spain is ranked third in this metric, when diving into the energy mix of the power generation in Spain, we notice that solar energy is ranked fourth among the energy sources for power generation since solar energy contributes with 11.51% to the electricity production (Our World In Data, 2024d).

Spain's energy mix of power generation is mainly based on natural gas since it contributes with 30.56% to the power generation, and after natural gas, wind, and nuclear energy come after with 21.71% and 20.53%, respectively. Hydropower, oil, coal, and bioenergy follow after solar energy with a contribution equal to 6.59%, 4.04%, 2.67%, and 2.39%, respectively, according to data retrieved from Our World In Data (2024d).

Lastly, through the implementation of the Royal Decree 244/2019 legislation introduced in 2019, prosumers in Spain can be remunerated through a net billing policy scheme, which compensates them for the excess electricity they inject into the grid according to the wholesale electricity price retrieved from OMIE, similar to the case of Portugal (Spanish Government Gazette, 2019). This legislation was a radical change compared to former policy schemes since now in Spain surpluses are compensated, but they do not include any type of FiT or feed-in premium. Moreover, the incentives framework for collective self-consumption in Spain is quite favorable with no grid fees or taxes attached to it.

Additionally, in November 2023, the Spanish government approved an addition of €500 million to encourage new self-consumption facilities through the Recovery, Transformation, and Resilience Plan (Climate Action Network, 2024a).

Based on the case study specifications and the ENCLUDE scenario typology, we ask the following Research Questions (RQs):

***RQ*$_{1.1}$**	*"Can a people-powered transition based on citizen investments in small-scale PV systems support the transition to climate neutrality by 2050 in the European Union's residential sector?"*
***RQ*$_{1.2}$**	*"What is the emission reduction (decarbonization) potential of different transition pathways under a "Power to the People" storyline at the local level across different Member States?"*
***RQ*$_{1.3}$**	*"What are the potential benefits of prosumerism for European Union's citizens under different potential evolutions of the future?"*

6.1.2. *"Band Together" in Collective Energy Initiatives (CEIs)*

In the context of the EU's transition to a future greener energy system and achieving the vision of climate neutrality by 2050, CEIs as an important collective expression of the concept of energy citizenship are expected to play a vital role. Over the past few years, more and more CEIs and other relevant cooperatives have come to the surface.

The three (3) case studies selected in the context of the "*Band Together*" storyline to be analyzed with the use of the ANIMO modeling framework are: (i). the "*Cloughjordan Ecovillage*" in Ireland, (ii). the "*EnergieC Midden-Delfland*" in the Netherlands, and (iii). the "*Belica Energy Community*" in North Macedonia. These cases were chosen following discussions with colleagues from and based on the "on-the-ground" work conducted as part of WP3, considering their richness in data and comprehensive documentation.

In this context thus, a well-established CEI is the "Cloughjordan Ecovillage" in Ireland, the village with the lowest carbon footprint in Ireland (*Cloughjordan Ecovillage*, 2023). When it comes to energy transition advancements, Ireland is a pioneer country in the EU since it is second in wind energy use, after Denmark (Wind Europe, 2022). However, in terms of solar energy, Ireland is not in a leading position, being 26th in the EU's solar PV installed capacity per capita ranking (*Statista*, 2022).

However, Cloughjordan Ecovillage is one of the few pioneers of solar energy in Ireland, since there are 500 m^2 of solar PV panels installed in the village (Kennedy & Buckley, 2021), which showcases the potential that Ireland could also embody in the field of solar energy. The latter makes initiatives like the Cloughjordan Ecovillage an excellent case study, when it comes to the "Band Together" storyline.

On the other hand, contrary to Ireland, Netherlands is a leading country in the field of solar energy and the first EU's solar PV installed capacity per capita ranking country, with (*Solar Power Europe*, 2023), with more than 1.044 kW/cap of solar PV installed capacity per capita. In this context, initiatives like the "EnergieC Midden-Delfland" energy cooperative, a CEI that paves the way for a green transition in the Midden-Delfland municipality and in the Netherlands as a whole, can support the further diffusion of such collective expressions of energy citizenship.

The "EnergieC Midden-Delfland" energy community aims to make the Midden-Delfland municipality a sustainable energy producer (Energie C Midden-Delfland, 2023), and thus it serves as another excellent case study to apply our ANIMO modeling framework.

Finally, the "Belica Energy Community" in North Macedonia is a case of a CEI still at the very early stages of maturity (the project was expected to be operational by end of 2023), although relevant stakeholders and representatives from the local community consider this case as an emerging one, serving as the first CEI in North Macedonia.

The cooperative has recently joined the "European federation of citizen energy cooperatives REScoop.eu[12]", while local actors are very eager to learn and replicate successful practices of growth to

[12] https://www.rescoop.eu/network/all/sun

make the "Belica Energy Community" a successful CEI project, as it could lay the foundations for more similar projects in North Macedonia and in the Balkan area.

Overall, our selection of CEI case studies comprises of: a well-established ecovillage structure with high potential in solar energy in a Member State that is an EU pioneer in wind energy, but is behind when it comes to solar energy; a well-established energy community structure which strives to make the local municipality autonomous and turn it into a sustainable energy producer in a Member State that is an EU pioneer when it comes to solar energy; and an emerging energy community structure with high potential, but still at early stages of implementation, in a country which is not yet an EU member state, but could serve as a pioneer of CEIs in the Balkan area.

"Cloughjordan Ecovillage" (Ireland)

The "*Cloughjordan Ecovillage*" was founded in 1999, through the establishment of a registered educational charity and national non-governmental organization of the Irish Environmental Network, Sustainable Projects Irelands Ltd (Muzzarelli et al., 2023). Cloughjordan Ecovillage's official purpose statement gives the description stating (Muzzarelli et al., 2023): "*Cloughjordan Ecovillage is a response to the greatest challenges facing humanity today: the growing impact of human activity on the planet and how its people live and work together. The deeper purpose of the Ecovillage is to create a living example of a healthy and harmonious future while treading more lightly on Planet Earth*".

This initiative aims to promote sustainable and innovative living through eco-friendly manners in different activities like energy consumption, heating, and crop production. The main target of the "Cloughjordan Ecovillage" is to create a community that could live side by side with nature in a sustainable and environmental-friendly way.

The "Cloughjordan Ecovillage" counts around 130 residents living in more than 50 buildings in the village, which are considered as "low energy consumption" buildings (Kress et al., 2023; Muzzarelli et al., 2023). Concerning the heating system, the ecovillage has a district heating system that is fueled by biomass, contributing to make it the village with the lowest ecological footprint in Ireland (Kirby, 2020).

In terms of energy production, the residents of the village have also the opportunity to produce their own electricity since 500 m^2 of solar PV systems have already been installed (Kress et al., 2023). The residents of the village are also land workers since there are almost 200,000 m^2 (50 acres) available for allotments, woodland, and farming. Finally, the "Cloughjordan Ecovillage" promotes the so called "voluntourism" since tourists from all over the world can be accommodated in the eco-friendly hotels of the village and simultaneously perform volunteering activities (Kress et al., 2023).

"EnergieC Midden-Delfland" energy community (Netherlands)

The "EnergieC Midden-Delfland" energy cooperative in the Netherlands aims to become climate neutral by producing sustainable energy that will be shared fairly between all the members of the local community. The population of the Midden-Delfland municipality is around 19,500 inhabitants and the municipality covers an area of 47.19 km^2 (*StatLine*, 2020). Midden-Delfland calls all the residents to be part of this transition by financing a project through crowdfunding, and more specifically, through the purchase of solar panels' parts. The idea back from this, is to return back part of the profit from the electricity generated from the project to the participants.

More specifically, the energy cooperative receives a subsidy from RVO (Netherlands Enterprise Agency) and this subsidy is paid to participants based on the number of solar panels installed on the buildings of the Midden-Delfland municipality (Energie C Midden-Delfland, 2023). Until today, the number of the energy cooperative members is 122 (0.63% of the total municipality population) (Energie C Midden-Delfland, 2023).

Another key activity of the cooperative is consultation to increase energy savings through local energy coaching. The project aims to reduce energy consumption in the Midden-Delfland municipality households without downgrading their living standards. Other projects have also been completed in the Midden-Delfland municipality of which include the total cover of four (4) roofs with a total installed capacity of 200 kW_p of solar PV system. The projects yielded 162,300 kWh of electricity in 2022 with 5,282 solar parts sold (Energie C Midden-Delfland, 2023).

The amount of electricity generated by the projects can effectively cover the energy consumption of 56 households in the municipality. Last but not least, another project has recently begun aiming to make the municipality natural gas free, which is also a key target at the national level (Energie C Midden-Delfland, 2023).

"Belica Energy Community" (North Macedonia)

The Belica village is located at the Kicevo municipality in the southwestern region in North Macedonia. Contrary to the cases of the "Cloughjordan Ecovillage" and the "EnergieC Midden-Delfland", the "Belica" cooperative is not considered a fully developed energy community structure yet. More specifically, the main objective of the initiative is to become the first energy community in North Macedonia. In a demographic context, according to the most recent data (a census that took place in 2021), the population of the village is 54 inhabitants, while 31 of them are overaged (+65 years old). Belica covers an area of 31.07 km^2 (*City Population Official Webpage*, 2023).

According to estimations (not official data) and based on local representatives' feedback during an on the ground visit of the village by the ENCLUDE consortium, there are around 100 households in the village, with only 10-20 of them been used on a daily basis (most of them are being used during weekends and in the summer season.

In terms of energy consumption, the residents of the village use biomass (wood) as a fuel for heating. It is noteworthy that a solar PV installation project is currently in process. The project will have 20 kW_p installed capacity and it will be installed on a community building of the village (a former school that is now being used as a social and educational center). As a result, when the project is completed, the installed capacity of solar PV per capita in the village will be 0.37 kW/cap.

The system is about to be operational by the end of 2023. Nevertheless, even if the target is to spread more solar PV systems on the village households' roofs, the expansion plans are at a very early stage up to this point.

Based on the case study specifications and the ENCLUDE scenario typology, we ask the following RQs:

RQ *2.1*	"*How can social and grassroot innovations, like Collective Energy Initiatives (CEIs), around Europe be further diffused and grow in the context of the short-term energy transition by 2030?*"
RQ *2.2*	"*What are the key driving factors that could support the further growth of social and grassroot innovations, like Collective Energy Initiatives (CEIs), in Europe by 2030?*"
RQ *2.3*	"*What is the emission reduction (decarbonization) potential of different transition pathways under "Band Together" storylines around Europe under different potential future evolutions?*"

6.1.3. *"Power to the People" and "Habitual Creatures" storylines towards just and inclusive transitions*

The energy transformation processes at the local and the regional level as supported by the EU's strategic visions and respective national policies have created a window of opportunity for the reconfiguration of Coal and Carbon Intensive Regions (CCIRs) in a way that can be aligned with sustainable development goals. Such municipalities and regions have in recent decades been affected by an array of negative trends, regarding loss of local jobs, population ageing, migration, lack of services as well as poor environmental quality conditions.

In these socially complex contexts, systemic inertia, aversion to change and immobilism has often been paramount. To overcome this, several factors that have to do with realizing the multiple dimensions that affect deliberate and fast change need to be taken into account. These have to do not only with injecting structural funds to trigger technology innovations, but also with many other more intangible, cultural, and perceptual dimensions related with the collective construction of meaning and action and that affect the willingness and the capacities of different local agents and communities to collaborate actively in transformative governance processes.

Harmonized policies need to consider all these cultural, identity, inequality and perceptual dimensions in order to foster the potential of local populations to contribute to systemic change in their own terms, which may eventually be expressed in more diversified, inclusive, and resilient transition pathways. Early gains in justice at the local and the regional level can create the necessary transformative conditions for achieving positive tipping points at larger scales and may also help to trigger chains of positive changes in other municipalities and regions.

Addressing inequalities and providing early mutual gains derived from tackling climate crisis are likely to help local and regional authorities to support climate and energy policies, and function as demonstrators for other municipalities and regions, showing that just and inclusive transformations are not only possible but desirable.

Such a CCIR case of interest at the local level in Greece is the municipality of Megalopolis (Area: 722.6 km^2, Population (2021): 8,791) (Hellenic Statistical Authority, 2022). Megalopolis retained a rural character until 1970, while since then, the Public Power Corporation started lignite exploitation in the Megalopolis deposit, making lignite mining and lignite-based power generation the dominant activities in the area, employing a remarkable percentage of the local workforce.

In 2019, with the publication of the first version of the Greek National Energy and Climate Plan (NECP), the gradual phase out of lignite for power generation was put in place, setting the dates for the decommissioning of all existing lignite power plants in Greece by 2023. Megalopolis is one of the directly and heavily affected areas since three (3) power plants have already been shut down, one (1) plant was planned for shut down by 2023 (unofficially extended to 2025), and only one (1) power plant will keep operating with natural gas (Ministry of the Environment and Energy, 2019).

However, the current transition plan of Megalopolis seems to be heading towards a new fossil fuel lock-in. While the region phases out lignite, natural gas is used for (i). power generation, and (ii). direct supply to households for space heating, through the already existing district heating network.

According to the existing national Just Transition Development Plan for post-lignite development, a gas distribution network is under construction in the Megalopolis municipality, while its residents will be exempted from connection fees. Furthermore, the cost of replacing existing heating boilers and relevant equipment with natural gas ones will be subsidized (Ministry of the Environment and Energy, 2022).

However, due to the latest developments and amid an energy price crisis, the existing plan for the energy transition in the Megalopolis' residential sector may need to be revised, as the decision to invest in natural gas infrastructure could cause a lock-in effect (negative tipping point), exposing households to high energy costs and potential gas shortages for the next decades.

This comes in line with scientific literature, which mentions that the further expansion of natural gas infrastructure and consumption exacerbates infrastructural and institutional lock in effects, which can decelerate the energy transition, causing stranded assets and detainments in renewable energy and energy efficiency investments, entailed by harmful environmental and economic consequences (Kemfert et al., 2022).

The greatest challenge concerning the transition seems to be its timing, as the transformation of the Megalopolis municipality, from a largely lignite-based economy to a more diversified and sustainable one cannot apparently be accomplished by 2028, when the withdrawal of the lignite units will be completed (The Green Tank, 2020).

Based on the feedback we received during our interactions with local stakeholders, a post-lignite development trajectory includes several opportunities for a just and inclusive transition, such as the establishment of RES projects, tourism development (e.g., an international motocross ring, rafting, etc.), alternative forms of agriculture, the reconstruction of museums and educational institutions, the optimization of the road network, and the construction of a business park to host the industries that plan to relocate.

Furthermore, stakeholders stated that establishing a secure, concrete legal and licensing framework for RES, while providing a low-risk environment, are significant steps toward ensuring an appealing environment for investments and that PV parks could be built by local small businesses to create job opportunities. Experts also emphasized the importance of energy efficiency, and the need to emphasize in the Just Transition Master Plan the upgrading of the energy performance of existing buildings. They stated that the NECP should be updated accordingly, and that natural gas will most likely not be eligible for grants as a building heating option, emphasizing the importance of prioritizing energy efficiency investments.

During the discussion, experts also mentioned existing proposals for developing energy communities while providing special tax exemptions to attract foreign investments. In this regard, they stated that optimizing energy consumption by forming energy communities could solve the problem of building heating and suggested that each affected municipality forms an energy community to provide cheap or even free green power to those in the region suffering from energy poverty.

However, part of these strategic visions of local stakeholders towards a green transition in Megalopolis will only be developed if citizens are willing to invest in the technological capabilities required. Before citizens decide to proceed with investing in energy efficiency and/ or RES, they need to be aware of the both the economic and the environmental value stemming their investments, as it is unlikely to invest in new technological capabilities having only environmental or other ancillary benefits for the energy system, e.g., demand-flexibility, grid stabilization, as their primary goals.

Thus, while technological infrastructure is already in place, exploratory analyses focusing on new and innovative business models and legal frameworks are required to maximize the value of the technological capabilities required to inform and convince citizens of the potential benefits.

In the context of the expected increasingly participatory role of citizens and other societal actors in the combat against the climate crisis, driving changes in the energy system at both the demand and the supply side, in this case study we use the DREEM model to analyze an *alternative "green" rebranding of Megalopolis into a city OF the people, BY the people, FOR the People*.

Based on the case study specifications and the ENCLUDE scenario typology, we ask the following RQs:

***RQ*$_{3.1}$**	"*Can a citizen-led transition based on energy efficiency investments and lifestyle and behavioral changes lead to a just and inclusive transition in the municipality of Megalopolis?*"
***RQ*$_{3.2}$**	"*What is the emission reduction (decarbonization) potential of different transition pathways under a combined "Power to the People" and "Habitual Creatures" storyline at the municipality level?*"
***RQ*$_{3.3}$**	"*What is the post-lignite development trajectory and the potential benefits of a people-powered transition that does not rely on traditional fossil fuels in a European Coal and Carbon Intensive Region?*"

6.2. Scenario design and transition pathways

In this segment, we delve into the specification process for the case studies described in the preceding chapters. This entails a meticulous exploration of the specific steps taken to define and quantify the variables involved in each case study, shedding light on the numerical parameters and assumptions that form the basis of the analytical approach that was followed.

Based on the case studies' specifications, as presented in **Section 6.1**, we employ the ENCLUDE scenario space framework to showcase its applicability to three (3) different model applications looking into diverse RQs, such as the potential benefits of prosumerism, the drivers that could support the further growth of social and grassroot innovations, the decarbonization potential of different transition pathways, etc.

This ultimately allows us to create three (3) different scenario spaces consisting of transition matrices with the evolution of different exogenous variables, e.g., emission factors, evolution of relevant energy prices and costs, technological costs and relevant updated configurations, benefits for citizens and/ or other power actors involved, according to the ENCLUDE scenario space.

Overall, our aim is to offer transparency and clarity regarding the methodologies employed, ensuring a robust foundation for the subsequent analyses and conclusions drawn from the case studies.

6.2.1. "Power to the People" through empowering prosumerism

"People-centered" storylines

Denmark

The modeling analysis for Denmark is conducted for two (2) cities, one in the North and one in the South; Aalborg and Copenhagen, respectively. The reference building in both cities represents a single-family house, constructed between 1973 and 1978, while the reference floor area is 117 m^2.

We apply the DREEM model to assess the potential benefits of a 3kW_p solar PV installation on the rooftop of the reference buildings under the two (2) available policy schemes for prosumers:

a. net metering with no direct remuneration, and

b. FiT with a fixed price for the remuneration of the prosumers, equal to 62 € per MWh (Wikberg, 2019).

France

The modeling analysis for France is conducted for two (2) cities, one in the South and one in the North; Marseille and Paris, respectively. The reference building in both cities represents a single-family house, constructed between 1975 and 1981, while the reference floor area is 130 m^2.

Since in France, a net metering policy scheme is not allowed (Fröding & Gasne, 2024; Oriol, 2018), we apply the DREEM model to assess the potential benefits of a 3kW_p solar PV installation on the rooftop of the reference buildings under the existing FiT scheme, with a fixed average price for the remuneration, equal to 62 € per MWh (Bellini, 2024).

Greece

The modeling analysis for Greece is conducted for two (2) cities, one in the South and one in the North; Athens and Thessaloniki, respectively. The reference building in both cities represents a single-family house, constructed before 1980, while the reference floor area is 162 m^2 for Athens and 187 m^2 for Thessaloniki.

We apply the DREEM model to assess the potential benefits of a 3kW_p solar PV installation on the rooftop of the reference buildings under the two (2) existing available policy schemes for prosumers:

a. net metering with no direct remuneration, and

b. FiT with a fixed price for the remuneration of the prosumers, equal to 87 € per MWh according to Article 4/L.4414/2016.A'149.

Portugal

The modeling analysis for Portugal is conducted for two (2) cities, one in the South and one in the North; Lisbon and Porto, respectively. The reference building in both cities represents a single-family house, constructed between 1960 and 1979, while the reference floor area is 131 m^2 for Lisbon and 145 m^2 for Porto.

We apply the DREEM model to assess the potential benefits of a 3kW_p solar PV installation on the rooftop of the reference buildings under the existing net billing scheme, in which the remuneration for the excess electricity fed into the grid is based on the wholesale market price, namely 72.15 €/MWh (Climate Action Network, 2024a).

Spain

The modeling analysis for Spain is conducted for three (3) cities, one in the North, one in the central part of the country and one in the South, Bilbao, Madrid, and Malaga, respectively. The reference building in all cities represents a single-family house, constructed between 1960 and 1979, while the reference floor area is 135 m^2 for Bilbao, 152 m^2 for Madrid, and 171 m^2 for Malaga, respectively.

We apply the DREEM model to assess the potential benefits of a 3kW_p solar PV installation on the rooftop of the reference buildings under the existing net billing scheme, in which the remuneration for the excess electricity fed into the grid is based on the wholesale market price, namely 72.17 €/MWh.

"Future-world" narratives

Future retail electricity prices and emission factors of electricity for the analyzed case study countries vary among the "*future-world*" narratives.

The 2024 values of the retail electricity price scenarios, which follow similar trends by 2050 are outlined in **Table 5**.

In the "*Familiar World*" narrative, future retail electricity prices for all the analyzed case studies are consistent with those *after the 2022 energy crisis*. In the "*Unified World*" narrative, future retail electricity prices for all the analyzed case studies are consistent with those *before the 2022 energy crisis*. In the "*Fragmented World*" narrative, future retail electricity prices for all the analyzed case studies are consistent with those *during the 2022 energy crisis*.

Table 5. 2024 values on the future evolution of prices following similar trends by 2050 for different Member States under the "*future-world*" narratives [Source: Country Economy (2024d, 2024c, 2024b, 2024a)].

	Retail electricity price (€/MWh)		
	"*Familiar World*"	"*Unified World*"	"*Fragmented World*"
Denmark	392.7	281.9	587.1
France	227.5	195.8	259.1
Greece	232.5	175.2	295.2
Portugal	255.8	213.3	298.3
Spain	282.4	229.8	335.0

In order to measure the economic benefits for prosumers, the Net Present Value (NPV), and the discounted payback period are calculated in **Section 7.1** for a 25-years life cycle investment, using the following equations:

$$NPV = -Capital\ Cost + \sum_{k=1}^{25} \frac{Cash\ Flow_k}{(1+i)^k}$$

$$Discounted\ Payback\ Period = Years\ Until\ Breakeven\ Point + \frac{Uncovered\ Amount}{Recovery\ Year\ Cash\ Flow}$$

The projections of the emission factors of electricity by 2050 are outlined in **Table 6**.

In the “*Familiar World*” narrative, future power sector emission factors for all the analyzed case studies evolve based on the current baseline for the power sector decarbonization in Europe. In the “*Unified World*” narrative, future power sector emission factors for all the analyzed case studies evolve based on a faster European power sector decarbonization trajectory compared to the baseline. In the “*Fragmented World*” narrative, future power sector emission factors for all the analyzed case studies evolve based on a slower European power sector decarbonization trajectory compared to the baseline.

Table 6. Projections of the emission factor of electricity until 2050 for different EU Member States for the “*future-world*” narratives. Source: European Commission (2020).

Emission factors of electricity ($kgCO_2/kWh$) - “*Familiar World*”					
Year	***Denmark***	***France***	***Greece***	***Portugal***	***Spain***
2024	0.0826	0.0386	0.2240	0.0780	0.0892
2050	0.0188	0.0281	0.0699	0.0066	0.0242
Emission factors of electricity ($tnCO_2/ktoe$) - “*Unified World*”					
Year	***Denmark***	***France***	***Greece***	***Portugal***	***Spain***
2024	0.0826	0.0386	0.2240	0.0780	0.0892
2050	0.0093	0.0140	0.0350	0.0033	0.0121
Emission factors of electricity ($tnCO_2/ktoe$) - “*Fragmented World*”					
Year	***Denmark***	***France***	***Greece***	***Portugal***	***Spain***
2024	0.0826	0.0386	0.2240	0.0780	0.0892
2050	0.0376	0.0561	0.1399	0.0132	0.0484

The ENCLUDE “*Power to the People*” scenario space

Considering the specifications of both the “people-centered” storylines and the “future-world” narratives, we develop the scenario space for the *“Power to the People”* storyline through empowering prosumerism (**Figure 19**).

The scenario space is split into two (2) parts, i.e., policy scheme specifications that pertain to the “*people-centered*” storyline and apply unchanged during all years of the analysis (i.e., until 2050), which are depicted in the upper part of the figure and contextual factor specifications that are consistent with the “*future-world*” narratives and vary by 2050, which are depicted in the lower part of the figure.

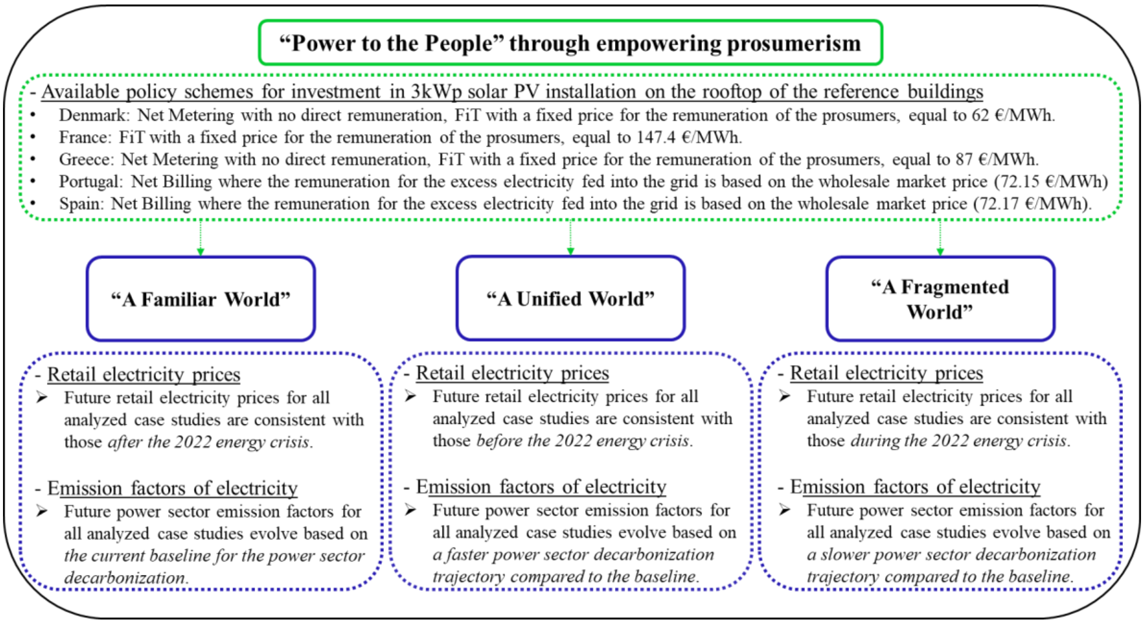


Figure 19. The ENCLUDE scenario space for the "*Power to the People*" storyline.

6.2.2. *"Band Together" in Collective Energy Initiatives (CEIs)*

"People-centered" storylines

In order to understand how citizen behavior and lifestyle is shaped within a community, a systematic process is followed, involving various steps that aim to realistically depict the development and growth of an energy community. The first step of our modeling analysis, thus, entails processing community-specific data that sheds light on crucial aspects of citizen behavior and lifestyle to eventually parameterize the ANIMO framework. The data on these energy communities was acquired through surveys conducted in the context of the ENCLUDE WP3 (Brenner-Fliesser et al., 2023).

Community members participated in these surveys, responded to a questionnaire that delved into both individual traits and collective aspects of life in the community. The questionnaire covered a wide range of topics, including participants' income and education levels, and aimed to gauge their attitudes and assess their knowledge related to environmental issues, transportation and lifestyle choices, their energy consumption, and preferred methods of house heating as well as their sense of connectedness with fellow community members.

To streamline the information, survey questions were categorized based on their influence on key attributes deemed significant in the decision-making process regarding participation to a CEI. These key "*character attributes*" have been integrated into the ANIMO model as *agent-related parameters*:

- **"*Financial concern*":** This parameter represents the worry that individuals experience regarding their financial well-being. It can motivate individuals to join collective energy initiatives that offer opportunities for cost savings but is also a metric of their risk aversion.
- **"*Environmental awareness*":** This parameter refers to the levels of awareness and interest that individuals have on environmental issues. Individuals with such concerns are often motivated to join a collective citizen initiative that addresses environmental challenges.
- **"*Energy independence*":** This parameter reflects the willingness of individuals to be self-sufficient when it comes to their energy needs and to be independent from the traditional power grid.
- **"*Sense of community*":** This parameter describes the feeling of belonging and connectedness among individuals. A strong sense of community is considered to influence individuals' willingness to join a collective energy initiative.

To enhance precision, irrelevant survey questions were discarded, ensuring that the subsequent analysis is focused on relevant aspects. Table 7 presents list of the survey questions that were incorporated into the parameterization of the ANIMO framework (Brenner-Fliesser et al., 2023).

Table 7. Survey questions used for the parameterization of the agent-related parameters in ANIMO in the context of the three (3) case studies selected under the "*Band Together*" storyline.

a/a	Question	Agent-related parameter
1	"*How would you describe your household income in comparison with average households in your country?*"	"Financial concern"
2	"*Have you ever had difficulties paying your bills for heating or electricity?*"	"Financial concern"
3	"*During the last winter, did you perceive your home as comfortable in terms of temperature?*"	"Financial concern"
4	"*During the last summer, did you perceive your home as comfortable in terms of temperature?*"	"Financial concern"
5	"*Which of the following is your highest level of education?*"	"Environmental concern"
6	"*Having a car is simply part of being an adult.*"	"Environmental concern"
7	"*Electric cars are no real alternative to fossil fueled cars.*"	"Environmental concern"
8	"*Public transport is no real alternative to driving your own car.*"	"Environmental concern"
9	"*Heating with fossil fuels is a good energy solution.*"	"Environmental concern"
10	"*I have the impression that most people in my neighborhood already take action against climate change.*"	"Environmental concern"
11	"*Investing in energy efficiency is beneficial for my household.*"	"Environmental concern"
12	"*Improving living conditions (e.g., thermal comfort) is as important for me as reducing energy consumption and bills.*"	"Environmental concern"
13	"*A vegetarian or vegan diet is sufficient for humans to have good health.*"	"Environmental concern"
14	"*Eating less meat would have a positive impact on the environment.*"	"Environmental concern"
15	"*We are human, and it is natural for us to eat meat every day.*"	"Environmental concern"
16	"*Which do you think are the causes of the rising world temperature?*"	"Environmental concern"
17	"*I'd rather depend on myself than others.*"	"Energy independence"
18	"*I rarely rely on others.*"	"Energy independence"
19	"*A reliable supply of electricity to private households can only be provided by companies.*"	"Energy independence"
20	"*I often do "my own thing".*"	"Sense of community"
21	"*It is important that I do my job better than others.*"	"Sense of community"
22	"*Winning is everything.*"	"Sense of community"
23	"*Competition is the law of nature.*"	"Sense of community"

24	“*If a co-worker would get a prize, I would feel proud.*”	“Sense of community”
25	“*The well-being of my co-workers is important to me.*”	“Sense of community”
26	“*To me, pleasure is spending time with others.*”	“Sense of community”
27	“*Parents and children must stay together as much as possible.*”	“Sense of community”
28	“*It is my duty to take care of my family, even when I have to sacrifice what I want.*”	“Sense of community”

Given that responses to the survey questionnaire were provided either in a tailored Likert scale or a multiple-choice method, questions were also categorized based on their Likert scale dimension, which was adapted differently depending on the question. Therefore, the classification distinguished between a five (5)-point, a three (3)-point, and a two (2)-point scale.

In order to assign numerical values to this process and to align this information with the requirements of the ANIMO framework, questions with Likert scales of the same dimension were scored similarly with certain weights. The weights’ values ranged from 0 to 1 with the number of increments in between being the same as the scale’s dimension. Then the number of responses for a given answer were multiplied by the respective answer's weight. This multiplication resulted in a score for each question, reflective of the significance and prevalence of each response.

To standardize these values, all the scores were then divided by the total number of participants or the number of total answers. This normalization process was essential for unbiased and meaningful comparisons. Following this, the average and standard deviation were calculated by grouping the scores of questions that share commonalities in terms of the agent-related parameters to which they correlate.

This step added depth to the interpretation of the data since it helped identify predominant values held by the community as a whole, which have a significant impact on agents’ behavior. Agents, just like society members, are influenced by the collective values and principles of the community, which in turn guides their actions and decision-making, simulating social influence phenomena.

This process also allowed for a visual representation through a four (4)-point radar chart (**Figure 20**), where each point corresponds to one of the specific agent parameters of the ANIMO model presented above. This chart provides a holistic view of the community's preferences and priorities as well as depicts the degree to which these attributes are prevalent within each community, offering a nuanced understanding of the key factors influencing each community members’ decision-making process.

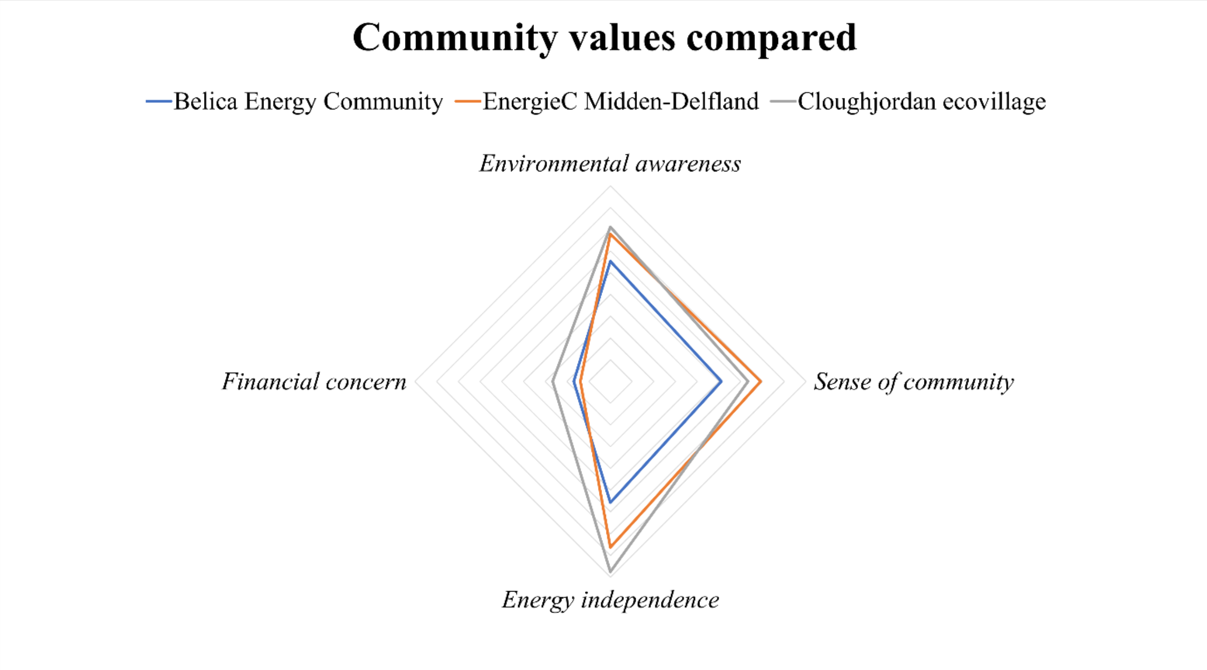


Figure 20. Radar chart depicting the prevalence of the agent-related parameters in each of the three (3) selected case studies, as extracted from the survey questionnaire.

Based on the previous steps and deriving from the scoring process, agents are parameterized by assigning values to the agent-related parameters. The assigning process is in accord with the statistical assessment of the community data completed in the previous phase. The varying distributions for each of the agent-related parameters translate into a plethora of different combinations of primary characteristics for each agent.

The characteristics incorporate various levels of *financial concerns*, *environmental awareness*, *desire for energy independence*, and *sense of community*, and as a result, agents are further categorized based on their primary motivations for joining and operating within a community. This led to the creation of "***Personas***" (archetypes) representing possible real-life incentives for participating to a CEI in the case of existing community members, as well as the reasoning behind the decision to join a CEI for prospective members.

This approach is in agreement with relevant scientific literature on human-computer interaction and human-centered design, in which a typical way to create models on users is the "*Persona method*", initially presented by Alan Cooper in the late 1990s (Cooper, 1999). The "Persona method" involves the creation of character descriptions that are realistic and based on user research. Personas are designed to represent the diversity of observed motivations, behaviors, and attitudes. Since its introduction, the use of the method has been relatively wide, including important adjustments to its original form.

Inspired by the work conducted under the ENCLUDE's sister project "GRETA[13]", in our case, and "*Personas*" are developed (**Table 8**) by emphasizing two (2) key agent-related parameters in each typology (project GRETA, 2023). These combinations offer a deeper understanding of individuals within the energy community, while also helping design solutions and communicate them to stakeholders. Each typology represents a unique perspective and therefore will allow for more targeted engagement and communication strategies based on the specific motivations and priorities of community members.

[13] https://projectgreta.eu/

Table 8. Personas/ Archetypes at the collective level for existing and potential members of collective energy initiatives, as developed based on the further analysis of the survey data to parameterize the ANIMO framework.

Personas/ Archetypes	**The "Eco-Conscious Savers"**	**The "Tech Trailblazers"**	**The "Self-Reliant Savers"**	**The "Security-Minded Sceptics"**	**The "Eco-Collaborators"**	**The "Green Guardians"**
"Financial concern"	*High*	-	*High*	*High*	-	-
"Environmental awareness"	*High*	-	-	-	*High*	*High*
"Energy independence"	-	*High*	*High*	-	-	*High*
"Sense of community"	-	*High*	-	*High*	*High*	-
Description	Environmentally conscious individuals that are financially savvy. Joining an energy community is a way to reduce their carbon footprint while also saving money on energy bills, or even generating income through participation in renewable energy production. Clear demonstrations of cost savings and potential financial benefits associated with RES can sway their decision.	Excited about the innovative aspects of an energy community, they value the potential for smart home integration and increased energy independence through community-managed systems. Additionally, they enjoy the sense of community and collaboration that comes with working towards shared goals.	Driven by a desire for self-sufficiency, these individuals prioritize both energy independence and financial savings. They are interested in reducing reliance on the traditional grid and potentially generating their own energy through community renewable sources. Lower energy bills and shared investment opportunities further incentivize them to join.	These individuals are drawn to the financial benefits offered by an energy community. They place value on a strong sense of community and trust the recommendations of neighbors who have already joined. Positive experiences shared within the community can convince them of the financial advantages and encourage them to adopt this innovative approach to energy management.	Community-oriented individuals that value collective action and believe it is essential for addressing climate change. The opportunity to contribute to a larger environmental movement alongside like-minded neighbors is a significant motivator. Additionally, they appreciate the community's focus on renewable energy sources, which aligns with their desire to reduce their environmental impact.	Environmentalists that prioritize both a sustainable lifestyle and achieving energy independence. They're deeply concerned about the impact of traditional energy production and actively seek ways to reduce their carbon footprint. In addition, on-site renewable energy generation and reduced reliance on the grid align perfectly with their desire for energy independence, empowering them to take control of their energy consumption.

Leveraging the questionnaire data from WP3 and fully utilizing it through the application of the ANIMO model, targeted outreach efforts, crucial for maximizing community adoption rates, can be prioritized. By identifying the core motivations of potential members (environmental consciousness, financial concerns, willingness to cooperate or to be independent from the grid), organizers and community leaders are empowered to tailor their messaging to resonate with specific demographics.

Figure 21, **Figure 22**, and **Figure 23** present the distribution of "Personas" at the collective level for existing and potential members in the "*Cloughjordan Ecovillage*", the "*EnergieC Midden-Delfland*", and the "*Belica Energy Community*", respectively. As we see in the preceding charts, the prevailing Personas in all the case studies are the "*Eco-Collaborators*", the "*Green Guardians*", and the "*Tech Trailblazers*". This is also in line with the survey findings under WP3 (Brenner-Fliesser et al., 2023).

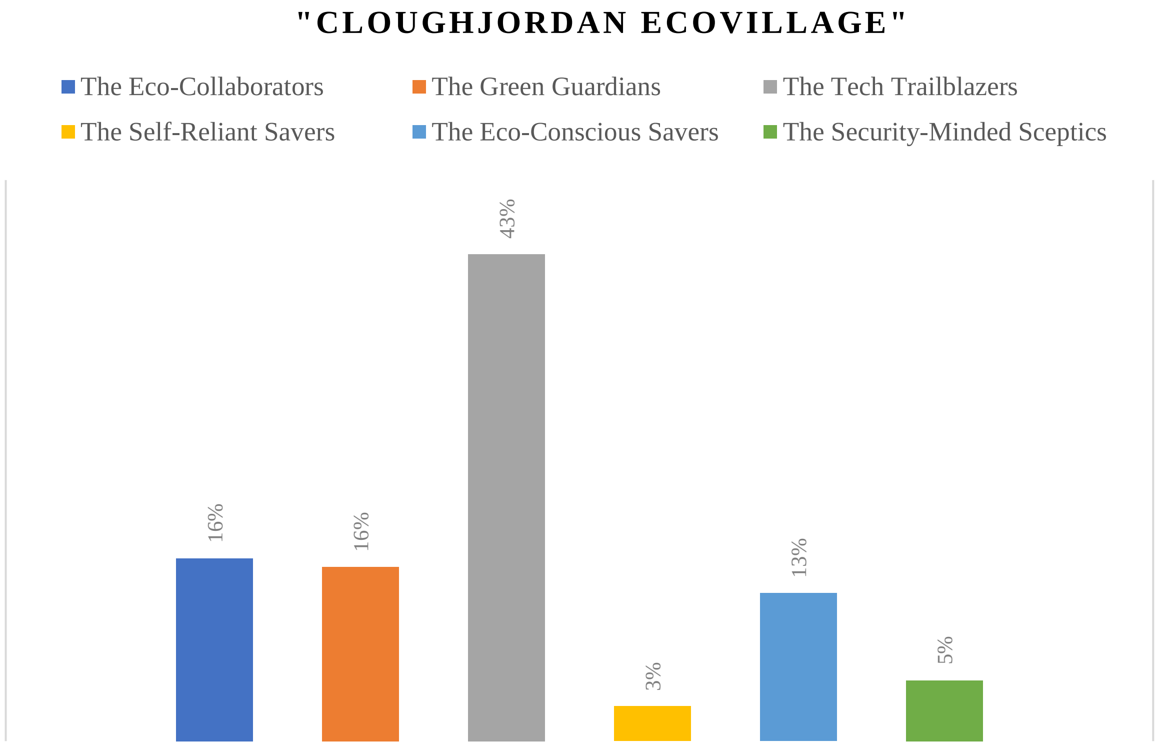


Figure 21. Distribution of Personas (Archetypes) at the collective level in "*Cloughjordan Ecovillage*".

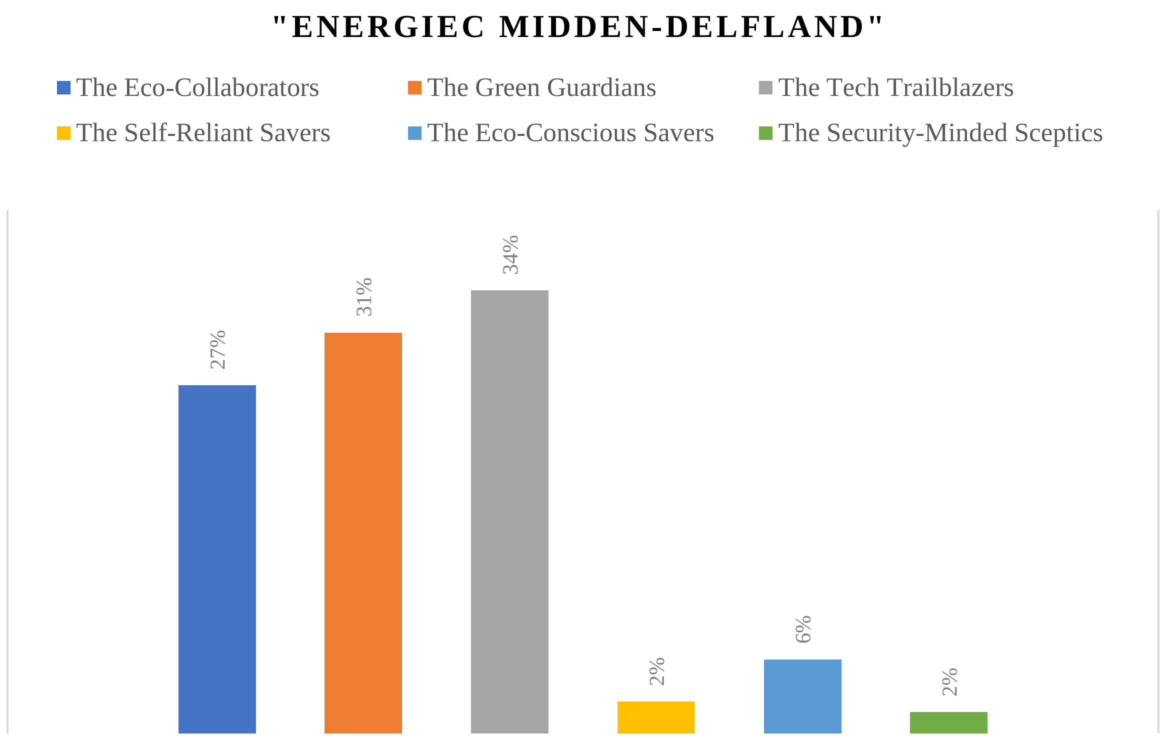


Figure 22. Distribution of Personas (Archetypes) at the collective level in the "*EnergieC Midden-Delfland*" energy community.

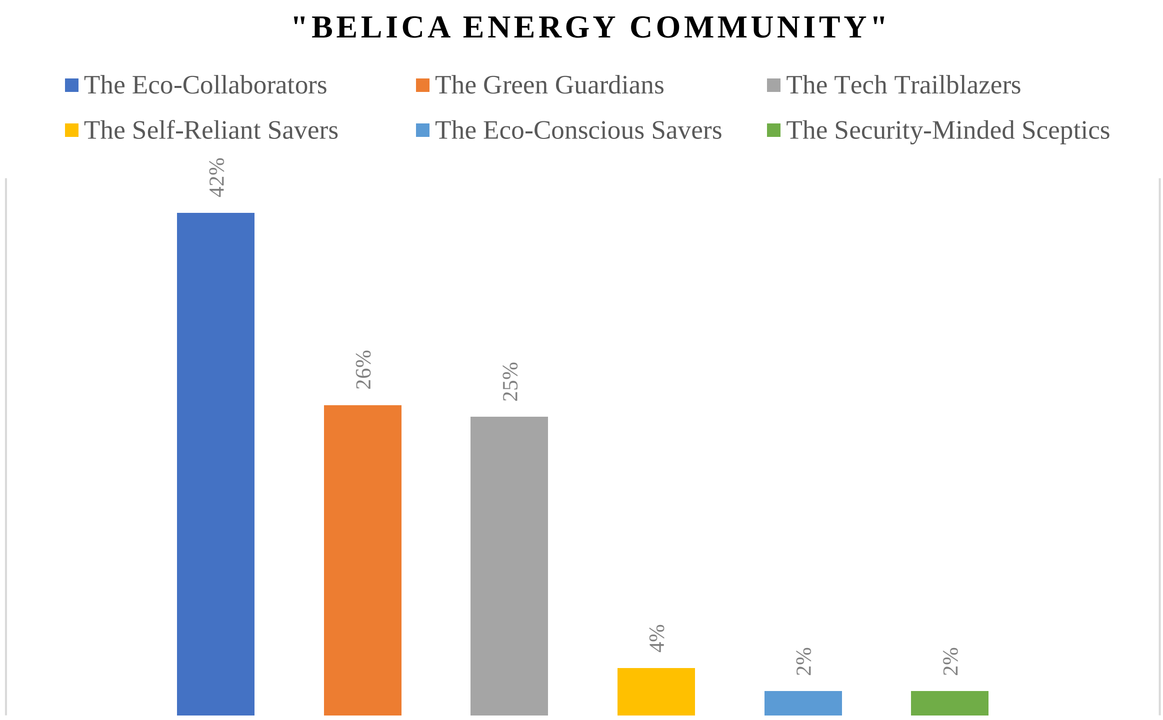


Figure 23. Distribution of Personas (Archetypes) at the collective level in the "*Belica Energy Community*".

In summary, this systematic process was designed to collect, calibrate, and utilize the available data, to simulate a pluralistic community of agents working together to shape energy behavior and lifestyle within the community as well as disseminate it to non-members aiding in the growth of the community, all while taking into consideration elements such as individual temperaments and community values.

"Future-world" narratives

Having processed the data that are used as input into the ANIMO framework to calibrate the agent-related parameters, we turn to specifying the remaining model's parameters (as already described in **Section 4.1**) affecting the design and structure of the social network of agents the frequency of interactions among "*Prospects*" and "*Members*", the threshold required for action, as well as the assignment of adopter groups, drawing from the scenario space and the transition pathways developed, and the descriptions of the "*future-world*" narratives, in particular, as follows:

- "***Adopter group assignment***"

Naturally, the degree to which a social innovation is adopted by the public heavily correlates to the contextual external circumstances of the social group under study. Therefore, following the work of Everett Roger, we can assume the traditional adoption curve, (as presented in **Section 4.1**) to simulate baseline transition pathways under the "*Familiar World*" narrative, as this curve describes the typical attitude of individuals towards innovation.

However, to portray the differences between the different "future-world" narratives, the scenario space can be further informed and differentiated by incorporating various degrees of social acceptance and behavior adoption related to the decision-making process of joining a CEI. Therefore, the adoption curve may be adapted to the needs of each narrative, by assuming a skewed distribution of the adoption curve and, thus, different percentages for the adopter groups.

As a result, two (2) new adoption curves are created (**Figure 24**) with the respective percentages for the different adopter groups (**Table 9**); one (1) correlating to positive systemic changes (i.e. "Unified World"), that drive cooperation forward and assumes widespread early adoption of sustainable practices, and one describing a world in which growing disbelief is prevalent, which deters individuals from incorporating such practices into their lifestyle and in which adoption of innovations is delayed (i.e. "Fragmented World").

By designing depictions of potential future narratives with adoption curves exhibiting both positive and negative skewness, that represent the eagerness- or lack thereof- of the public to welcome social innovations related to energy citizenship, such as the formation of new CEIs, we manage to add an informed quantitative aspect to our analysis.

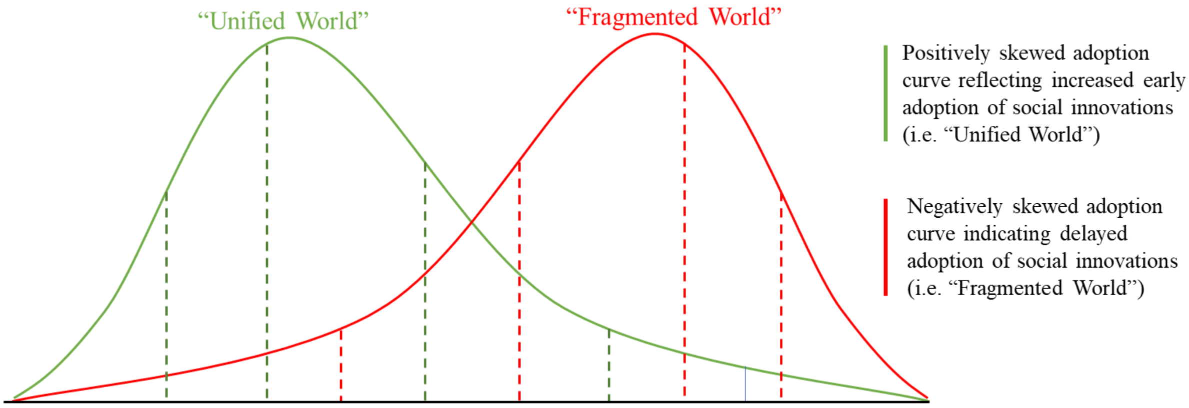


Figure 24. Skewed adoption curves representing the attitude towards social innovations under the "Unified World" and the "Fragmented World" narratives.

Table 9. Adopter groups' probabilities under the different "future-world" narratives as parameterized in the ANIMO modeling framework.

Adopter group	"*Familiar World*"	"*Unified World*"	"Fragmented *World*"
"Innovators"	2.5%	6.5%	0.5%

"Early Adopters"	13.5%	17.5%	7.5%
"Early Majority"	34%	34%	34%
"Late Majority"	34%	34%	34%
"Laggards"	16%	8%	24%

"***Prospects' threshold to join*** **(θ_p)**"

Prospective members of CEIs may exhibit varying degrees of receptivity to external influences by peers in their social group. This implies that in certain contexts, prospective members may display heightened responsiveness to new information and a lower resistance to taking action. Environments that are characterized by positive external developments, strong social cohesion, and trust (i.e., "Unified World"), facilitate the dissemination of positive attitudes and perceptions towards innovations, as individuals are more likely to be influenced by the endorsements and experiences of their peers and social groups.

Conversely, in transition pathways under a "Fragmented World" narrative, individuals harbor more skepticism and distrust towards influence from their social circle, rendering them less susceptible to mobilization and motivation.

To account for this variability in the case studies' scenario space, apart from the assignment of the adopter groups, we can further inform the "*future-world*" narratives, by introducing normal distributions that assign *Prospects* their *threshold to join* values for every adopter group (threshold θ_p value). To further illustrate the implemented methodology, **Figure 25** and **Table 10** provide the mean and the variance values of the applied distributions.

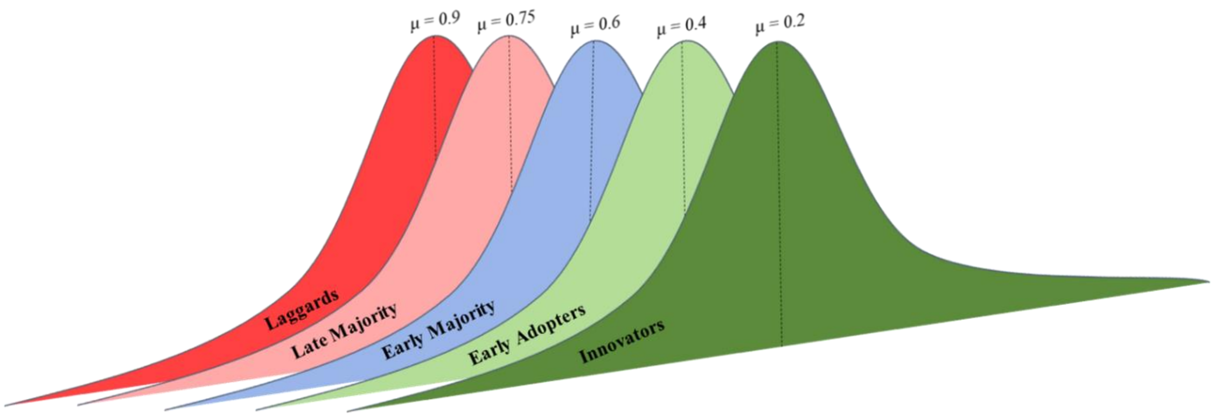


Figure 25. The multitude of normal distributions utilized for assigning probability values in the "*threshold to join*" agent-related parameter for each adopter group.

Table 10. Mean and variance of the utilized normal distributions for assigning probability values in the "*threshold to join*" agent-related parameter for each adopter group.

Adopter group	**Mean and variance of distributions for the *threshold to join* (θ_p) values**
"Innovators"	$\mu = 0.2$, $\sigma^2 = 0.05$
"Early Adopters"	$\mu = 0.4$, $\sigma^2 = 0.05$
"Early Majority"	$\mu = 0.6$, $\sigma^2 = 0.05$
"Late Majority"	$\mu = 0.75$, $\sigma^2 = 0.05$
"Laggards"	$\mu = 0.9$, $\sigma^2 = 0.05$

“***Prospects’ receptivity towards innovations (P_p)***”

Similarly to the previous agent-related parameter, *Prospects* are also characterized by their *receptivity towards innovations*, descriptive of the varying predispositions that shape their propensity to embrace new ideas, technologies, or practices, when influenced from *Members* of the CEI under study.

As expected, the social context plays a pivotal role in shaping individuals' predispositions towards innovation adoption, since in transition pathways under a “Unified World” narrative, individuals may feel more empowered to explore and embrace new ideas, technologies, and practices as well as engage in experimentation and risk taking. This comes in contrast with transition pathways in the context of a fragmented society, (i.e., "Fragmented World" narrative), where the perceived risks associated with innovation adoption are amplified.

The assignment of adopter groups to *Prospects*, informs the “*receptivity towards innovations*” agent-related parameter, which is inserted in ANIMO as a probability denoted as P_p. The values for the probabilities are derived from an ensemble of normal distributions, similar, but not identical, to the ones previously described.

This is done in order to capture the most diverse spectrum of *receptivity towards innovations* possible. To further illustrate the implemented methodology, Figure 26 and Table 11 provide the mean and the variance values of the applied distributions.

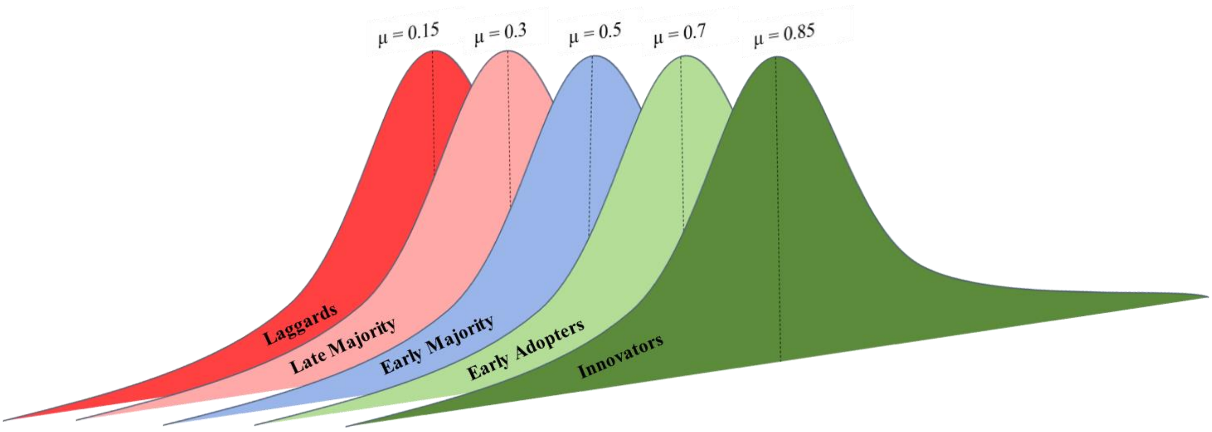


Figure 26. The multitude of normal distributions utilized for assigning probability values in the “*receptivity towards innovations*” agent-related parameter for each adopter group.

Table 11. Mean and variance of the utilized normal distributions for assigning probability values in the “threshold to join” agent-related parameter for each adopter group.

Adopter group	**Mean and variance of distributions for the *threshold to join* (θ_p) values**
“Innovators”	$\mu = 0.85, \sigma^2 = 0.05$
“Early Adopters”	$\mu = 0.7, \sigma^2 = 0.05$
“Early Majority”	$\mu = 0.5, \sigma^2 = 0.05$
“Late Majority”	$\mu = 0.3, \sigma^2 = 0.05$
“Laggards”	$\mu = 0.15, \sigma^2 = 0.05$

“***The “Reach”* agent-related parameter**”

This parameter represents the ability of community *Members* to establish connections to *Prospects* within the model over the simulation period. This parameter is dynamic and can be adjusted to reflect positively or negatively evolving trends in the external environment.

For instance, in transition pathways under the "*Unified World*" narrative, characterized by heightened cooperation and social cohesion, agents are inclined to form more connections, thereby simulating a tightly knit society that facilitates the dissemination of information.

Conversely, in transition pathways under the "*Fragmented World*" narrative, where distrust and skepticism prevail, individuals are reluctant to forge new connections, resulting in a decrease in the average connectedness between the two (2) agent classes.

Additionally, in selecting the range for the "*reach*" parameter of "*Members*", we took into consideration the fact that, while individuals may engage daily with a wide array of individuals, particularly facilitated by social media platforms, the sphere of influence regarding investment decisions tends to be confined to a select subset within one's social network.

The assignment of value ranges for the "*reach*" agent-related parameter of the "*Members*" class is provided in **Table 12**.

Table 12. Value ranges for the "reach" agent-related parameter in the ANIMO framework across the different "future-world" narratives.

Values range	"Familiar World"	"Unified World"	"Fragmented World"
5-7	33.3%	50%	20%
3-5	33.3%	30%	30%
0-3	33.3%	20%	50%

"***Geographical information***"

Lastly, regarding the specification of the number of prospective members that will be incorporated as input into the ANIMO model in the "Band Together" narrative, we turn to specific geographical information for each of the selected case studies. We assume an area of a 3 km radius around the energy community of interest, which equals an area of around 28.27 km^2. We also draw from data the population density for the particular region that the community of interest belongs to (**Table 13**).

Table 13. Population of prospective members for each case study under the "Band Together" storyline.

Collective Energy Initiative (CEI)	Municipality/ Region	Population density	Population
"*Cloughjordan Ecovillage*"	Tipperary	39.5/km^2	1,117
"*EnergieC Midden-Delfland*"	Midden-Delfland	410.7/km^2	11,600
"*Belica Energy Community*"	Jugozapaden	5.3/km^2	150

The ENCLUDE "*Band Together*" scenario space

Considering the specifications of both the "*people-centered*" storylines and the "*future-world*" narratives, we develop the ENCLUDE scenario space for the *"Band Together"* storyline in CEIs (**Figure 27**).

The scenario space is split into (2) two parts, i.e., the specifications of the CEI members' "Personas" that remain the same across the transition pathways under study and are depicted in the upper part of the figure and the specifications of the factors that are related to the adoption of social innovations and the attributes of the potential CEI members that are consistent with the "*future-world*" narratives and vary across the transition pathways under study, which are depicted in the lower part of the figure.

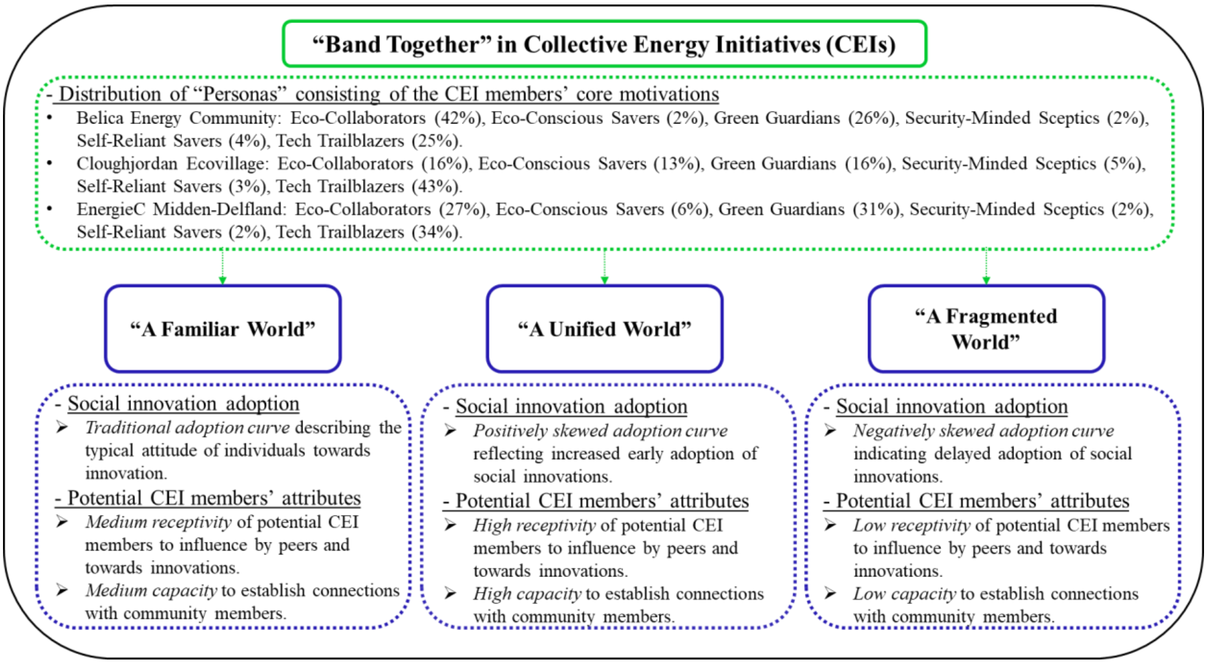


Figure 27. The ENCLUDE scenario space for the "*Band Together*" storyline.

6.2.3. *Combining "Power to the People" with "Habitual Creatures" storylines towards just and inclusive transitions*

"People-centered" storylines

The citizens of Megalopolis will have to endure the impact of the energy transition of the region after the closing down of the lignite power plants, at least in the short term. This impact is going to be three-fold: (i). potential loss of jobs, (ii). susceptibility to electricity price increases due to reliance on natural gas, and (iii). uncertainty about the diverse heating options and their corresponding cost, which until now was largely provided by the lignite-fueled, district heating system.

In this respect, Megalopolis could become a less attractive place to live, since not only the income of the citizens will be at risk, but also the cost of living will increase at the same time.

In this study, we explore how investing in electrification affects the transition impacts of Megalopolis, compared to using natural gas as a transition fuel. In other words, we compare the energy consumption reduction, environmental footprint, and potential extra charge on households for residential heating.

We focus on the residential sector in Megalopolis, which numbers a total of 3,545 households, and we explore three transition scenarios towards 2050, drawing from the descriptions of the "*future-world*" narratives, simulated with the DREEM model.

To specify the context in which the modeling exercises will take place and provide a common point of reference in order to extract meaningful insights from simulating the three (3) scenarios, certain model inputs remain constant across all the narratives. The following specifications were made:

Energy mix

The existing energy mix for the heating systems in the residential sector in Megalopolis is presented in **Table 14**.

Table 14. Existing heating system energy mix in Megalopolis residential building stock (Hellenic Statistical Authority (ELSTAT), 2020).

Existing heating system energy mix	
Technology	*Number of households*
Oil	1,514
Electric Heating System	1,407
Heat Pumps	23
Natural Gas	0
District Heating	432
Biomass	169

Renovations

All the dwellings that have their heating technology substituted are also renovated through envelope/ window upgrades:

- *In dwellings built before 1981:* Exterior wall insulation & window replacements.
- *In dwellings built during the period 1981-2000:* Exterior wall insulation.

Emissions Trading System (ETS) costs

Assuming the EU's building sector, it is expected to be included in a parallel ETS by 2026. Therefore, to realistically assess the financial viability of each transition pathway under study, beyond fuel and renovation costs, we consider the costs resulting from the EU ETS, as buildings are among the sectors that will be part of the newly introduced expanded coverage (Koasidis et al., 2022). Table 15 presents the considered trend (Trading Economics, 2024).

Table 15. Evolution of costs related to the expected inclusion of the European Union's building sector to the Emissions Trading System by 2026.

Period	(2022-2025)	(2026-2030)	(2031-2050)
Carbon price (€/tn)	0	50	100

Technological costs

Table 16 presents the cost evolution by 2050 for the technological infrastructure used in the different transition pathways under study.

Table 16. Evolution of technological infrastructure costs by 2050 for the transition pathways under study.

Year	2022	2030	2050	Source(s)
Natural gas (€)	5,000	4,904	4,713	(De Vitae et al., 2018; Renewable Heating Hub, 2021)
Heat pumps (€)	12,000	7,680	4,086	
Building envelope and window upgrades (€)	5,000	5,000	5,000	

Emission factors

Table 17 provides projections on the future emission factors for electricity, heating oil, natural gas, and biomass, derived from the Greek “Long-Term Strategy towards 2050” (Hellenic Ministry of Environment and Energy, 2019).

Table 17. Projections on the future evolution of emission factors for electricity, heating oil, natural gas, and biomass by 2050 in Greece for all the transition pathways under study.

Emission factors ($tnCO_2$/ktoe)				
Year	**Electricity**	**Heating oil**	**Natural gas**	**Biomass**
“2023”	*5,006*	*2,821*	*2,332*	*2,337*
“2025”	*4,476*			
“2030”	*3,947*			
“2035”	*3,418*			
“2040”	*2,889*			
“2050”	*2,360*			

“Future-world” narratives

Below we provide a qualitative account of each “*future-world*” narrative, describing the course of action followed for the transition pathways analyzed in the residential sector of Megalopolis:

“*A Familiar World*”: Transition pathways developed under this narrative build on the baseline of the existing national policymaking for the municipality of Megalopolis and draws from the plan of substituting district heating and oil heating installations with natural gas by 2035. This means that citizens follow the current rates of decarbonization efforts and decide to invest in the technological solutions, as foreseen each time by current policymaking at the EU and the national level.

“*A Unified World*”: Transition pathways developed under this narrative build on the premise that citizens come together united in the battle against climate change and decide to invest in green solutions (energy renovation measures and heat pumps) as soon as possible, while they are also willing to adopt behavioral and lifestyle changes when it comes to managing their energy consumption patterns.

“*A Fragmented World*”: Transition pathways developed under this narrative build on a potential evolution of the future in which individuals are characterized by distrust and skepticism and are mainly concerned about their energy security and lower bills rather than combating climate crisis. Due to the potential worldwide disparities and the resulting energy crises, people turn to conventional sources of energy more and more, despite their increasing prices. The latter leads to the introduction of green solutions as heat pumps in 2040, at half the rate compared to the situation under the “Familiar World” narrative.

Table 18 provides projections on future price evolution by 2050 in Greece, as derived from the Greek "Long-Term Strategy towards 2050" (Hellenic Ministry of Environment and Energy, 2019), along with the trends for all the transition pathways under study.

Table 18. Projections on the future evolution of energy prices by 2050 in Greece for all the transition pathways under study.

“*Familiar World*”		
Energy carrier	**2023 value**	**Source(s)**

Heating oil (€/MWh)	114.6	(Greece - Household Electricity Prices, 2023; Energy Press, 2024)
Natural gas (€/MWh)	70.0	
Electricity (€/MWh)	232.5	
	"Unified World"	
Energy carrier	**2023 value**	**Source(s)**
Heating oil (€/MWh)	76.3	(Grigoriou et al., 2022; Hellenic Ministry of Development, 2021; Hellenic Ministry of Environment and Energy, 2019)
Natural gas (€/MWh)	48.2	
Electricity (€/MWh)	175.2	
	"Fragmented World"	
Energy carrier	**2023 value**	**Source(s)**
Heating oil (€/MWh)	123.2	(Hellenic Ministry of Development, 2022b, 2022c, 2022a; Hellenic Ministry of Environment and Energy, 2019)
Natural gas (€/MWh)	276.8	
Electricity (€/MWh)	295.2	

The ENCLUDE joint "*Power to the People*" and "*Habitual Creatures*" scenario space

Considering the specifications for both the "*people-centered*" storylines and the "*future-world*" narratives, the ENCLUDE scenario space for a joint "*Power to the People*" and "*Habitual Creatures*" storyline is developed and depicted in Figure 28.

The scenario space is split into two (2) parts, i.e., the specifications of building stock, policies, and technologies that provide a baseline across the transition pathways under study and are depicted in the upper part of the figure, and the specifications of the fuels and the timing of technology implementation that are consistent with the "*future-world*" narratives and vary across the transition pathways under study, as depicted in the lower part of the figure.

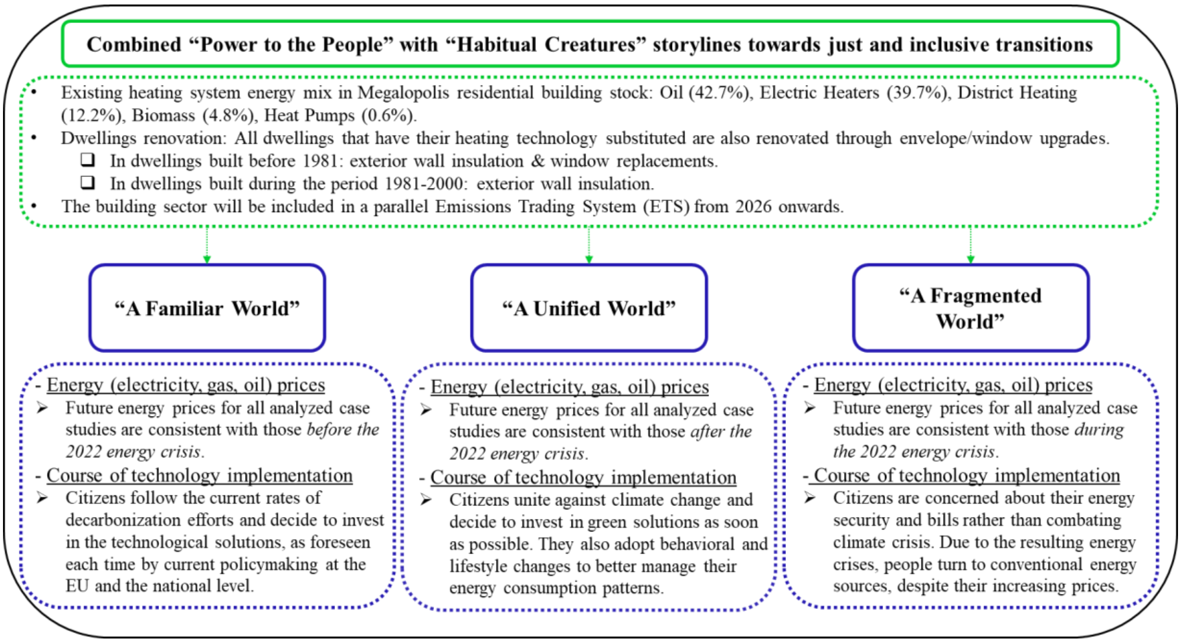


Figure 28. The ENCLUDE scenario space for a joint "*Power to the People*" and "*Habitual Creatures*" storyline.

7. Model application and results

The model application section of this deliverable is a critical juncture in our exploration of the decarbonization potential of energy transition pathways inspired by "people-centered" storylines of energy citizenship. In this section, the modeling exercises described in the previous chapters are taking place and results from the ANIMO and the DREEM modeling frameworks are presented and further discussed.

7.1. "Power to the People" and citizen investments in small-scale PV systems

In this section, we present results from the DREEM model on annual electricity demand and electricity generation from rooftop PV profiles, for the five (5) countries and the respective cities under study.

The fundamental premise behind the development and deployment of the DREEM model is that, in order for citizens to actively engage in the energy transition, they must first understand the financial benefits of investing in new energy products and services. In this context, for each case under study we present the accompanying benefits for prosumers in terms of Net Present Value (NPV) of their investment under the existing policy schemes in each Member State.

Finally, the emission reduction (decarbonization) potential of prosumerism in the cities under study by 2050 is also presented.

Denmark

Figure 29 presents the electricity demand and generation from a small-scale PV system in the city of Aalborg on an annual basis. Findings indicate notable distinctions emerge in electricity generation, with the installed PV system capable of meeting electricity demand in April, May, and June.

Specifically, the electricity demand during this period is 432 kWh, 428 kWh, and 510 kWh, respectively, while the electricity generation from the PV is 460 kWh, 498 kWh, and 526 kWh.

In addition, and as expected, electricity demand is peaking from July to September when temperatures are higher. Figure 30 indicates the total electricity demand throughout the year for the reference building in Aalborg, totaling 6,307 kWh. Of this total demand, 5,206 kWh is attributed to appliance usage, and 1,101 kWh to the electricity demand for cooling.

Alongside, the electricity generation from the 3 kW_p solar PV system on the rooftop of the reference building is able to cover around 56% of the electricity demand through the year since it is able to generate 3,518 kWh.

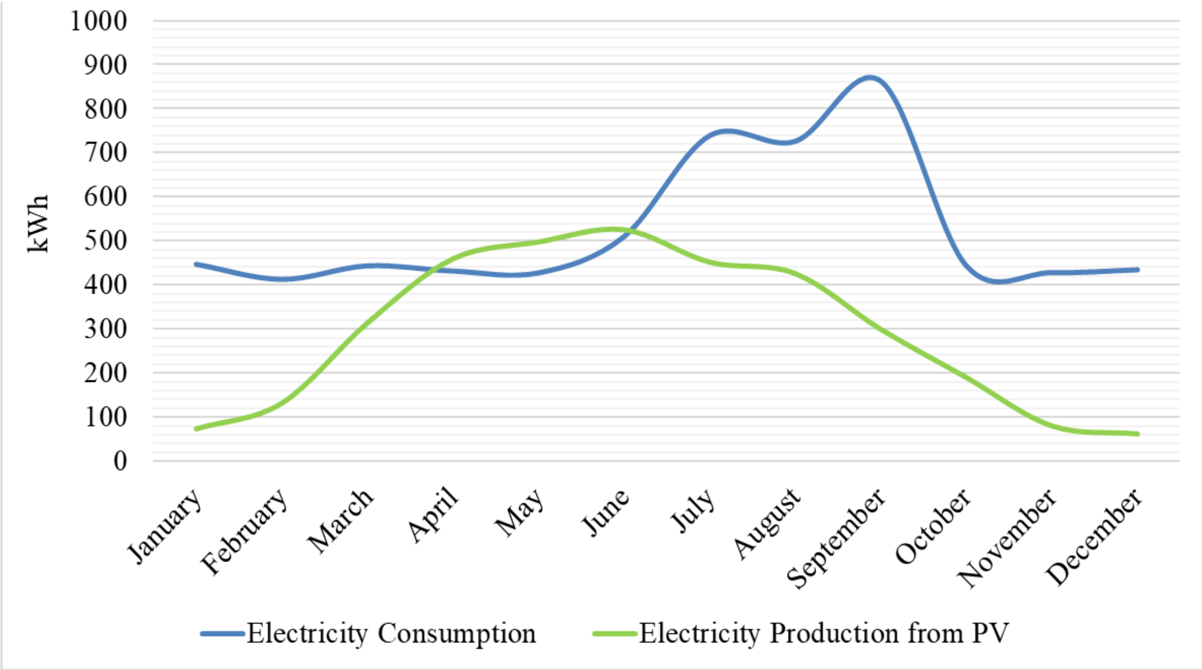


Figure 29. Electricity demand and generation from a small-scale solar PV in the city of Aalborg on an annual basis.

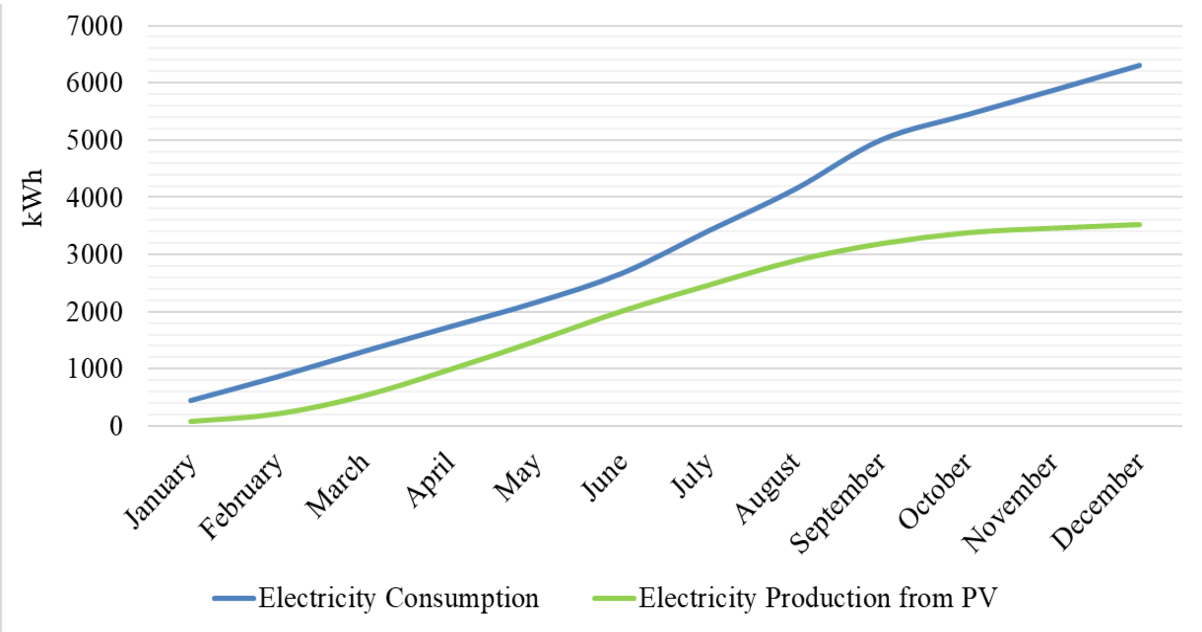


Figure 30. Cumulative electricity demand and generation from a small-scale solar PV in the city of Aalborg on an annual basis.

For the city of Copenhagen, **Figure 31** presents the electricity demand and generation from a small-scale PV system on an annual basis. Electricity demand peaks in September reaching 790 kWh, while electricity generation peaks in June reaching 458 kWh.

Moreover, **Figure 32** presents the cumulative curves of the electricity demand and generation from the PV. The total annual electricity demand is equal to 6,187 kWh. Of this, 5,206 kWh are attributed to appliance usage and 981 kWh to cooling needs. The total annual electricity generation is equal to 2,976 kWh, with the PV system capable of covering around 48% of the total electricity demand of the household under study.

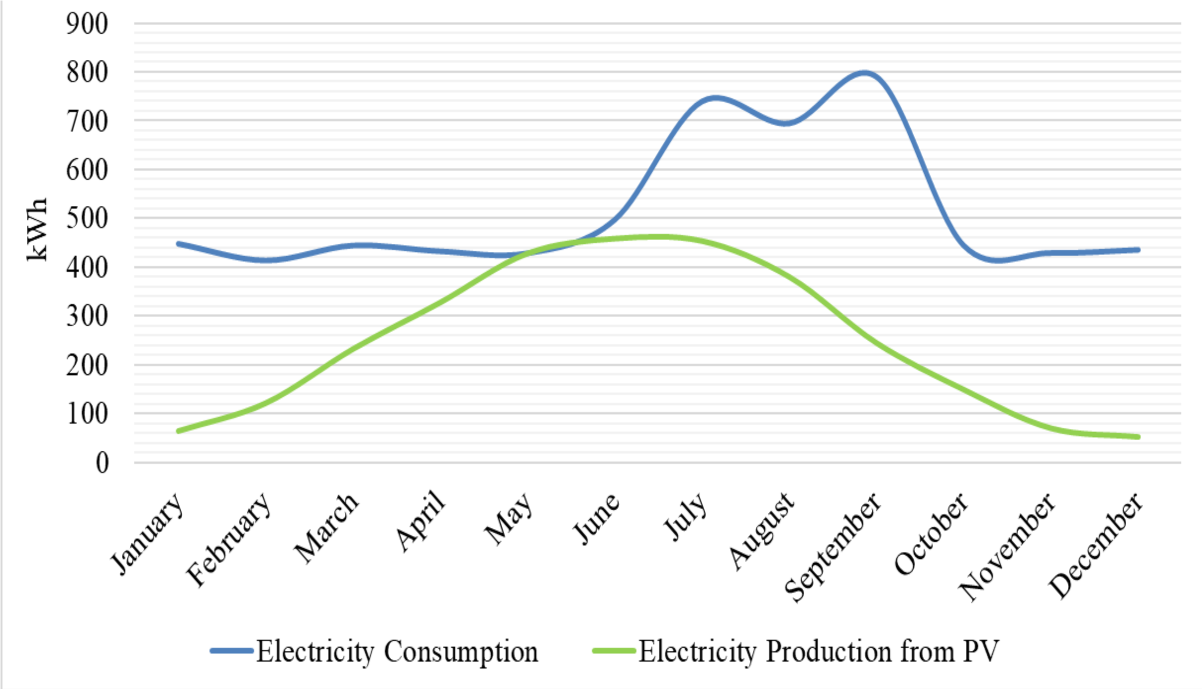


Figure 31. Electricity demand and generation from a small-scale solar PV in the city of Copenhagen on an annual basis.

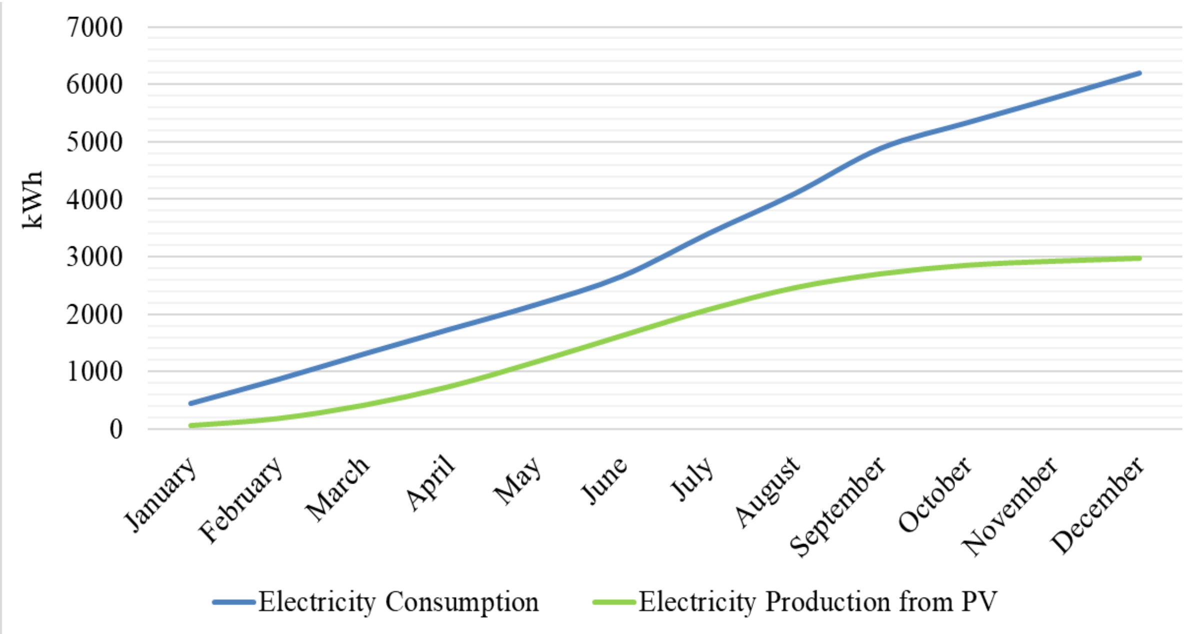


Figure 32. Cumulative electricity demand and generation from a small-scale solar PV in the city of Copenhagen on an annual basis.

Overall, modeling results on the economic viability of citizen investments in prosumerism in the case of Denmark highlight the impact of the retail price of electricity on the profitability of the investment in small-scale PV systems, since for small installations, where the majority of the generated electricity is consumed on-site, the benefits are significantly greater, the higher electricity prices are (**Figure 33**).

In particular, for a 3 kW_p solar PV system connected to the grid under the existing net metering scheme in Aalborg, assuming no subsidy on the capital cost of the investment, benefits for prosumers are calculated in terms of the NPV index.

By considering the retail price of electricity for the "*Familiar World*" narrative (0.3927 €/kWh) in Denmark (Country Economy, 2024a), we find that the NPV of this investment under the existing net metering scheme is approximately 12,520 € after a 25-year life cycle, while for the "*Unified World*" and the "*Fragmented World*" narratives, the NPV after a 25-year life cycle is around 8,150 € and 20,190 €, respectively.

Moreover, the discounted payback period of the investments under the existing net metering scheme in Denmark, for the three (3) future-world narratives are: *(i).* "*Familiar World*": 2.4 years, *(ii).* "*Unified World*": 3.4 years, and *(iii).* "*Fragmented World*": 1.6 years (it is noted that the discounted payback period on the figure is where the NPV curve intersects the x-axis).

This indicates the impact of retail electricity price on the profitability of the investment, since in a "*Fragmented World*", where the prices are very high, prosumers have a stronger incentive to invest in a rooftop solar PV system, considering that they remain environmentally aware and eager to combat against the climate crisis.

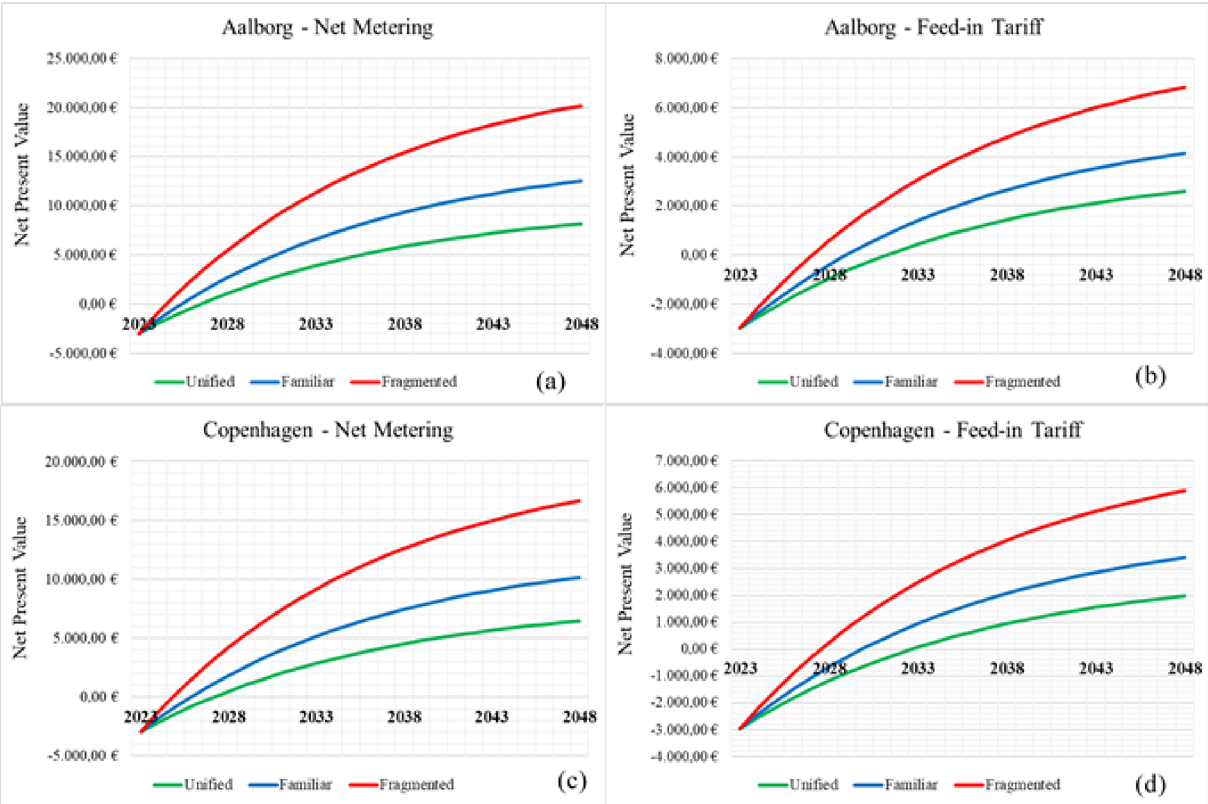


Figure 33. Evolution of the Net Present Value metric for a 3 kW_p rooftop solar PV investment in Denmark under the existing net metering and feed-in-tariff schemes and for the "*future-world*" narratives under study in the cases of Aalborg and Copenhagen.

Furthermore, based on the existing FiT scheme in Denmark, where prosumers are paid a fixed price of 62 €/MWh for the excess electricity they supply into the grid, the NPV of investing in small-scale PV prosumerism in Aalborg for the world narratives under study is estimated to be approximately:

(i). "*Familiar World*": 4,140 €, *(ii).* "*Unified World*": 2,600 €, and *(iii).* "*Fragmented World*": 6,840 €, during a 25-year life cycle, while the respective investments' discounted payback period is calculated as: *(i).* "*Familiar World*": 5.9 years, *(ii).* "*Unified World*": 8.1 years, and *(iii).* "*Fragmented World*": 4.1 years.

By considering the retail price of electricity under the "*Familiar World*" narrative (0.3927 €/kWh) in Denmark, the NPV for the future-world narratives under the existing net metering scheme in Copenhagen is calculated to be approximately:

(i). "*Familiar World*": 10,130 €, *(ii)*. "*Unified World*": 6,430 €, and *(iii)*. "*Fragmented World*": 16,620 €, after a 25-year life cycle, whereas the discounted payback period of the investments is: *(i)*. "*Familiar World*": 2.9 years, *(ii)*. "*Unified World*": 4.3 years, and *(iii)*. "*Fragmented World*": 1.9 years.

As for the profitability of this investment under the existing FiT scheme with a fixed price equal to 62 €/MWh, assuming a 0.9% annual degradation rate of the PV system, the NPV of the investment in Copenhagen for the future-world narratives under study is around:

(i). "*Familiar World*": 3,400 €, *(ii)*. "*Unified World*": 1,980 €, and *(iii)*. "*Fragmented World*": 5,900 €, over a 25-year life cycle. The respective discounted payback period under the FiT scheme is equal to: *(i)*. "*Familiar World*": 9.5 years, *(ii)*. "*Unified World*": 6.8 years, and *(iii)*. "*Fragmented World*": 4.5 years.

Finally, we also quantify the emission reduction (decarbonization) potential from investing in PV prosumerism in the Danish residential sector, and in the cities of Aalborg and Copenhagen, in particular.

To do so, we estimate the carbon emission reduction resulting from the electricity generation capacity of the small-scale PV systems under study in both Aalborg and Copenhagen, combined with data from the EU Reference Scenario 2020.

Comparing results for the two (2) cities under study reveals differences in emission reduction (decarbonization) potential, influenced by factors such as solar PV output and the composition of Denmark's electricity generation. Also, there is a big disparity under the different "*future-world*" narratives.

More specifically, in Aalborg, a 3 kWp rooftop solar PV system is estimated to reduce carbon emissions by 2050 approximately (**Figure 34**): *(i)*. "*Familiar World*": 3.04 tnCO_2eq., *(ii)*. "*Unified World*": 1.52 tnCO_2eq., and *(iii)*. "*Fragmented World*": 6.08 tnCO_2eq.

Meanwhile, in Copenhagen, a 3 kWp rooftop solar PV system is projected to reduce carbon emissions by approximately: *(i)*. "*Familiar World*": 2.57 tnCO_2eq., *(ii)*. "*Unified World*": 1.29 tnCO_2eq., and *(iii)*. "*Fragmented World*": 5.15 tnCO_2eq. by 2050.

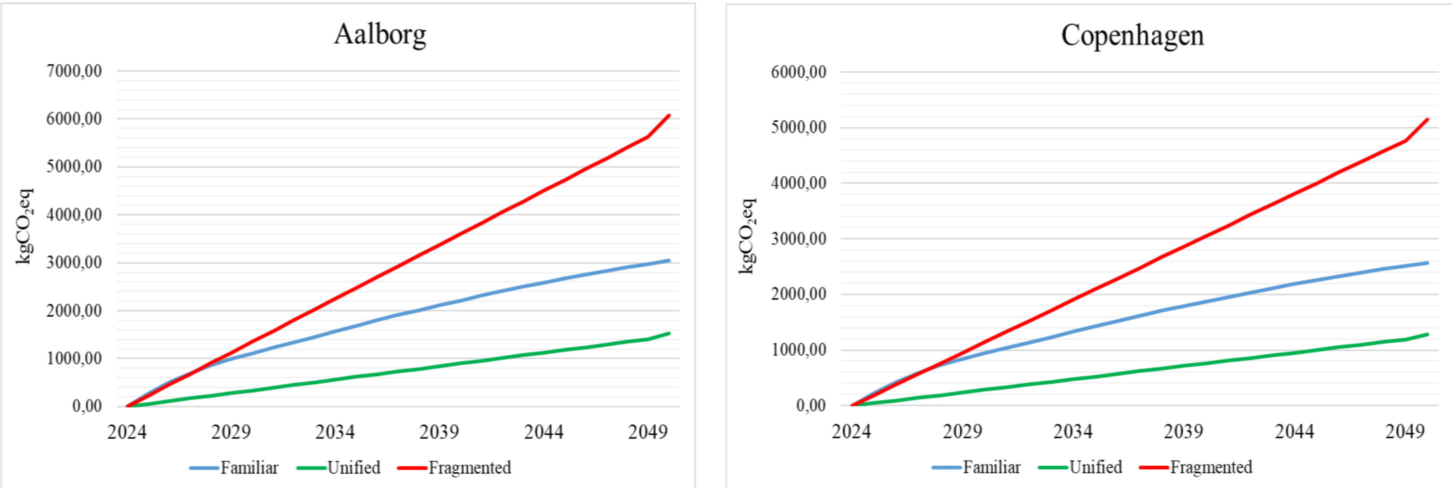


Figure 34. Evolution of the cumulative levels of CO_2 emissions avoided (tnCO_2) in the residential sector of Aalborg and Copenhagen by 2050, under a potential "*Power to the People*" storyline (household level) and for the three (3) different "*future-world*" narratives under study.

France

Figure 35 presents the electricity demand and generation from a small-scale solar PV in the city of Marseille on an annual basis. The highest electricity demand in Marseille is observed during the summer months; specifically, the peak demand is recorded in July, reaching a value of 522 kWh. On the other hand, electricity generation from the 3 kWp solar PV system reaches its highest point of 590 kWh in July, exceeding electricity demand.

Additionally, the cumulative curves of electricity demand and generation from the same PV system are depicted in Figure 36. The annual electricity demand has been tracked as 3,516 kWh, comprising 1,797 kWh allocated to appliance consumption and 1,719 kWh allocated to cooling needs. In terms of overall electricity generation, the annual production is at 4,710 kWh. The 3 kW_p solar PV system installed in Marseille has the capability to surpass the building's electricity needs by around 134% of its total.

The latter implies that the significant electricity generation in Marseille plays a pivotal role in shaping the decision-making process of potential prosumers. This is due to its ability to meet all the electricity requirements of the reference building throughout the year, with the exception of September, when electricity demand amounts to 475 kWh, while output from the small-scale PV system is only 448 kWh.

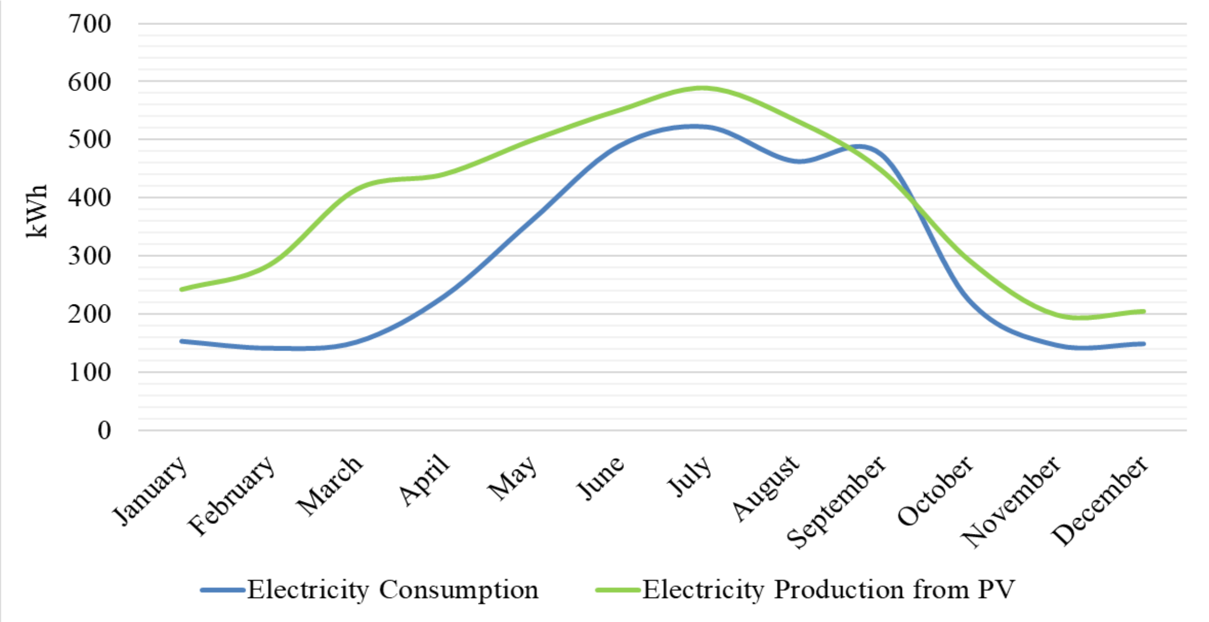


Figure 35. Electricity demand and generation from a small-scale solar PV in the city of Marseille on an annual basis.

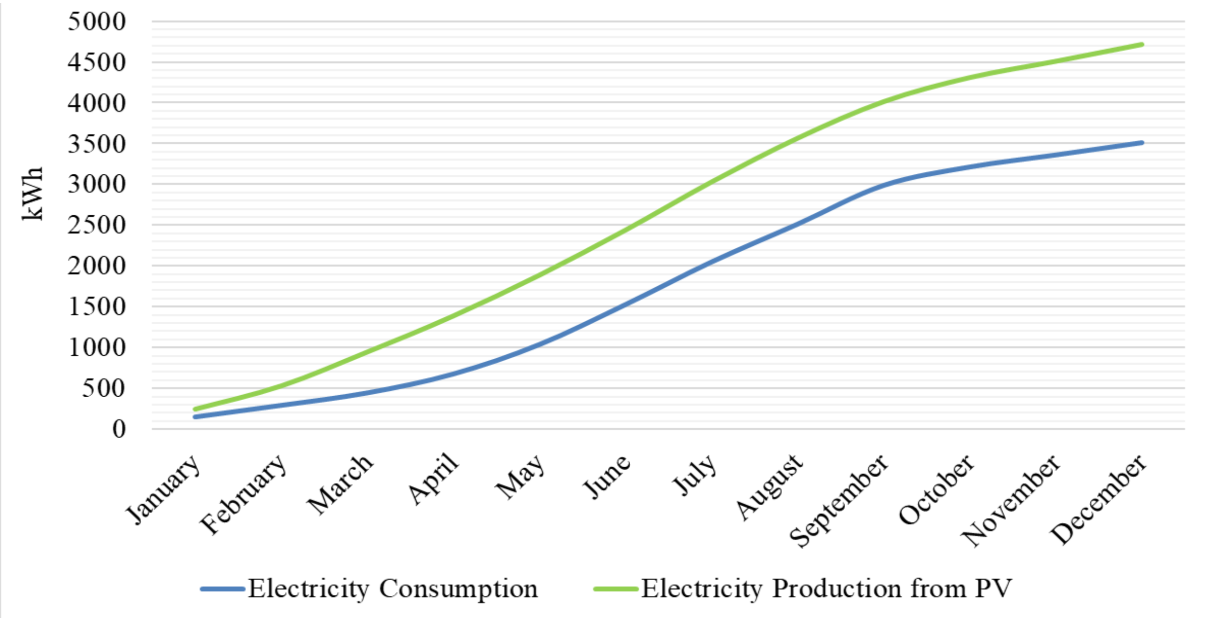


Figure 36. Cumulative electricity demand and generation from a small-scale solar PV in the city of Marseille on an annual basis.

Figure 37 presents the electricity demand and generation from a small-scale solar PV in the city of Paris on an annual basis. Electricity demand in Paris does not display a peak and maintains equilibrium throughout the year, with an average monthly consumption of 323 kWh.

Furthermore, the cumulative curves of electricity demand and generation from the 3 kW_p PV system are depicted in Figure 38, where the total annual electricity demand is equal to 3,879 kWh, which is mainly attributed to appliance usage, as this reference building in Paris does not necessitate electricity demand for cooling throughout the year.

In addition, the total PV electricity generation amounts to 3,793 kWh annually. Lastly, a 3 kW_p solar PV system installation on the rooftop of the Paris reference building has the capacity to meet nearly the entire electricity demand of the building, accounting for approximately 98% of its total. This substantial electricity generation may play a crucial role in influencing the decision-making process of potential prosumers in Paris.

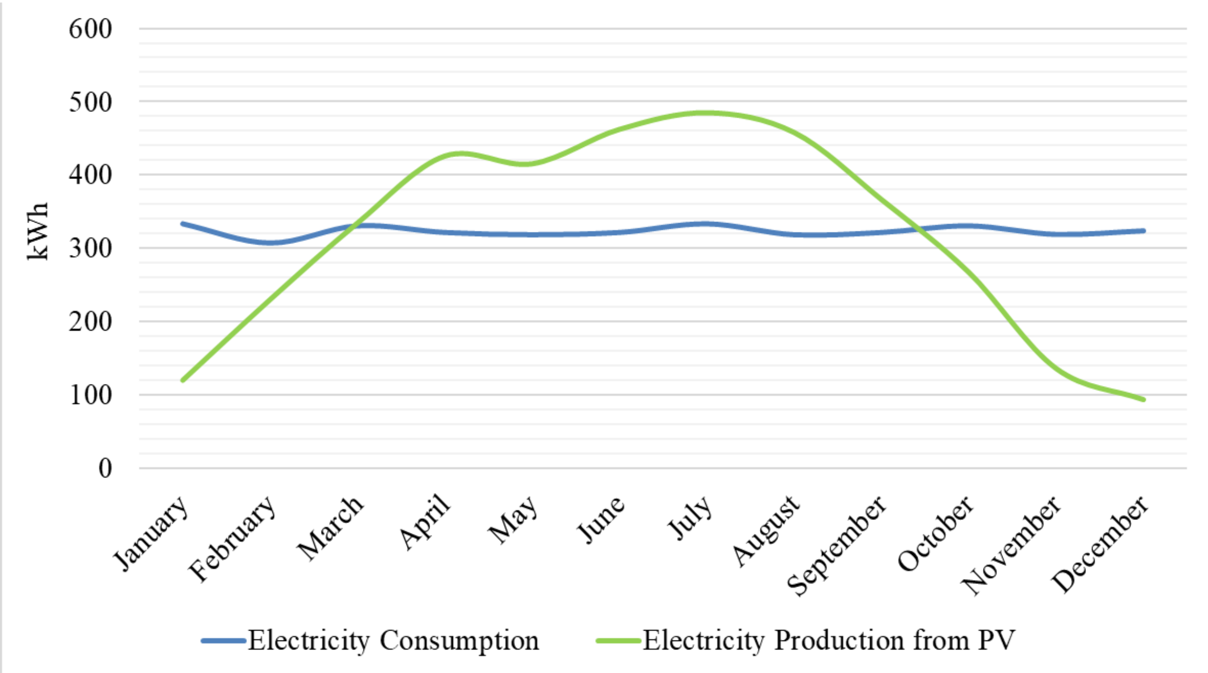


Figure 37. Electricity demand and generation from a small-scale solar PV in the city of Paris on an annual basis.

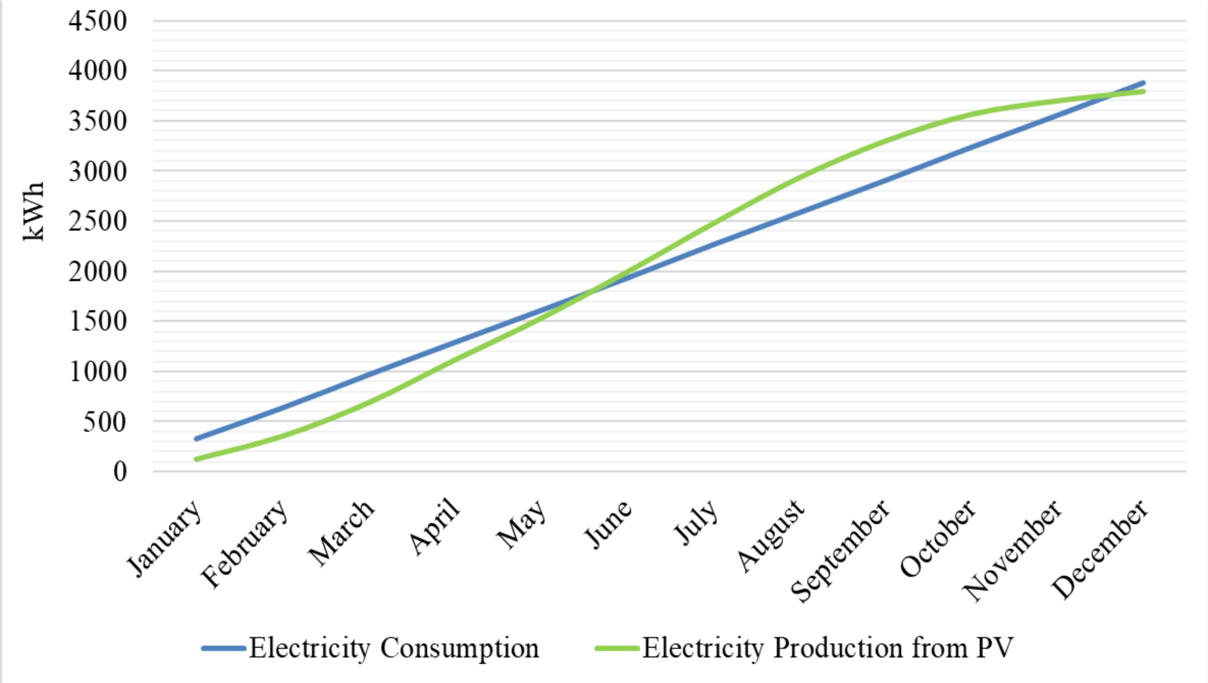


Figure 38. Cumulative electricity demand and generation from a small-scale solar PV in the city of Paris on an annual basis.

We also present modeling results on the economic viability of citizen investments in prosumerism in the case of France (**Figure 39**).

In particular, based on the existing FiT policy scheme, in which prosumers are paid a fixed price of 147.4 €/MWh for the excess electricity they supply into the grid, as well as on the retail electricity price for the "*Familiar World*" narrative (0.2275 €/kWh) (Country Economy, 2024b), the NPV of investing PV prosumerism, assuming a 0.9% annual degradation rate of the PV system, for the three (3) different "*future-world*" narratives is around:

(i). "*Familiar World*": 10,810 €, *(ii).* "*Unified World*": 10,245 €, and *(iii).* "*Fragmented World*": 11,370 €, over a 25-year life cycle. The respective discounted payback periods under the FiT scheme are equal to: *(i).* "*Familiar World*": 8.2 years, *(ii).* "*Unified World*": 8.5 years, and *(iii).* "*Fragmented World*": 7.9 years.

On the other hand, for the case of Paris, the NPV of investing PV prosumerism, assuming a 0.9% annual degradation rate of the PV system, for the three (3) different "*future-world*" narratives is around: *(i).* "*Familiar World*": 7,860 €, *(ii).* "*Unified World*": 7,260 €, and *(iii).* "*Fragmented World*": 8,460 €, during a 25-year life cycle, while the respective investments' discounted payback period is calculated to be: *(i).* "*Familiar World*": 10.1 years, *(ii).* "*Unified World*": 10.5 years, and *(iii).* "*Fragmented World*": 9.6 years.

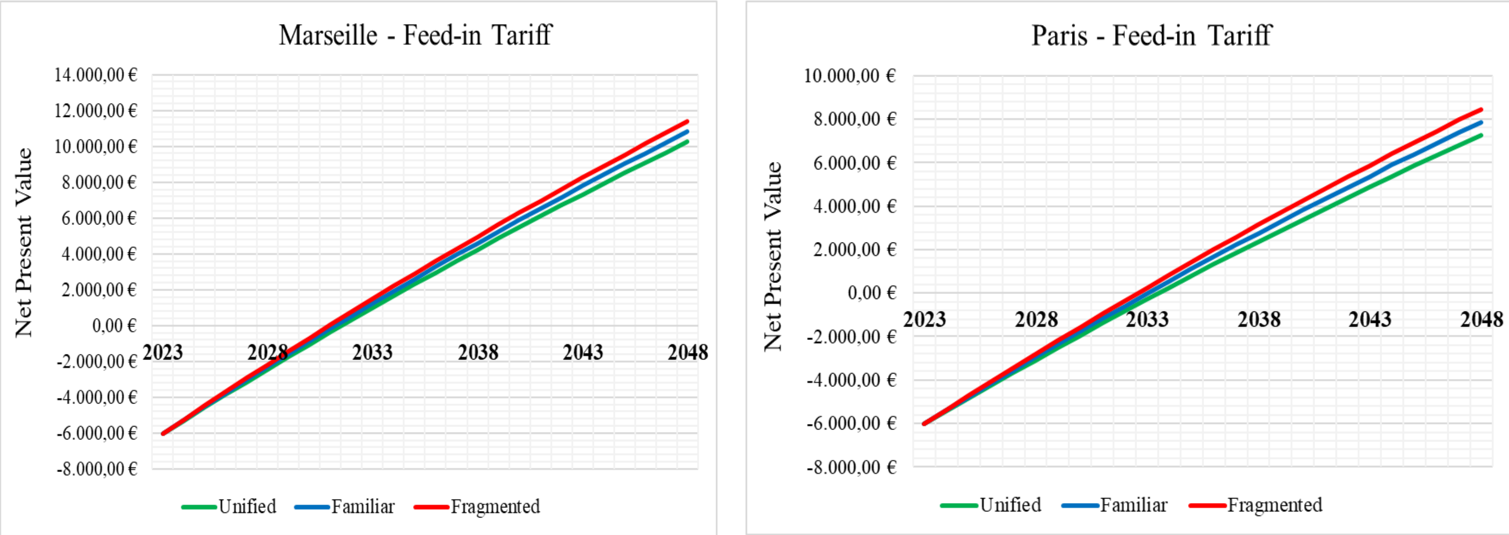


Figure 39. Evolution of the Net Present Value metric for a 3 kW_p rooftop solar PV investment in France under the existing feed-in-tariff scheme and for the "*future-world*" narratives under study in the cases of Marseille and Paris.

Finally, we also quantify the emission reduction (decarbonization) potential from investing in PV prosumerism in the French residential sector, and in the cities of Marseille and Paris, in particular (**Figure 40**).

To do so, we estimate the carbon emission reduction resulting from the electricity generation capacity of the small-scale PV systems under study in both Marseille and Paris, combined with data from the EU Reference Scenario 2020.

The analysis of modeling outcomes for the two (2) cities under study highlights differences in their emission reduction (decarbonization) potential, which are shaped by factors like the productivity of solar PV systems and France's power sector.

Furthermore, significant disparities exist across the different "*future-world*" narratives. Specifically, in Marseille, a 3 kWp rooftop solar PV system is projected to reduce carbon emissions by approximately: *(i). "Familiar World":* 3.81 $tnCO_2eq$., *(ii). "Unified World":* 1.90 $tnCO_2eq$., and *(iii). "Fragmented World":* 7.63 tnCO2eq. by 2050, indicating the higher solar PV output of Marseille contrary to Paris, which results to a higher emission reduction (decarbonization) potential.

Conversely, in Paris, a 3 kWp rooftop solar PV system is expected to lower carbon emissions by approximately: *(i). "Familiar World":* 3.07 $tnCO_2eq$, *(ii). "Unified World":* 1.54 $tnCO_2eq$, and *(iii). "Fragmented World":* 6.14 $tnCO_2eq$ by 2050.

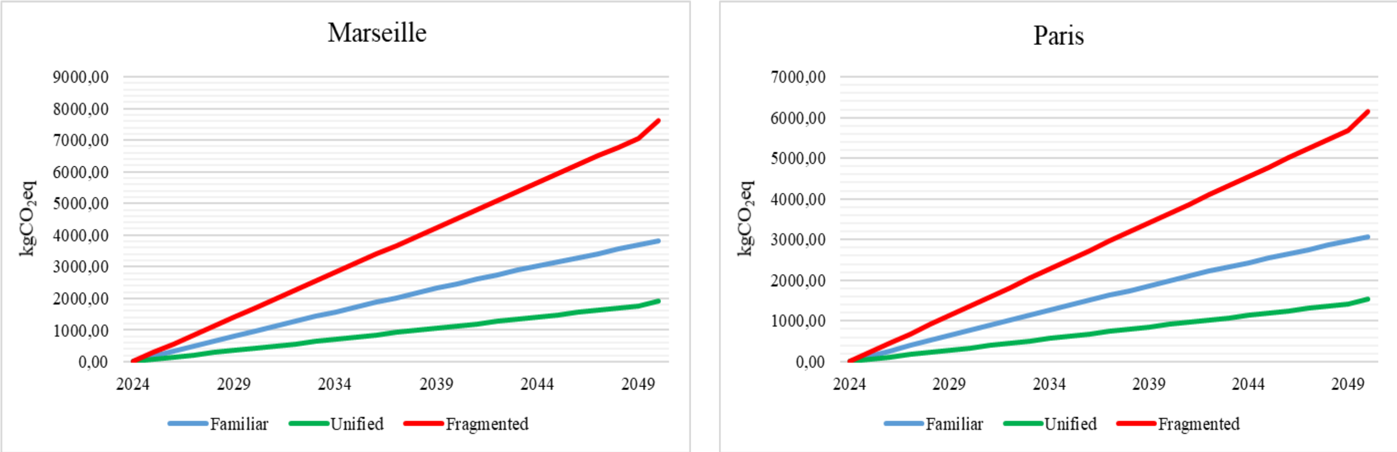


Figure 40. Evolution of the cumulative levels of CO_2 emissions avoided ($tnCO_2$) in the residential sector of Marseille and Paris by 2050, under a potential "*Power to the People*" storyline (household level) and for the three (3) different "*future-world*" narratives under study.

Greece

Expected electricity demand and generation from a 3 kW_p solar PV system in the city of Athens on an annual basis is presented in **Figure 41**.

Furthermore, **Figure 42** illustrates the cumulative electricity demand and generation from a small-scale solar PV in the city of Athens on an annual basis.

Overall, modeling results indicate that the total electricity consumption of the reference building over the course of the year amounts to 5,911 kWh, from which 3,298 kWh is attributed to cooling and 2,613 kWh to appliance usage.

On the other hand, we notice that the total electricity generation of the 3 kW_p solar PV installation is 5,643 kWh per year, covering around 95% of the total electricity demand on an annual basis, with peak production occurring from May to August, as expected.

Moreover, a peak in electricity consumption is observed from June to September, corresponding to increased cooling needs during these months.

It is noted that from January to June, the 3 kW_p PV installation is capable of meeting the entire electricity demand of the building, while from July to December the building needs to draw electricity from the grid.

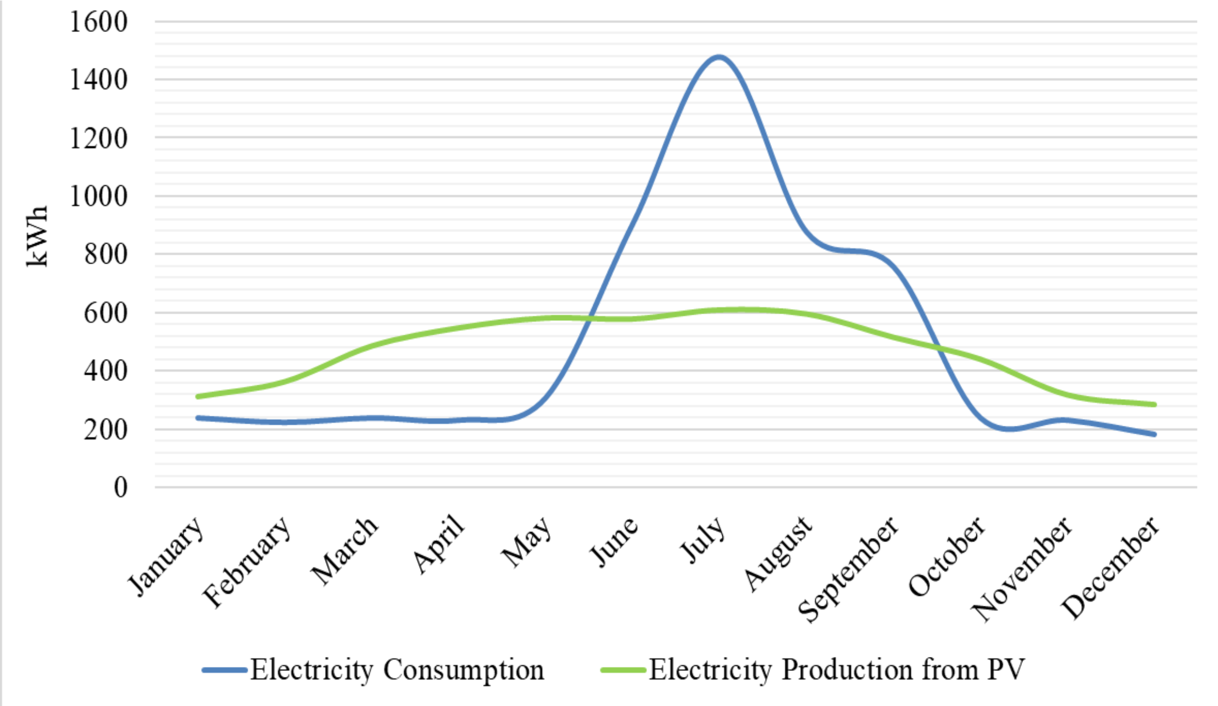


Figure 41. Electricity demand and generation from a small-scale solar PV in the city of Athens on an annual basis.

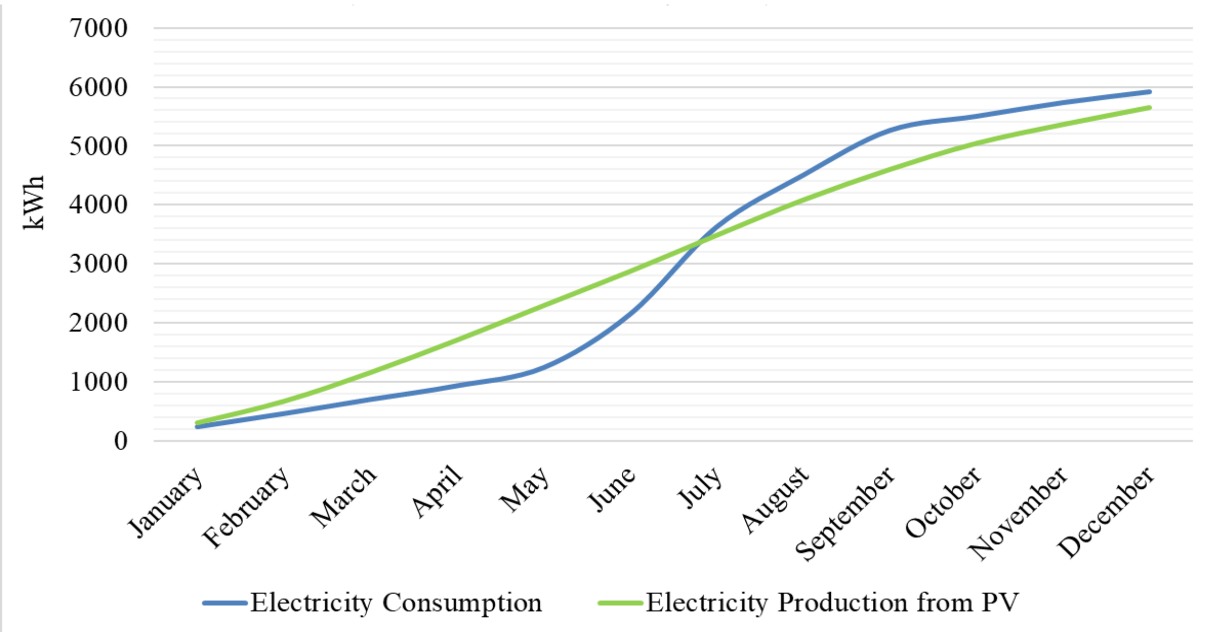


Figure 42. Cumulative electricity demand and generation from a small-scale solar PV in the city of Athens on an annual basis.

On the hand, Figure 43 presents the electricity demand and generation from a small-scale solar PV in the city of Thessaloniki on an annual basis.

Slight differences compared to the case of Athens can be observed, especially during the summer months, where in Thessaloniki the need for cooling is slightly lower, likely due to the comparatively lower temperatures experienced during the summer season compared to Athens. The same also applies to the case of PV generation.

Furthermore, Figure 44 presents cumulative electricity demand and generation from a small-scale solar PV in the city of Thessaloniki on an annual basis, indicating that a 3 kW_p installed solar PV capacity can cover around 85% of the total electricity demand on a yearly basis.

Such an installation, in the case of Thessaloniki, is able to fully cover the electricity needs of the reference building from March to June, while from July to December the building will have to supplement electricity needs from the grid.

Total electricity demand is equal to 5,543 kWh per year, with 2,670 kWh attributed to cooling needs and 2,872 kWh to appliance usage. Moreover, the solar PV installation is able to generate 4,693 kWh on an annual basis.

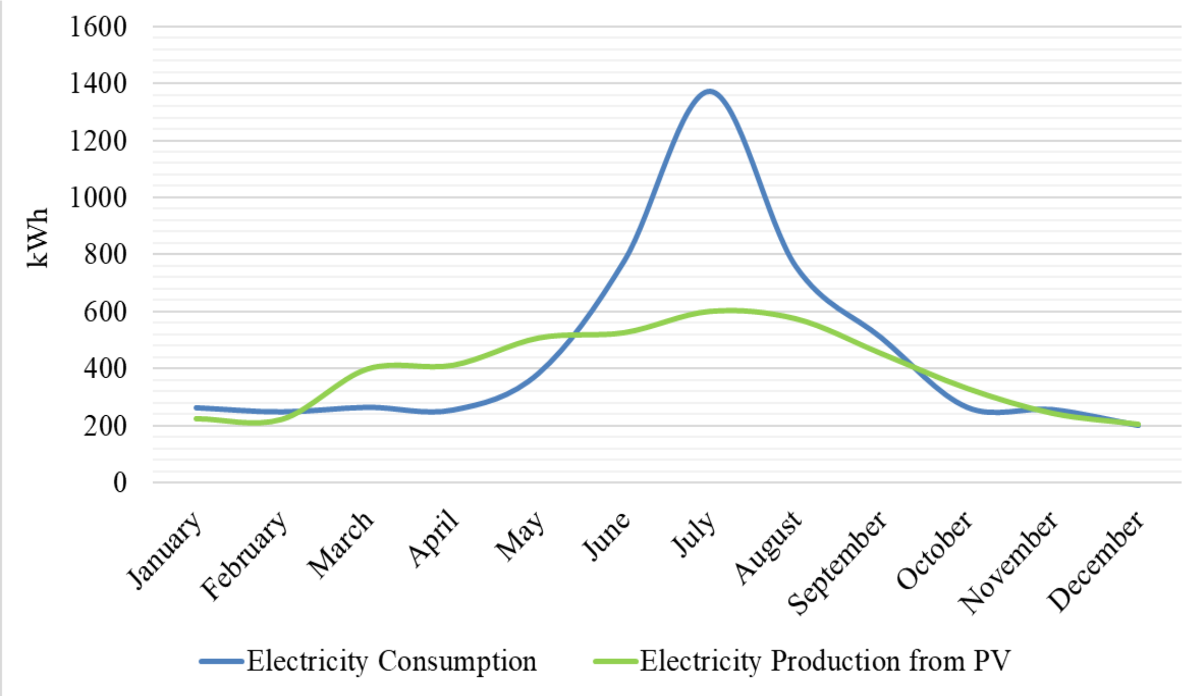


Figure 43. Electricity demand and generation from a small-scale solar PV in the city of Thessaloniki on an annual basis.

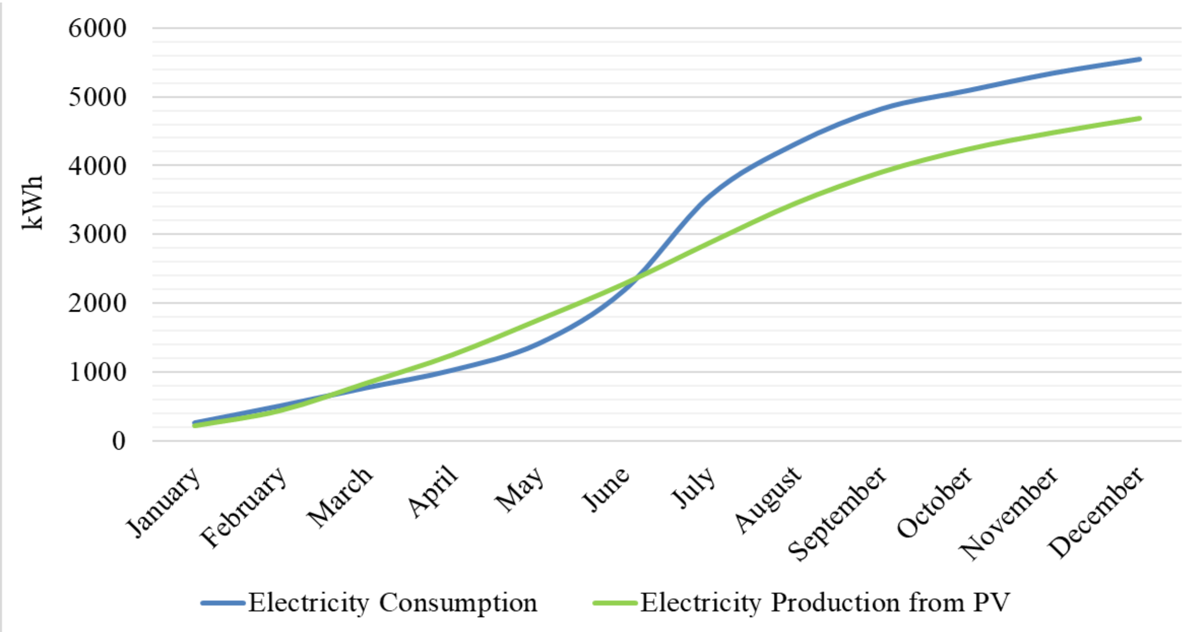


Figure 44. Cumulative electricity demand and generation from a small-scale solar PV in the city of Thessaloniki on an annual basis.

We also present modeling results on the economic viability of citizen investments in prosumerism in the case of Greece (**Figure 45**).

Considering the retail price of electricity paid by households in Greece- set at 0.2325 €/kWh according to the recently introduced "*Green Invoice for Households*" (Public Power Corporation, 2024), including all relevant regulated tariffs- modeling outcomes indicate that a net metering scheme with no remuneration for the electricity fed into the grid is characterized by larger profitability (in terms of NPV) for prosumers, with the estimated NPV for the "*future world*" narratives totaling approximately: *(i). "Familiar World":* 10,380 €, *(ii). "Unified World":* 6,750 €, and *(iii). "Fragmented World":* 14,350 €, for a 25-year life cycle.

Furthermore, the discounted payback period of the investment under the net metering scheme and the "*future-world*" narratives is: *(i). "Familiar World":* 3.9 years, *(ii). "Unified World":* 5.5 years, and *(iii). "Fragmented World":* 3.0 years.

Furthermore, based on the existing FiT scheme, in which prosumers are paid a fixed price of 87 €/MWh for the excess electricity they supply to the grid, the NPV of investing in PV prosumerism in Athens for the "*future world*" narratives is estimated approximately at:

(i). "Familiar World": 4,190 €, *(ii). "Unified World":* 2,835 €, and *(iii). "Fragmented World":* 5,680 €, for a 25-year life cycle, while the respective investment's discounted payback period is estimated at: *(i). "Familiar World":* 7.4 years, *(ii). "Unified World":* 9.2 years, and *(iii). "Fragmented World":* 5.8 years.

The analysis for the city of Thessaloniki mirrors the conducted for Athens; we consider the same policy schemes in place, i.e., a net metering with no direct remuneration for the prosumers and a FiT scheme with a fixed price set at 87 € per MWh.

In this case, modeling results indicate that, an investment in solar PV prosumerism in Thessaloniki yields an NPV, for the "*future-world*" narratives, of: *(i). "Familiar World":* 7,900 €, *(ii). "Unified World":* 4,890 €, and *(iii). "Fragmented World":* 11,200 €, for a 25-year life cycle, whereas the discounted payback period of the investment is: *(i). "Familiar World":* 4.6 years, *(ii). "Unified World":* 6.7 years, and *(iii). "Fragmented World":* 3.5 years.

As for the profitability of the investment under the existing FiT scheme in the case of Thessaloniki, assuming a 0.9% annual degradation rate of the PV system, the NPV for the different "*future-world*" narratives is estimated at: *(i). "Familiar World":* 2,320 €, *(ii). "Unified World":* 3,580 €, and *(iii). "Fragmented World":* 4,955 €, over a 25-year life cycle.

The respective discounted payback period, under the FiT scheme, is equal to: *(i). "Familiar World":* 8.0 years, *(ii). "Unified World":* 10.4 years, and *(iii). "Fragmented World":* 6.5 years.

Results on the economic viability of investing in solar PV prosumerism in the cities of Athens and Thessaloniki indicate that the existing FiT scheme in Greece offers greater profitability to prosumers when the installed capacity of the PV system is significantly larger.

On the other hand, when prosumers choose to install smaller capacities, such as in the analyzed case (3 kW_p), the existing net metering scheme seems to be more attractive in terms of its profitability.

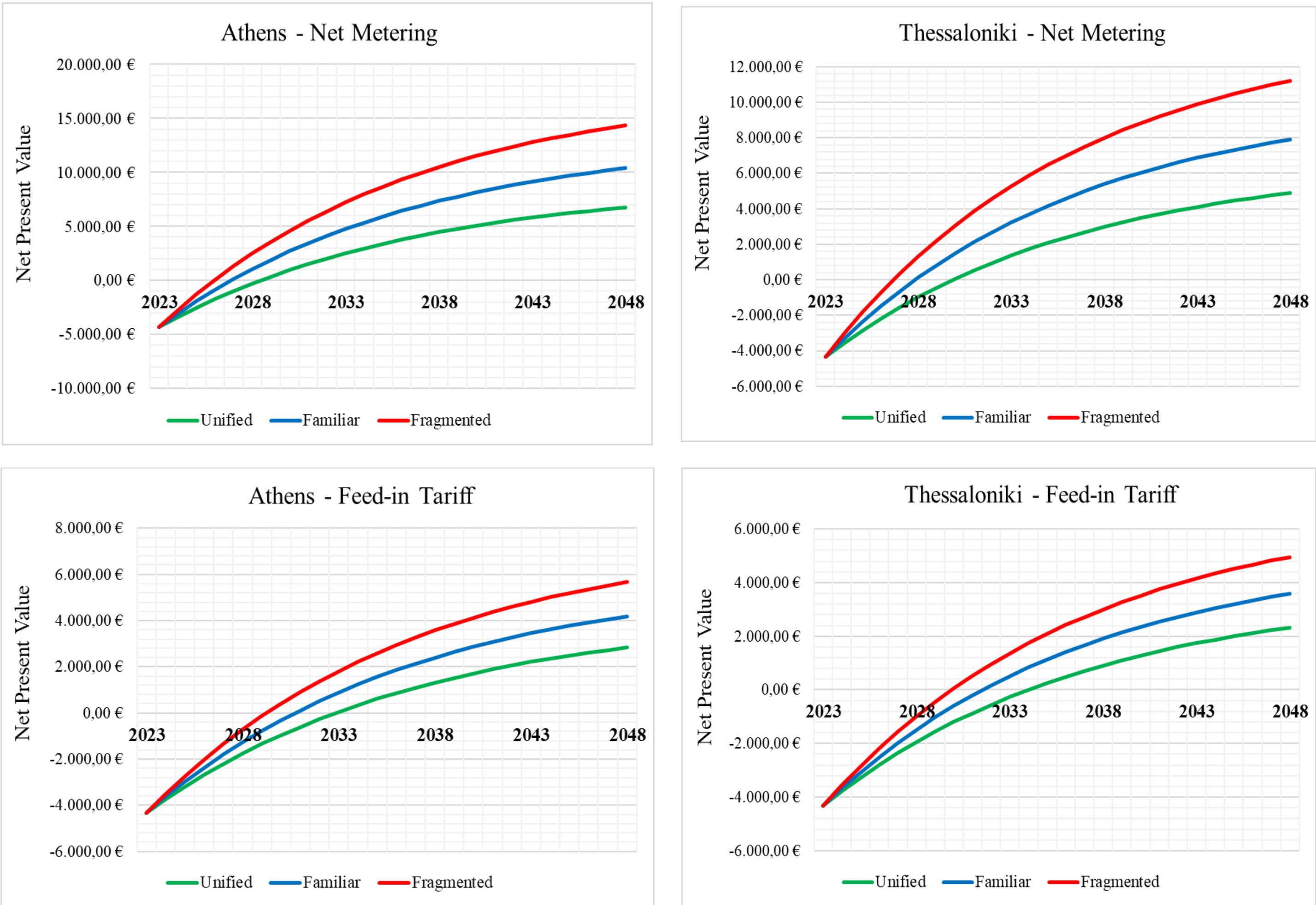


Figure 45. Evolution of the Net Present Value metric for a 3 kW_p rooftop solar PV investment in Greece under the existing net metering and feed-in-tariff schemes and for the "*future-world*" narratives under study in the cases of Athens and Thessaloniki.

Finally, we also quantify the emission reduction (decarbonization) potential from investing in PV prosumerism in the Greek residential sector, and in the cities of Athens and Thessaloniki, in particular (**Figure 46**).

More specifically, in the case of Athens, modeling results show a higher level of emission reduction (decarbonization) potential under the three (3) "*future-world*" narratives, as a 3 kWp rooftop solar PV system could lower carbon emissions by approximately: *(i). "Familiar World":* 14.44 $tnCO_2$eq., *(ii). "Unified World":* 7.22 $tnCO_2$eq., and *(iii). "Fragmented World":* 28.88 $tnCO_2$eq. by 2050.

Conversely, in Thessaloniki, a similar solar PV system could reduce carbon emissions by approximately: *(i). "Familiar World":* 12 $tnCO_2$eq., *(ii). "Unified World":* 6.2 $tnCO_2$eq., and *(iii). "Fragmented World":* 24.1 $tnCO_2$eq. by 2050.

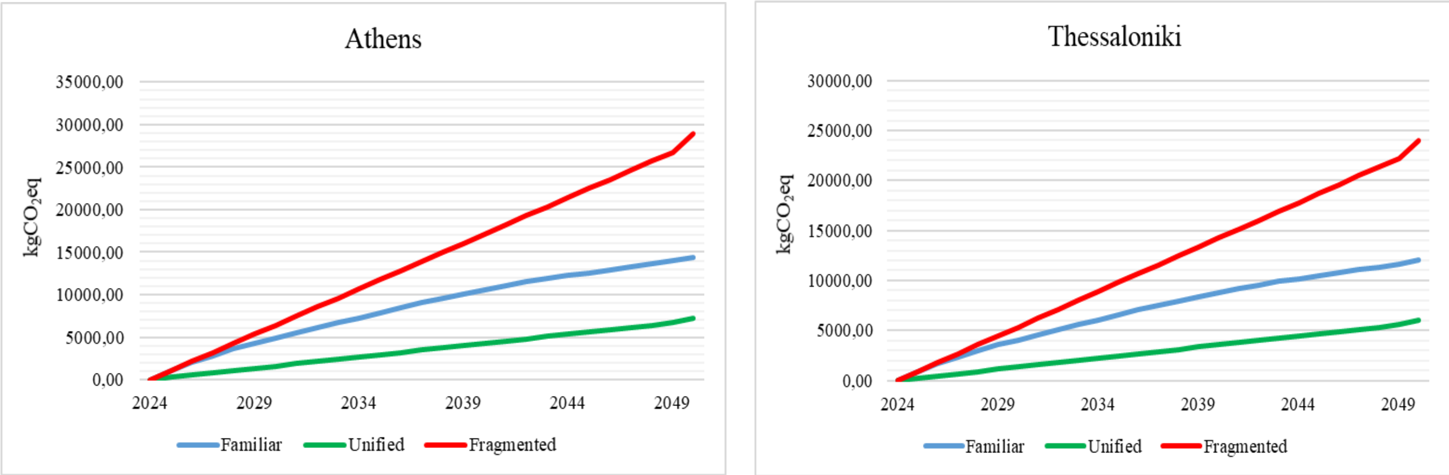


Figure 46. Evolution of the cumulative levels of CO_2 emissions avoided (tnCO_2) in the residential sector of Athens and Thessaloniki by 2050, under a potential "*Power to the People*" storyline (household level) and for the three (3) different "*future-world*" narratives under study.

Portugal

Electricity demand and generation from a 3 kW$_p$ solar PV system in the city of Lisbon on an annual basis are depicted in **Figure 47**.

The electricity demand in this case presents its peak during the months characterized by elevated temperatures, specifically from May to September. During this period, electricity demand averages 383 kWh on a monthly basis, indicating increased cooling needs.

Furthermore, the solar PV generation consistently exceeds electricity consumption on a monthly basis, reaching its highest potential in July, at 614 kWh.

Concerning the cumulative electricity demand and generation from a small-scale solar PV in the city of Lisbon on an annual basis, illustrated in **Figure 48**, it is observed that the aggregated electricity demand on an annual basis amounts to 2,827 kWh, while the annual electricity generation is 5,499 kWh.

Finally, the 3 kW$_p$ solar PV system on the rooftop of the Lisbon reference building possesses the capability to significantly surpass the electricity demand. This system achieves a coverage rate of approximately 195%, indicating that the solar PV output is nearly double the amount of electricity consumption.

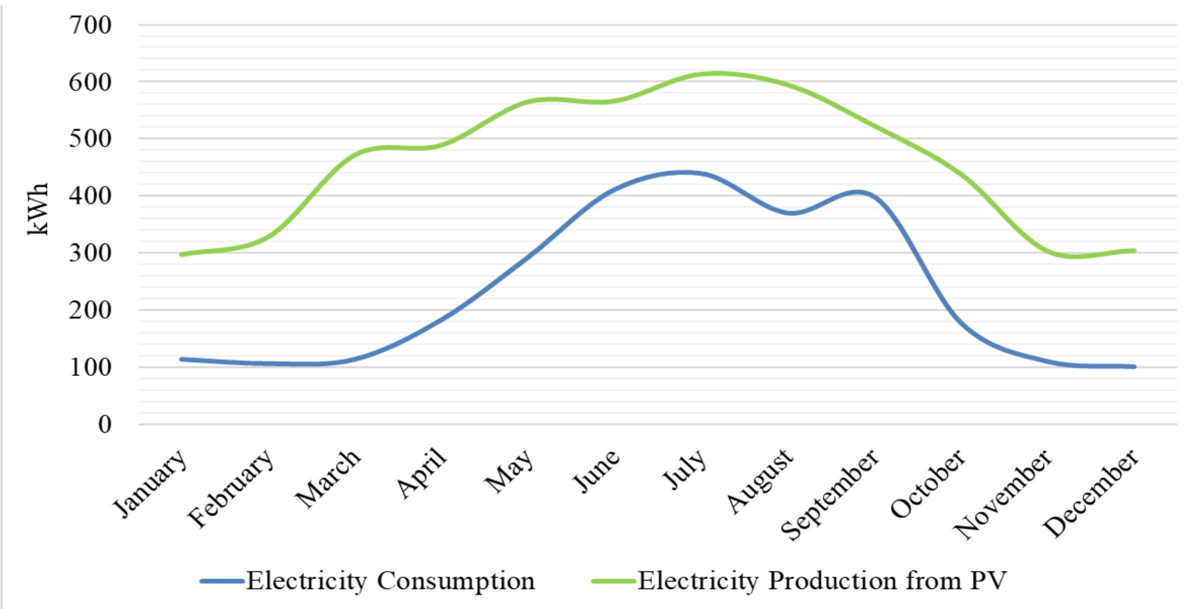


Figure 47. Electricity demand and generation from a small-scale solar PV in the city of Lisbon on an annual basis.

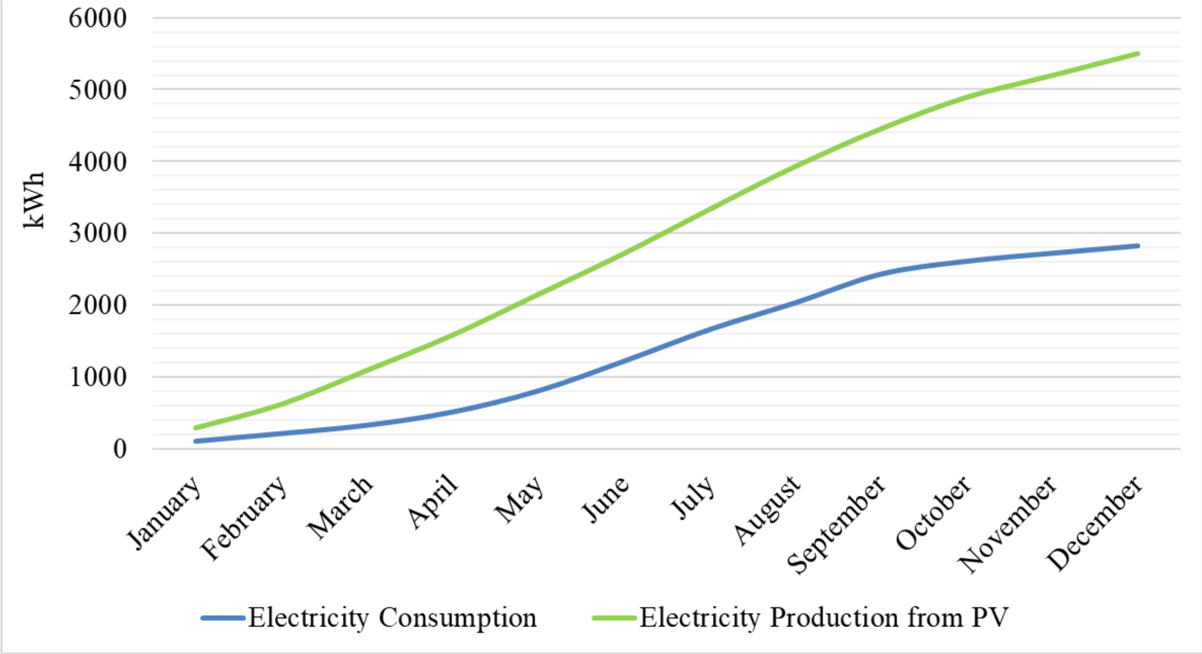


Figure 48. Cumulative electricity demand and generation from a small-scale solar PV in the city of Lisbon on an annual basis.

On the other hand, the electricity demand and generation from a small-scale solar PV in the city of Porto on an annual basis, is presented in **Figure 49**.

The electricity demand for the reference building in Porto is 19.53% lower even than the electricity demand of the reference building in Lisbon, while it presents its highest electricity demand during months with high temperatures, notably from May to September, where the needs for cooling are elevated.

During this time, the average monthly electricity demand amounts to 295 kWh, while solar PV generation constantly surpasses monthly electricity demand on a monthly basis, peaking in July, when solar PV generation reaches 592 kWh.

Overall, total electricity generation from the PV system under study amounts to 5,153 kWh on an annual basis (**Figure 50**).

Conversely, total annual electricity demand amounts to 2,275 kWh, with 964 kWh attributed to cooling and 1,311 kWh to appliance usage.

The 3 kW_p solar PV system has the capacity to exceed the electricity demand for the full year and it demonstrates a coverage rate of around 226%, signifying that the solar PV output surpasses the electricity demand by more than twofold.

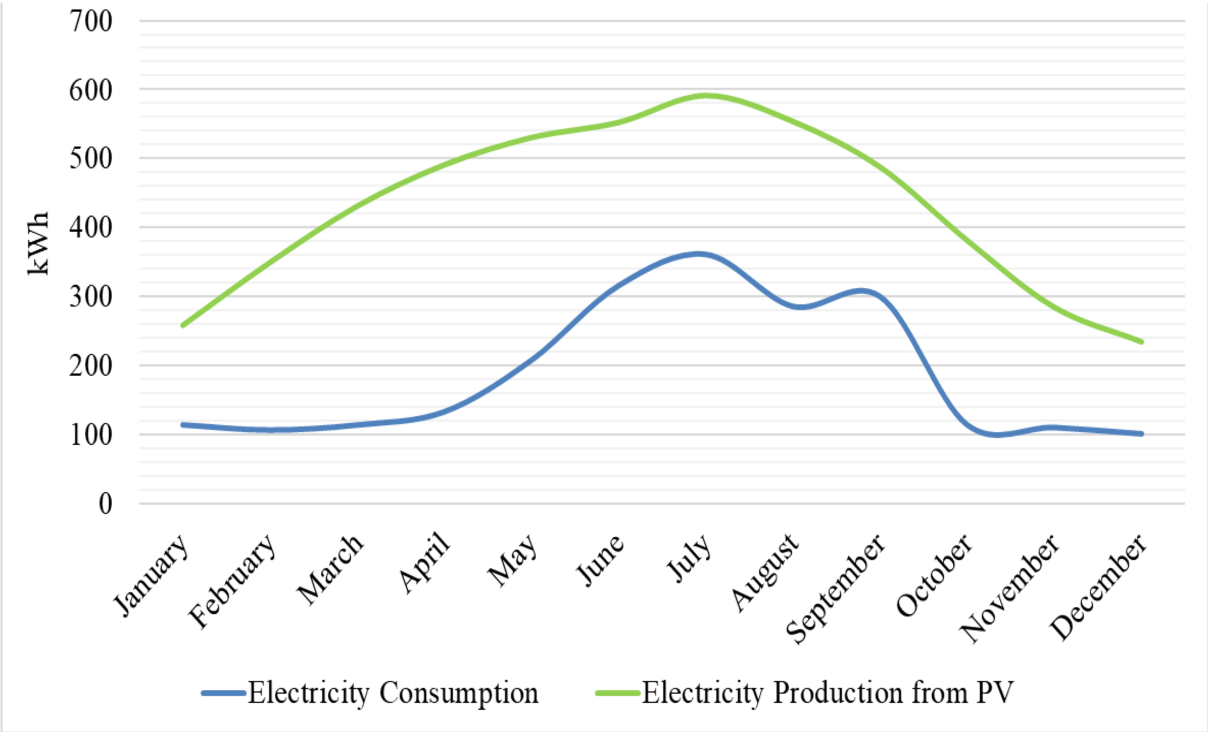


Figure 49. Electricity demand and generation from a small-scale solar PV in the city of Porto on an annual basis.

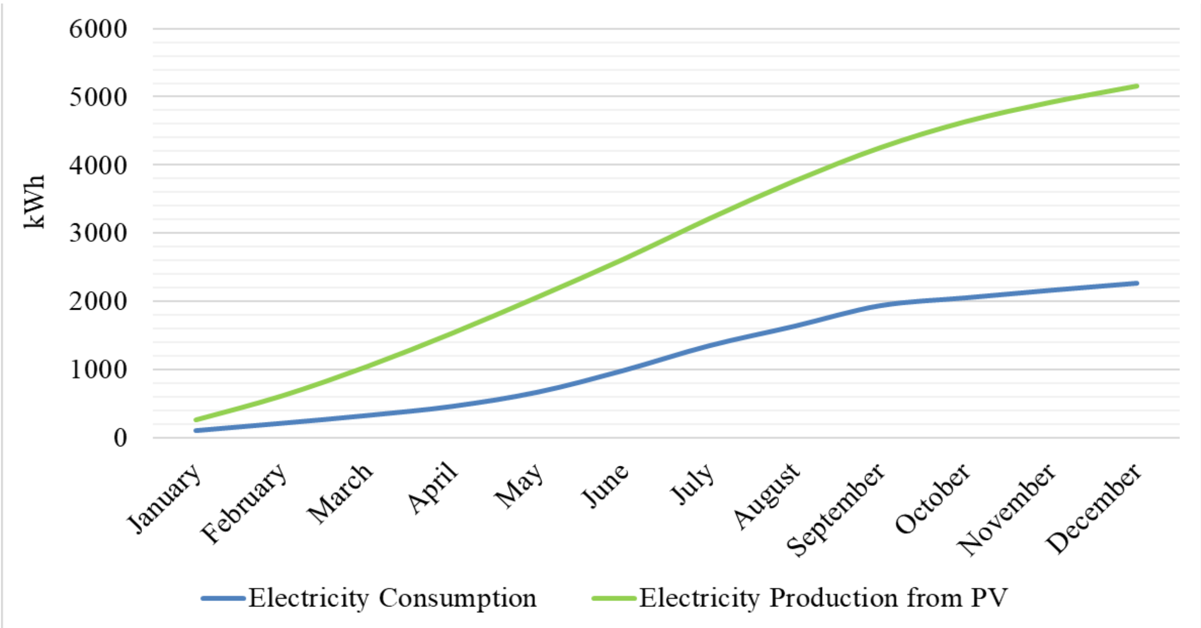


Figure 50. Cumulative electricity demand and generation from a small-scale solar PV in the city of Porto on an annual basis.

We also present modeling results on the economic viability of citizen investments in prosumerism in the case of Portugal (**Figure 51**) for the existing net billing scheme.

Considering capital costs as well as the retail price of electricity in Portugal, we provide a post analysis on the economic viability for prosumers. With a retail price of electricity equal to 0.2558 €/kWh (Country Economy, 2024c), the calculated NPV for the "*future-world*" narratives under study stands at: *(i). "Familiar World":* 2,850 €, *(ii). "Unified World":* 2,490 €, and *(iii). "Fragmented World":* 3,200 €.

Furthermore, the discounted payback period of the investment is: *(i). "Familiar World":* 8.3 years, *(ii). "Unified World":* 9.2 years, and *(iii). "Fragmented World":* 7.8 years.

By considering the retail price of electricity under the "*Familiar World*" narrative in Portugal, as mentioned before, the NPV for the "*future-world*" narratives under the existing net billing scheme in Porto is estimated to be approximately:

(i). "Familiar World": 2,380 €, *(ii). "Unified World":* 2,065 €, and *(iii). "Fragmented World":* 2,690 €, for a 25-year life cycle, whereas the discounted payback period of the investment is: *(i). "Familiar World":* 9.4 years, *(ii). "Unified World":* 10.2 years, and *(iii). "Fragmented World":* 8.7 years.

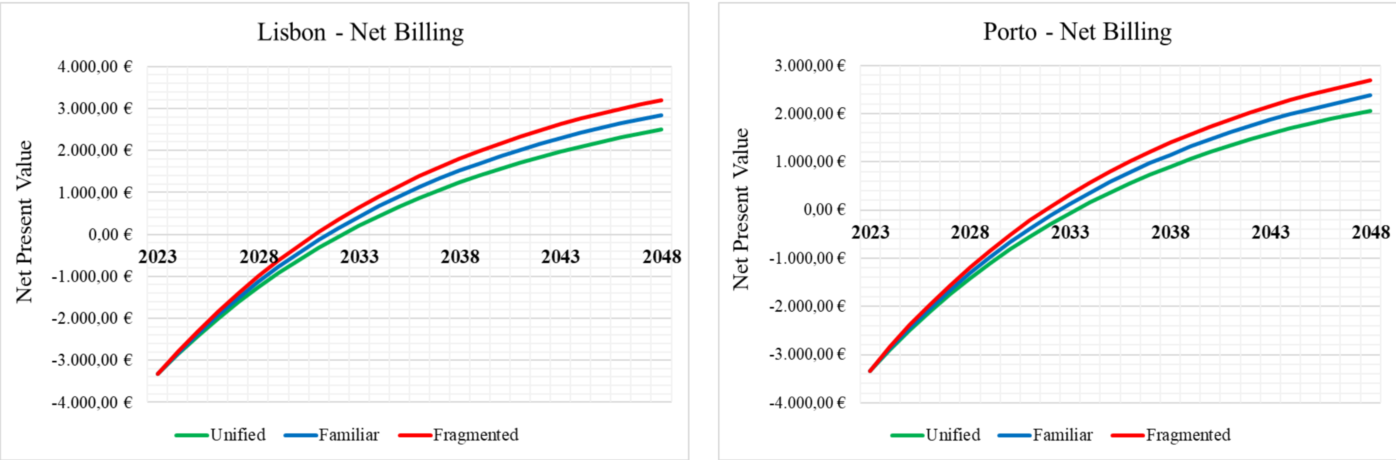


Figure 51. Evolution of the Net Present Value metric for a 3 kWp rooftop solar PV investment in Portugal under the existing net billing scheme and for the "*future-world*" narratives under study in the cases of Lisbon and Porto.

Finally, we also quantify the emission reduction (decarbonization) potential from investing in PV prosumerism in the Portuguese residential sector, and in the cities of Lisbon and Port, in particular (**Figure 52**).

Analyzing the outcomes for the two (2) cities reveals differences in their potential for emission reduction (decarbonization), influenced by factors such as solar PV output and the structure of Portugal's electricity generation. Additionally, there are significant variations across different future scenarios.

In Lisbon, a 3 kWp rooftop solar PV system is expected to reduce carbon emissions for the "*future-world*" narratives by approximately: *(i). "Familiar World":* 2.87 $tnCO_2eq.$, *(ii). "Unified World":* 1.44 $tnCO_2eq.$, and *(iii). "Fragmented World":* 5.75 $tnCO_2eq.$ by 2050.

Subsequently, in Porto, a similar solar PV system is projected to decrease carbon emissions by around: *(i). "Familiar World":* 2.69 $tnCO_2eq.$, *(ii). "Unified World":* 1.35 $tnCO_2eq.$, and *(iii). "Fragmented World":* 5.38 $tnCO_2eq.$ by 2050.

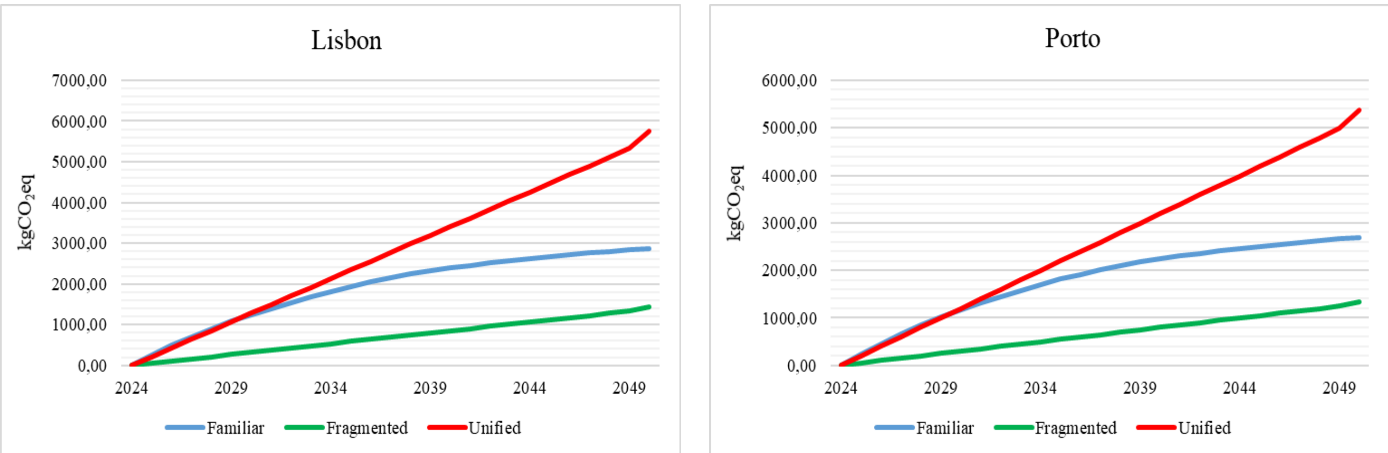


Figure 52. Evolution of the cumulative levels of CO_2 emissions avoided ($tnCO_2$) in the residential sector of Lisbon and Porto by 2050, under a potential "*Power to the People*" storyline (household level) and for the three (3) different "*future-world*" narratives.

Spain

Electricity demand and generation from a 3 kW_p solar PV system in the city of Bilbao on an annual basis are depicted in **Figure 53**. Electricity demand peaks from June to September, with an average consumption of 690 kWh during these months. The highest solar PV output is observed from April to August, averaging 475 kWh during these five (5) months, while excess electricity is produced only in April and May.

Moreover, **Figure 54** shows the cumulative electricity demand and generation from a small-scale solar PV in the city of Bilbao on an annual basis. Only 16.43% of this demand is attributed to cooling needs, while 83.57% is attributed to appliance usage.

The total annual electricity generation is 4,316 kWh, meaning that the 3 kW_p solar PV system installed can cover around 69% of the total electricity demand of the household under study in the city of Bilbao.

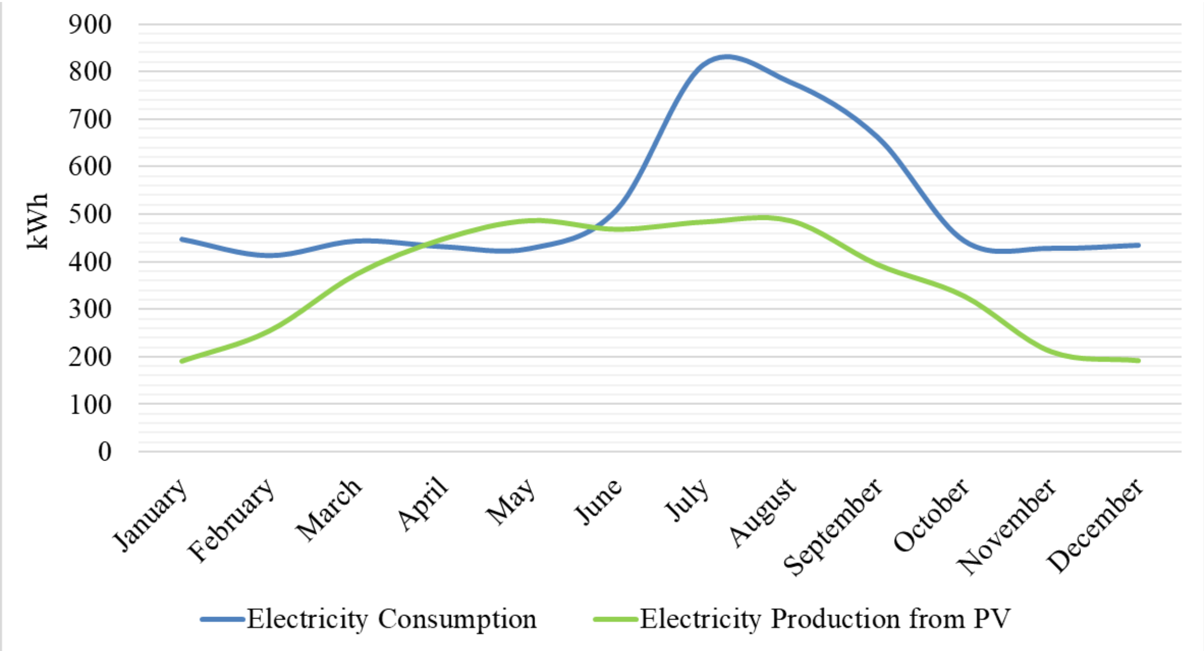


Figure 53. Electricity demand and generation from a small-scale solar PV in the city of Bilbao on an annual basis.

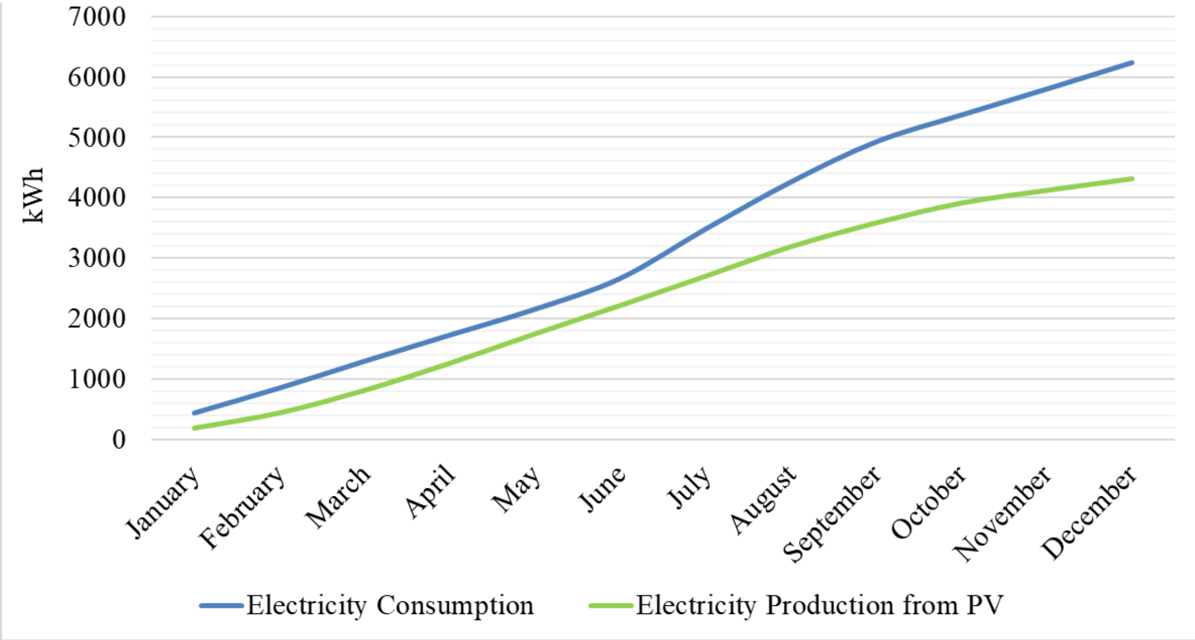


Figure 54. Cumulative electricity demand and generation from a small-scale solar PV in the city of Bilbao on an annual basis.

Electricity demand and generation from a 3 kW_p solar PV system in the city of Madrid on an annual basis are depicted in **Figure 55**.

The results indicate a very high electricity demand, exceeding 400 kWh over the course of the year. Peaks in electricity demand are observed in July, August, and September, with 1,021 kWh, 999 kWh, and 801 kWh, respectively.

Regarding the electricity generated from the 3 kW_p solar PV system placed on the rooftop of the Madrid reference household, it peaks between April and August, with solar PV outputs ranging from 505 kWh (in April) to 588 kWh (in August).

As for the cumulative electricity demand and generation from a small-scale solar PV in the city of Madrid on an annual basis, illustrated in **Figure 56**, it is observed that total annual electricity demand amounts to 6,851 kWh while annual PV electricity generation is equal to 5,319 kWh.

Lastly, such a PV system possesses the capability to cover 78% of the total electricity demand for the household under study in the city of Madrid, indicating that larger PV systems are needed to cover the full electricity demand.

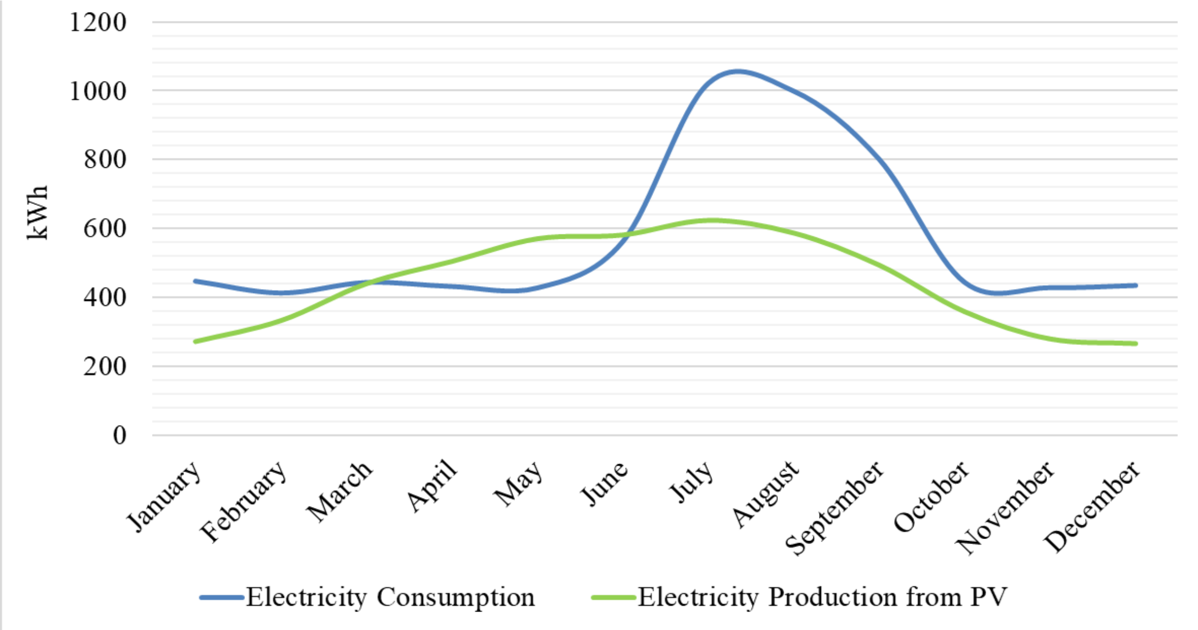


Figure 55. Electricity demand and generation from a small-scale solar PV in the city of Madrid on an annual basis.

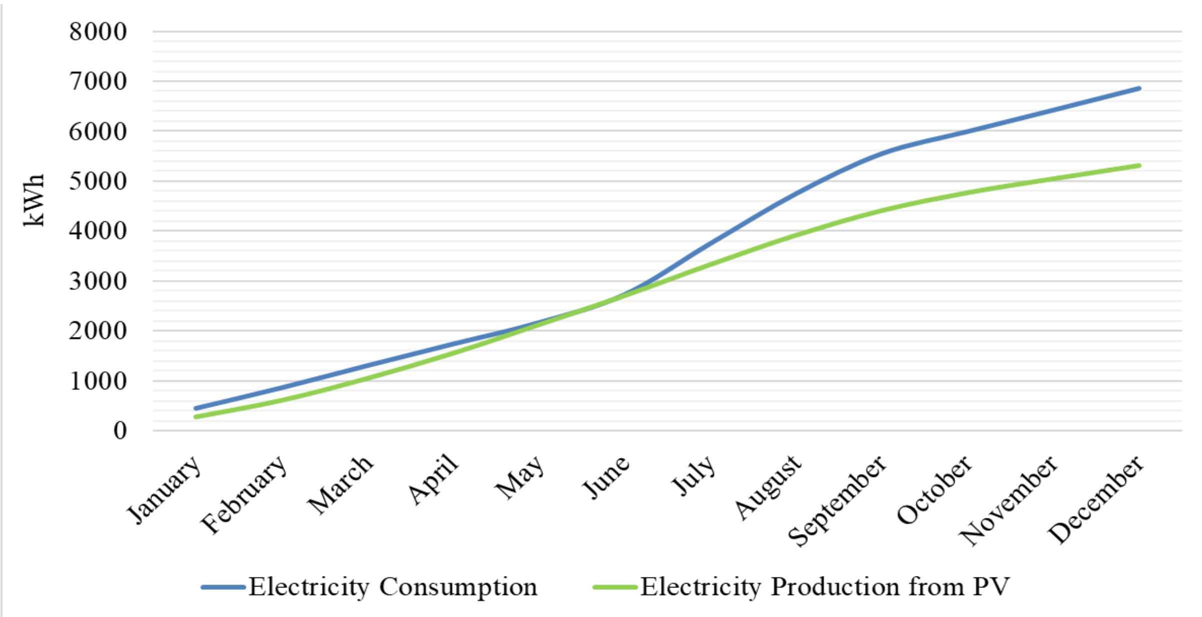


Figure 56. Cumulative electricity demand and generation from a small-scale solar PV in the city of Madrid on an annual basis.

Finally, **Figure 57** presents the electricity demand and generation from a small-scale solar PV in the city of Malaga on an annual basis.

Electricity consumption in Malaga reaches its highest point during the months of July, August, and September, with notable values of 1,138 kWh, 1,122 kWh, and 979 kWh, respectively. The average electricity generation for the period spanning from April to September amounts to 555 kWh.

Moreover, **Figure 58** illustrates the cumulative electricity demand and generation from a small-scale solar PV in the city of Malaga on an annual basis.

The total annual electricity demand amounts to 7,274 kWh, while the electricity need for cooling amounts to 28.5% of the total electricity demand, with the remaining 71.5% attributed to appliance usage.

On the other hand, the total annual electricity produced from the 3 kW_p solar PV system amounts to 5,623 kWh.

Overall, modeling results demonstrate that a solar PV system of 3 kW_p is capable of meeting around 77% of the total annual electricity demand.

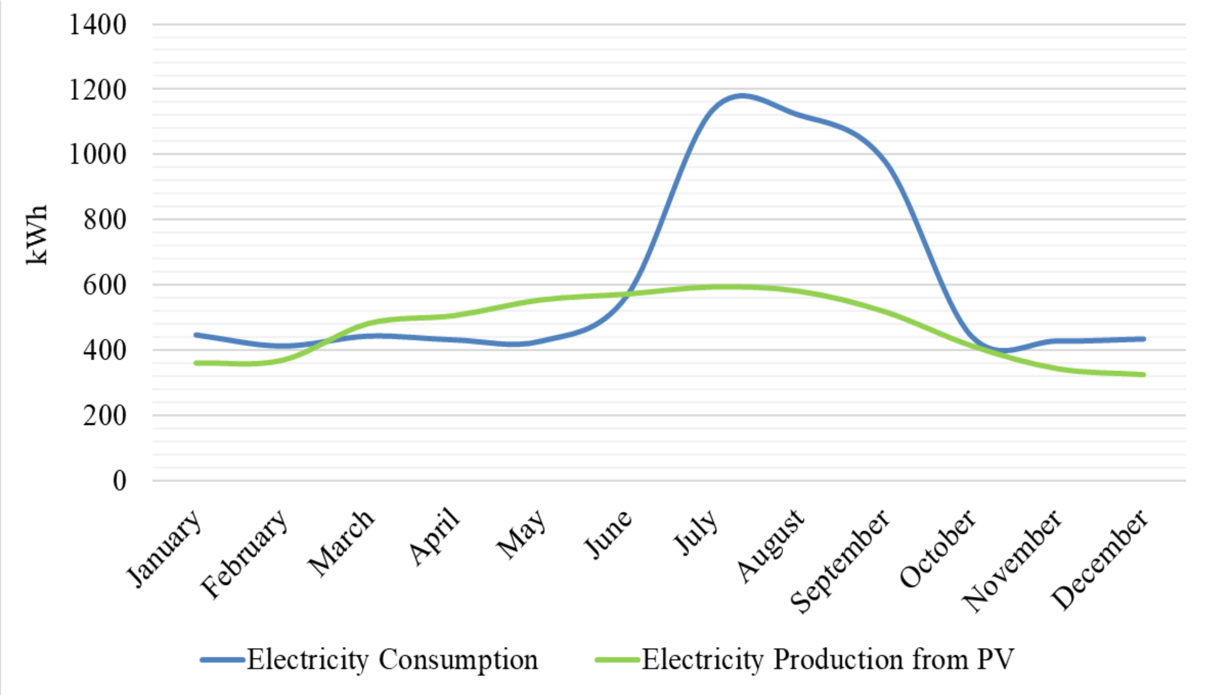


Figure 57. Electricity demand and generation from a small-scale solar PV in the city of Malaga on an annual basis.

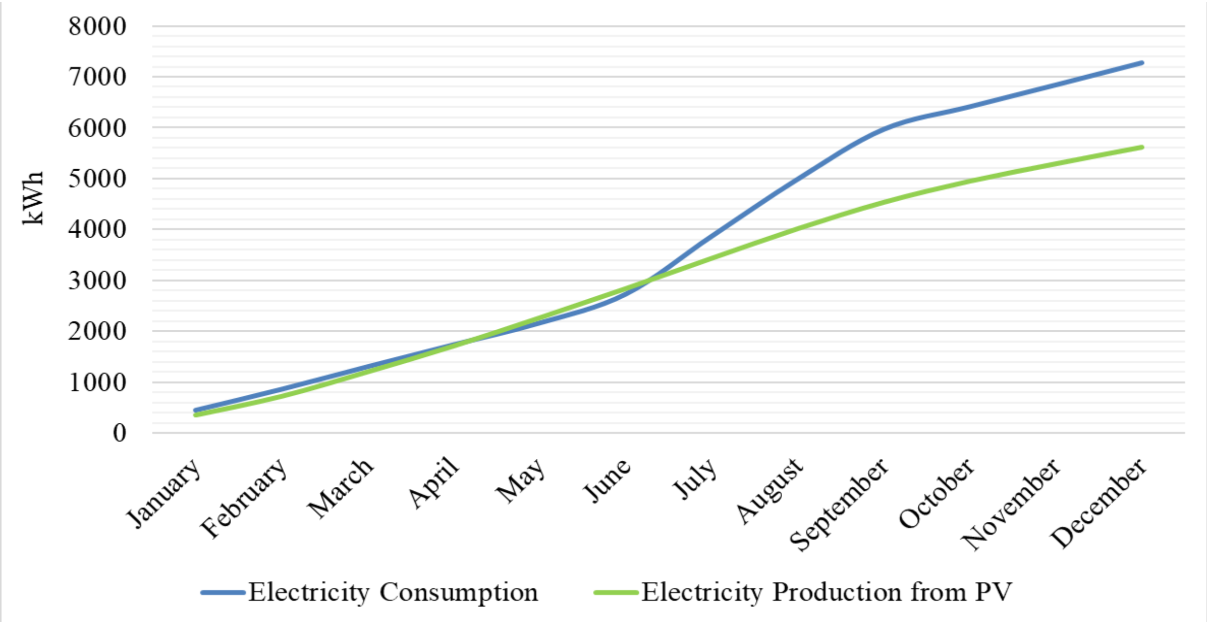


Figure 58. Cumulative electricity demand and generation from a small-scale solar PV in the city of Malaga on an annual basis.

We also present modeling results on the economic viability of citizen investments in prosumerism in the case of Spain (**Figure 59**), for the existing net billing scheme.

Considering the initial expenses associated with this investment, along with the prevailing retail price of electricity in Spain (0.2824 €/kWh) Country Economy (2024d)), we performed a retrospective evaluation of the advantages that prosumers could obtain by investing in a 3 kW_p solar PV system in the city of Bilbao.

More specifically, the NPV value for a 25-year life cycle for the "*future-world*" narratives amounts to: *(i). "Familiar World":* 2,500 €, *(ii). "Unified World":* 1,570 €, and *(iii). "Fragmented World":* 3,430

€, while the discounted payback period of the investment is: *(i). "Familiar World":* 10.7 years, *(ii). "Unified World":* 13.3 years, and *(iii). "Fragmented World":* 9.1 years.

Furthermore, the NPV value for the "future-world" narratives under the existing net billing scheme in the case of Madrid amounts to: *(i). "Familiar World":* 3,885 €, *(ii). "Unified World":* 2,820 €, and *(iii). "Fragmented World":* 4,950 €.

In addition, the discounted payback period of the investment is: *(i). "Familiar World":* 8.5 years, *(ii). "Unified World":* 10.2 years, and *(iii). "Fragmented World":* 7.3 years.

Finally, the NPV of the investment in the city of Malaga for the "*future-world*" narratives under study is estimated at: *(i). "Familiar World":* 4,290 €, *(ii). "Unified World":* 3,180 €, and *(iii). "Fragmented World"*: 5,390 €.

In addition, the discounted payback period equals to: *(i). "Familiar World":* 8.1 years, *(ii). "Unified World":* 9.6 years, and *(iii). "Fragmented World":* 6.9 years.

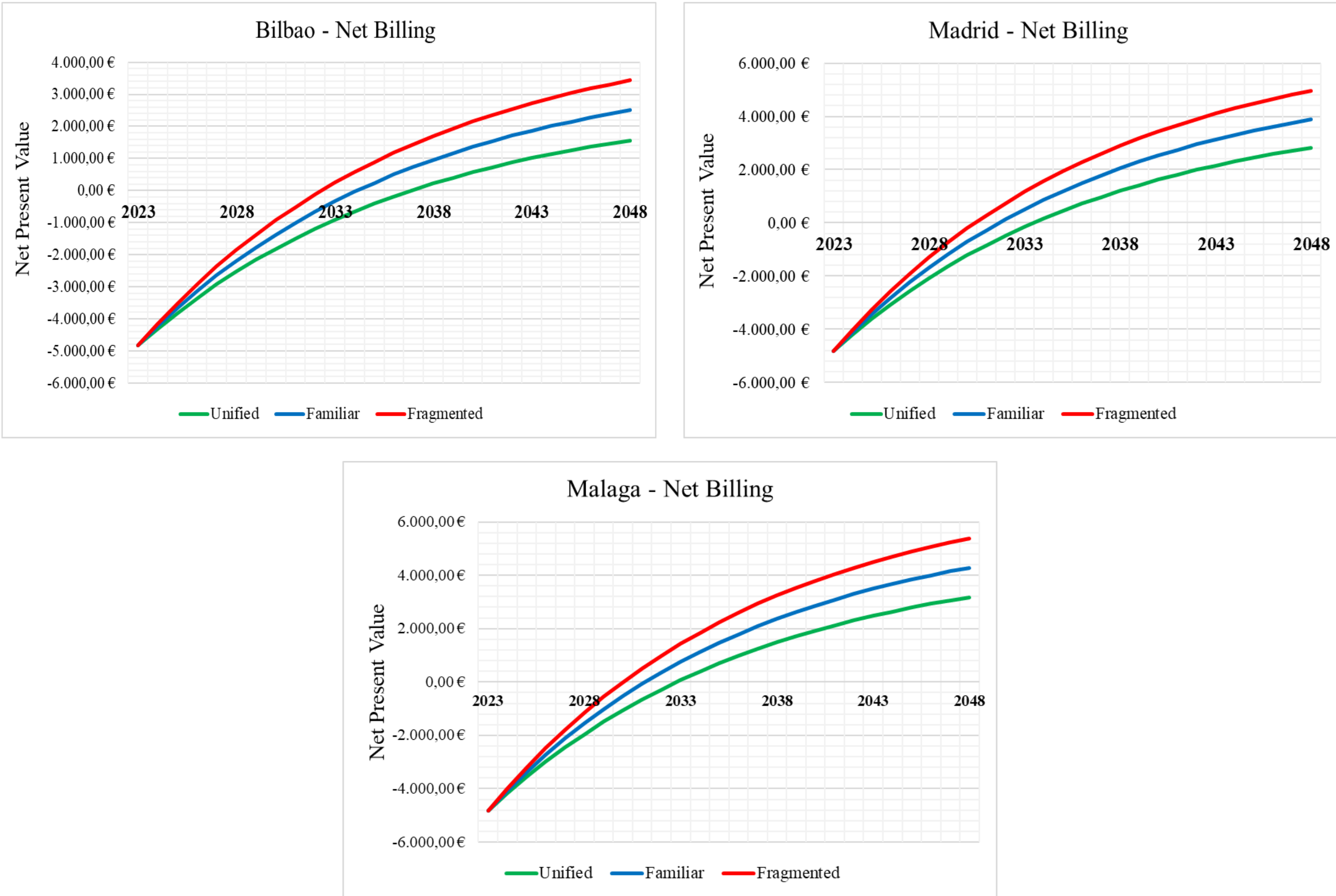


Figure 59. Evolution of the Net Present Value metric for a 3 kW_p rooftop solar PV investment in Spain under the existing net billing scheme and for the "*future-world*" narratives under study in the cases of Bilbao, Madrid, and Malaga.

Finally, we also quantify the emission reduction (decarbonization) potential from investing in PV prosumerism in the Spanish residential sector, and in the cities of Bilbao, Madrid, and Malaga, in particular (**Figure 60**).

Lastly, the decarbonization potential expected from the installation of a 3 kWp rooftop solar PV in the three (3) cities under study, is estimated to:

- For Madrid: *(i). "Familiar World":* 5.42 $tnCO_2eq.$, *(ii). "Unified World":* 2.7 $tnCO_2eq.$, and *(iii). "Fragmented World":* 10.83 $tnCO_2eq.$, by 2050.

- For Bilbao: *(i). "Familiar World":* 4.39 $tnCO_2eq.$, *(ii). "Unified World":* 2.2 $tnCO_2eq.$, and *(iii). "Fragmented World":* 8.79 $tnCO_2eq.$, by 2050.
- For Malaga: *(i). "Familiar World":* 5.73 $tnCO_2eq.$, *(ii). "Unified World":* 2.86 $tnCO_2eq.$, and *(iii). "Fragmented World":* 11.45 $tnCO_2eq.$, by 2050.

These outcomes highlight the different climatic data between the cities under study, in which the solar PV output is different.

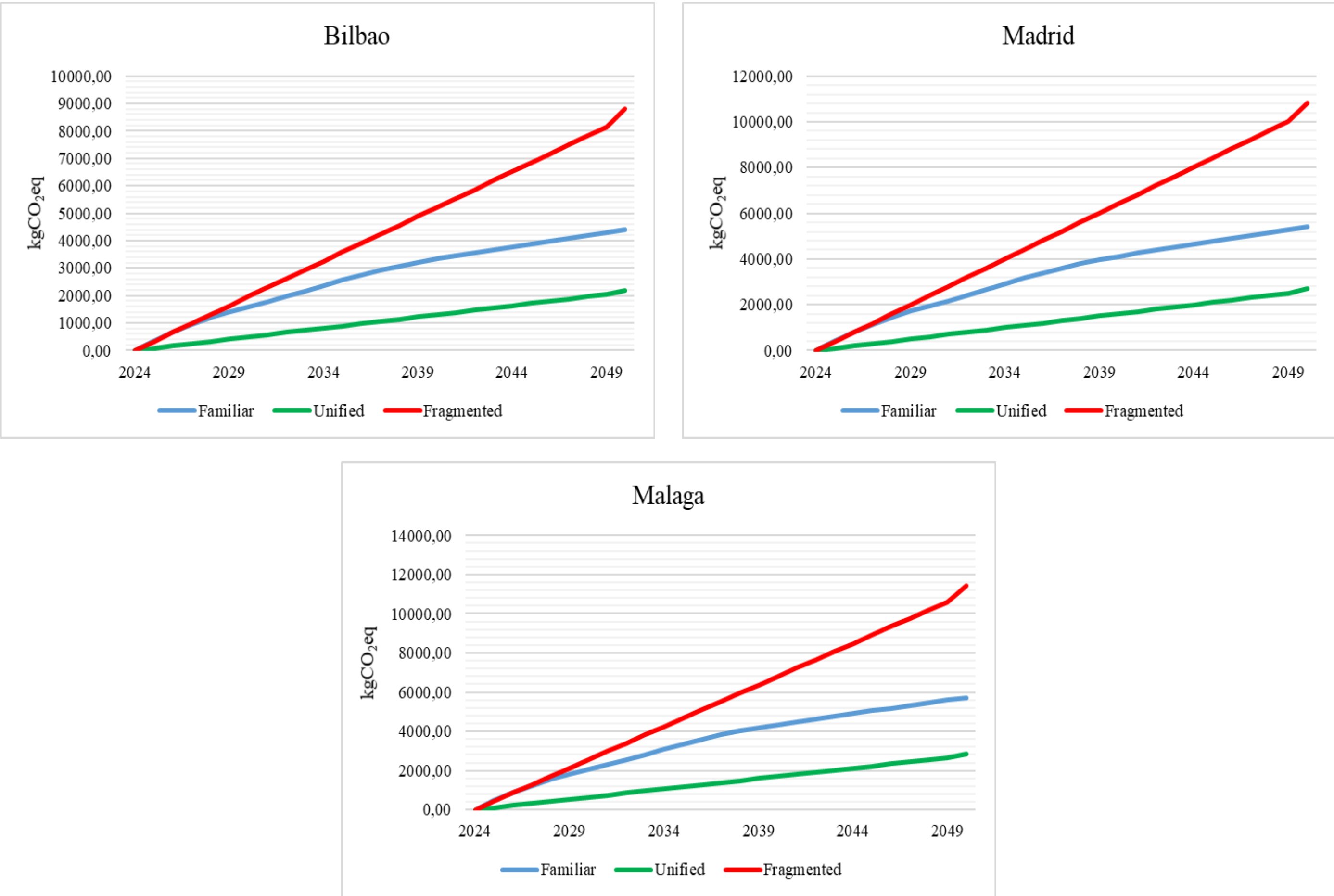


Figure 60. Evolution of the cumulative levels of CO_2 emissions avoided ($tnCO_2$) in the residential sector of Bilbao, Madrid, and Malaga by 2050, under a potential "*Power to the People*" storyline (household level) and for the three (3) different "future-world" narratives.

Cross-country comparison

Overall, a cross-country comparison (**Table 19**) of the results from the DREEM model highlights stronger financial incentives for citizens towards investments in PV prosumerism in the cases of Denmark and Greece.

This highlights the economic viability of the existing net metering schemes in both countries, especially when combined with lower installed capacities, as in these cases prosumers do not have the motivation to produce excess of electricity and sell it to the grid.

The main influence factor on this implication is the retail price of electricity since prosumers' profitability depends on it. We can observe the latter when comparing the economic implications for prosumers under the "*Unified World*" narrative, with the respective implications under the "*Fragmented World*" narrative.

More specifically, under a "*Unified World*" narrative, the economic benefits are considerably lower for the prosumers; this is mainly attributed to the decreased levels of retail price of electricity, since they determine (along with the capital costs which remain constant during the process because we assume that the investment takes place at the beginning of 2024) the profitability of the investment.

On the other hand, under a "*Fragmented World*" narrative, retail price of electricity reaches significantly increased levels. This results in significantly higher economic benefits for prosumers, since they have a greater profitability, which mainly results from self-consumption.

Furthermore, modeling results show that, when a FiT scheme is characterized by a high fixed price for the remuneration of prosumers, it can produce considerable economic benefits. This is evident in the case of France, where the NPV value under a FiT scheme is comparable to the net metering schemes in Denmark and Greece. Therefore, a higher fixed price for France would be necessary to provide prosumers with an even higher discounted payback period (Roulot & Raineri, 2018).

The comparison between Portugal and Spain reveals important insights regarding the profitability and incentives for prosumers under a similar net billing policy scheme, particularly in the context of the retail price of electricity and small-scale solar PV capacities in the residential sector.

In both countries, net billing policy schemes allow prosumers to offset their electricity consumption with the electricity generated by their rooftop solar PV systems. Any excess electricity generated beyond what is consumed is typically fed back into the grid and credited to the prosumer's account, usually at a much lower rate than the retail price of electricity (McDevitt, 2022).

The latter implies that profitability under net billing policy schemes is primarily derived from the benefits of self-consumption, rather than from the excess electricity generated. This is especially pronounced when the retail price of electricity is relatively high.

In such cases, prosumers can realize significant cost-savings by using the electricity generated by their solar PV systems to offset their own consumption, thereby reducing their reliance on grid electricity, and lowering their electricity bills.

As a result, there is a weaker incentive for prosumers in the residential sector to install solar PV systems of larger capacities under net billing policy schemes. Since the focus is on optimizing self-consumption rather than maximizing electricity exports to the grid, prosumers may prioritize smaller-scale solar PV installations that meet their immediate energy needs (Ordóñez et al., 2022).

The latter is evident when comparing NPVs and payback periods in both Portugal and Spain. According to our results, self-consumption in Portugal is approximately 14%, while in Spain it is 35%, resulting in larger economic benefits for prosumers.

Overall, our results highlight the drawbacks of net billing as a policy scheme to further incentivize citizen prosumerism, when compared to the net metering scheme. This is an important insight to be considered by policymakers when deciding on the appropriate policy planning to further promote PV prosumerism in the EU's residential sector (Ahsan Kabir et al., 2023; Dufo-López & Bernal-Agustín, 2015).

On the other hand, when it comes to environmental benefits, our results indicate that Greece and Spain (especially Greece) demonstrate a relatively greater capacity for emission reduction (decarbonization) when it comes to PV prosumerism in the residential sector.

This may be primarily attributed to the energy composition of power generation in both countries, wherein natural gas serves as the predominant energy source for electricity production. This is further compounded by the anticipated carbon emission projections obtained from the EU Reference Scenario 2020 (European Commission, 2020).

Additionally, our findings suggest that France exhibits a comparatively lower potential for decarbonization in comparison to Greece. However, there is no significant disparity observed between France and Denmark in terms of decarbonization potential. The observed disparities might be ascribed once more to the composition of energy sources within the power sector in France; the primary source of electricity generation in France is largely derived from nuclear energy, which has an emission factor close to zero.

Table 19. Economic and environmental benefits of citizen investments in PV prosumerism in the residential sector of 11 different European Union's cities under the ENCLUDE "*future-world*" narratives.

"*Familiar World*"

City	Policy scheme	Net present value (€)	Discounted payback period (years)	Emissions avoided by 2050 ($tnCO_2$)
Aalborg	Net metering	12,520	2.41	3.04
	Feed-in tariff	4,140	5.90	
Copenhagen	Net metering	10,130	2.89	2.57
	Feed-in tariff	3,400	6.80	
Marseille	Feed-in tariff	10,810	8.22	3.82
Paris	Feed-in tariff	7,860	10.03	3.1
Athens	Net metering	10,380	3,88	10.44
	Feed-in tariff	4,190	7.38	
Thessaloniki	Net metering	7,900	4,64	12
	Feed-in tariff	3,580	8.01	
Lisbon	Net billing	2,850	8.32	2.87
Porto	Net billing	2,380	9.43	2.69
Bilbao	Net billing	2,500	10.71	4.4
Madrid	Net billing	3,885	8.52	5.42
Malaga	Net billing	4,280	8.08	5.73

"*Unified World*"

City	Policy scheme	Net present value (€)	Discounted payback period (years)	Emissions avoided by 2050 ($tnCO_2$)
Aalborg	Net metering	8,150	3.44	1.52
	Feed-in tariff	2,605	8.11	
Copenhagen	Net metering	6,430	4.22	1.29
	Feed-in tariff	1,980	9.53	
Marseille	Feed-in tariff	10,245	8.53	1.90
Paris	Feed-in tariff	7,260	10.53	1.54
Athens	Net metering	6,755	5.44	7.22
	Feed-in tariff	2,835	9.24	
Thessaloniki	Net metering	4,890	6.67	6.00
	Feed-in tariff	2,320	10.35	
Lisbon	Net billing	2,490	9.15	1.44
Porto	Net billing	2,065	10.17	1.35
Bilbao	Net billing	1,570	13.27	2.20

Madrid	Net billing	2,817	10,19	2.71
Malaga	Net billing	3,180	9.63	2.86

"***Fragmented World***"

City	Policy scheme	Net present value (€)	Discounted payback period (years)	Emissions avoided by 2050 ($tnCO_2$)
Aalborg	Net metering	20,190	1.57	6.08
	Feed-in tariff	6,840	4.04	
Copenhagen	Net metering	16,620	1.87	5.15
	Feed-in tariff	5,890	4.52	
Marseille	Feed-in tariff	11,370	7.94	7.63
Paris	Feed-in tariff	8,460	9.57	6.14
Athens	Net metering	14,350	2.96	28.88
	Feed-in tariff	5,680	5.80	
Thessaloniki	Net metering	11,200	3.49	24.02
	Feed-in tariff	4,960	6.51	
Lisbon	Net billing	3,200	7.84	5.75
Porto	Net billing	2,690	8.72	5.39
Bilbao	Net billing	3,435	9.06	8.79
Madrid	Net billing	4,955	7.29	10.83
Malaga	Net billing	5,385	6.93	11.45

7.2. "Band Together" and further diffusion of Collective Energy Initiatives across Europe

Having identified the parameters that have the biggest leverage on the projected growth of the CEIs under study, means that messaging and initiatives can now be tailored to resonate with the specific motivations of each group, and thus, significantly increase their interest and likelihood for participation in the CEI. For instance, some indicative strategies and recommendations to motivate for each of the prevalent "Personas":

"*The Eco-Collaborators*":

- Highlight of the collective environmental impact and how mass participation can make a real difference.
- Showcasing community projects, by organizing workshops, educational sessions, or tree-planting events that foster a sense of collaboration and shared purpose.
- Leverage of social media and digital tools such as online platforms for residents to connect, share ideas, and celebrate collective achievements towards environmental goals.

"*The Green Guardians*":

- Clear communication of the community's commitment to RES, reduced carbon footprint, and overall environmental benefits.
- Collaboration with local or national environmental groups to endorse the community and its environmental impact.

- Offer educational opportunities, by hosting workshops or seminars on climate change, renewable energy technologies, and the benefits of sustainable living.

"*The Tech Trailblazers*":

- Emphasis on innovation, smart technologies, and showcase the community's use of cutting-edge technologies for energy management, smart home integration, and data analysis.
- Organize tech workshops and demonstrations to provide opportunities for residents to experience technology firsthand and learn about its benefits.
- Partner with technology companies to offer exclusive discounts or early access to new products for community members.

Figure 61, **Figure 62**, and **Figure 63** present simulation results of the ANIMO modeling framework on the projected growth of the three (3) CEIs under study.

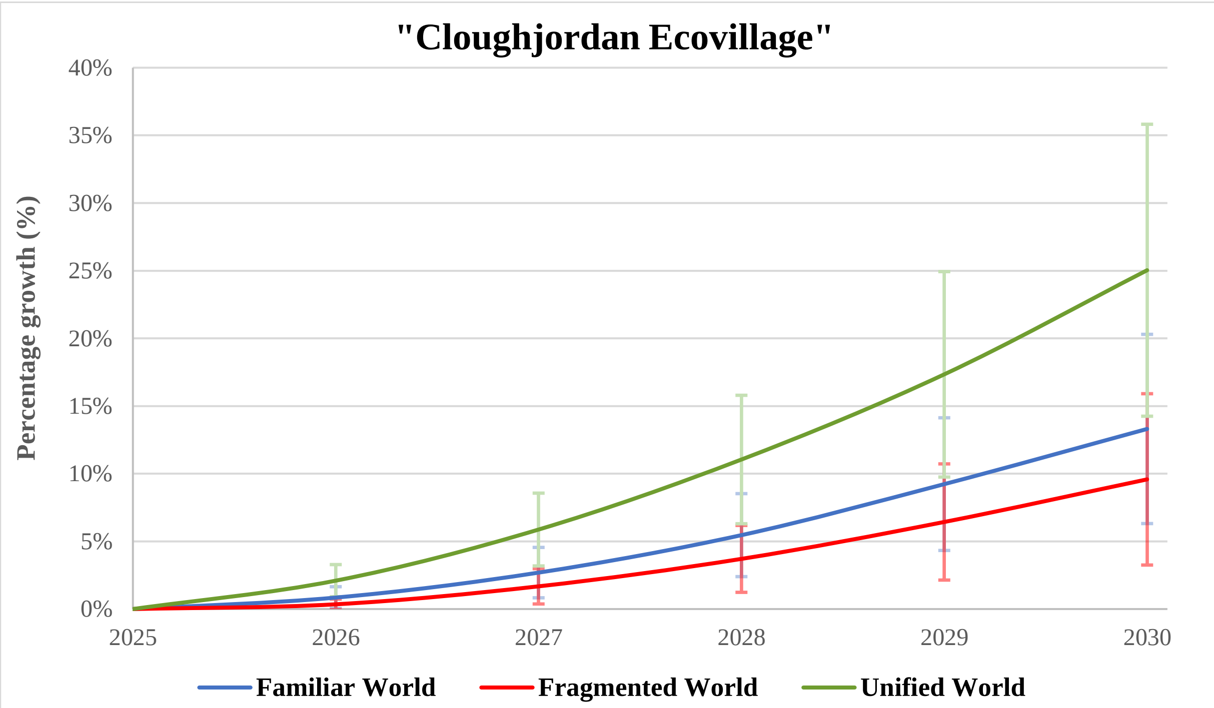


Figure 61. Projected growth of the "*Cloughjordan Ecovillage*" by 2030 based on the simulation results of the ANIMO framework.

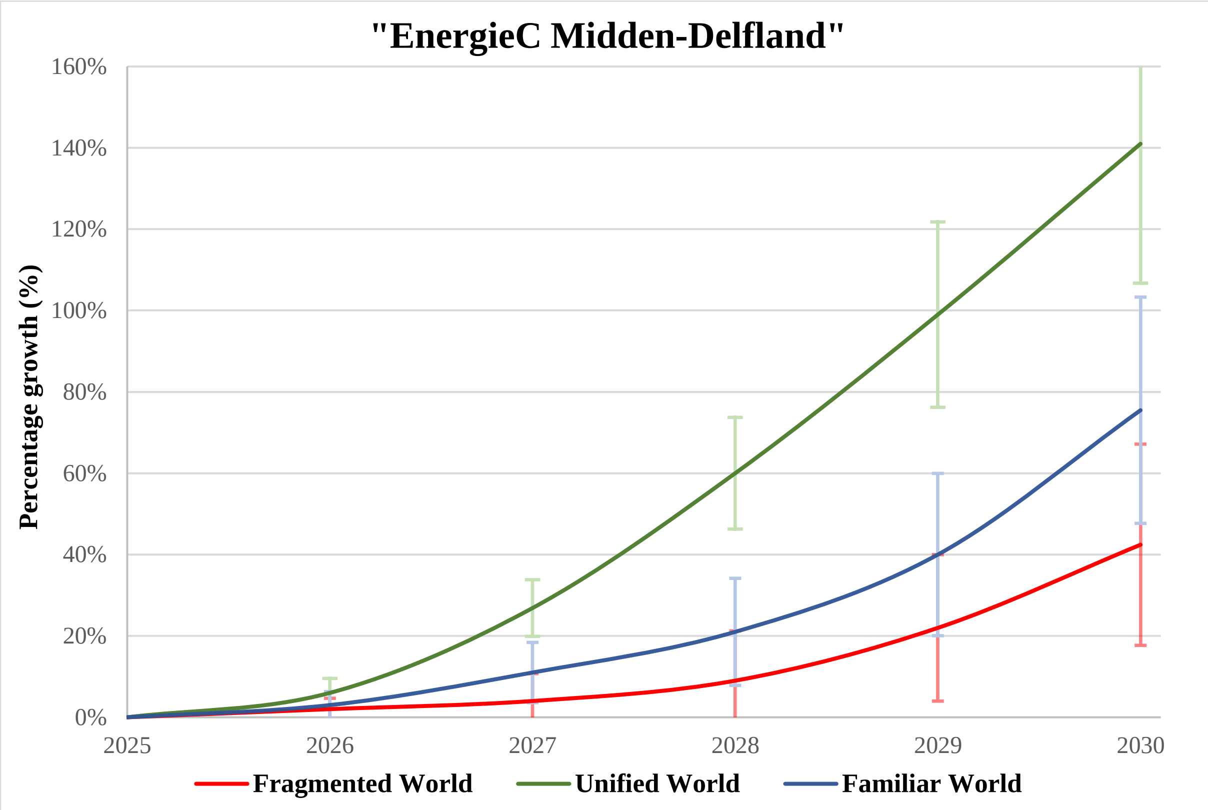


Figure 62. Projected growth of the "*EnergieC Midden-Delfland*" energy community by 2030 based on the simulation results of the ANIMO framework.

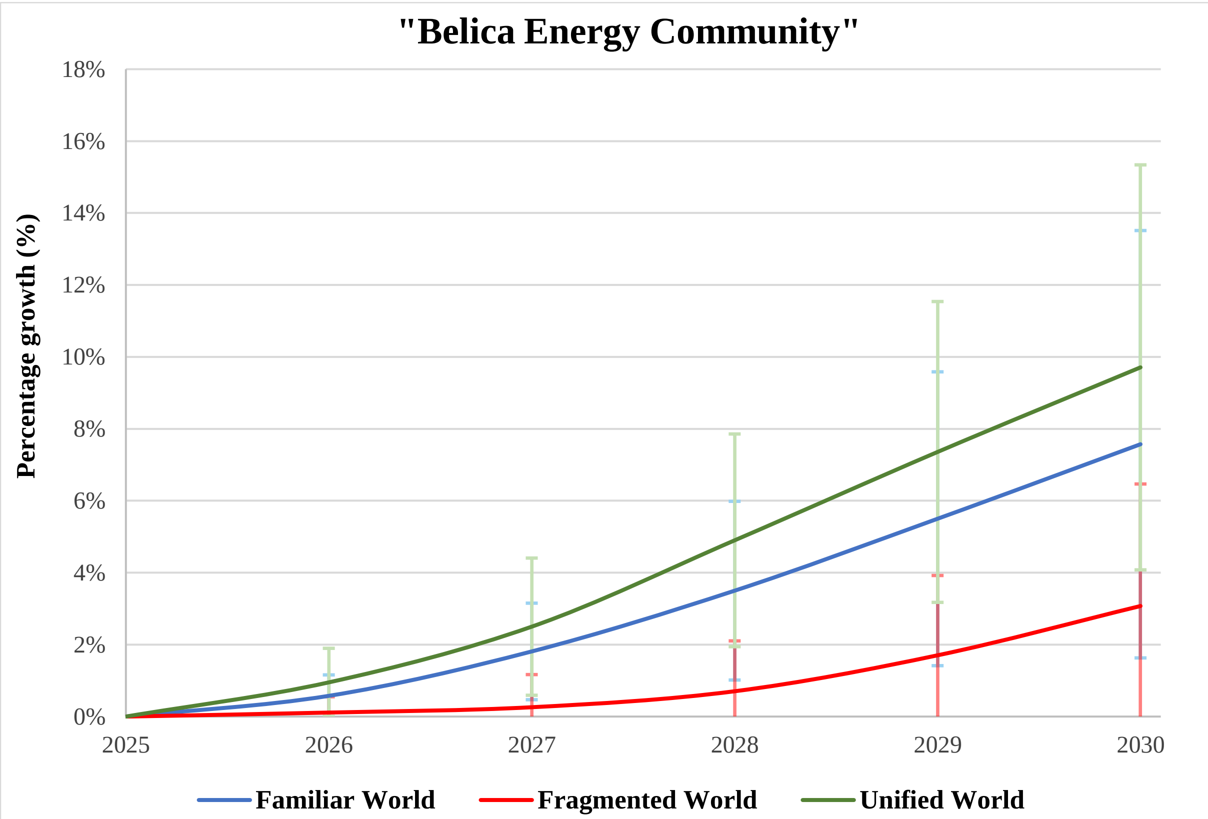


Figure 63. Projected growth of the "*Belica Energy Community*" by 2030 based on the simulation results of the ANIMO framework.

Our findings reveal a strong correlation between population density and projected growth of the CEIs under study. Densely populated areas facilitate faster CEI expansion, likely due to the enhanced effect of the “word-of-mouth” phenomenon. This is clearly demonstrated in the case of the “EnergieC Midden-Delfland” energy community, which is the most densely populated area out of the three (3) case studies. This trend is further supported when comparing case study results across the “future-world” narratives.

However, the key differentiator impacting growth appears to be the level of interconnectedness within a society, or, in other words, the number of social connections. In essence, closely knit societies, either purely due to size of population or due to the existence of strong social bonds facilitate faster dissemination of information about the benefits of collectivism, leading to higher growth rates.

Interestingly, even in the case of the “Fragmented World” narrative, characterized by limited interaction and skepticism, high population density manages to circulate information about the benefits of CEIs and propagate it throughout the community over time. The graphs further illustrate periods of rapid growth triggered by the cascade effect of influence. As more individuals join the CEI, the information spreads more readily through the social network, accelerating expansion.

This contrasts with the initial stagnant growth phase, where establishing a core group is crucial. Once a core foundation is laid, it facilitates influence on a larger audience, leading to both higher overall growth and a faster growth trajectory. This trend is most prominently emphasized in the Dutch case study and less so in the Irish and the North Macedonian ones.

In conclusion, in our analysis *population density* and *social connectivity* were identified as *key drivers of further CEI growth*. Remote locations, like the cases of Ireland and even more of North Macedonia, face inherent limitations due to lower population density. The graphs clearly demonstrate the cascade effect of mass participation that is encouraged by dense areas in terms of population such as the one in the Netherlands, highlighting a "*ripple effect*" that can significantly accelerate the energy transition. This phenomenon holds immense potential for achieving the ambitious decarbonization goals of the EU, particularly when combined with targeted policy actions designed to achieve widespread adoption of CEIs.

Focusing on the “Familiar World” narrative, in the case of the "EnergieC Midden-Delfland" energy community, data on CEIs in the Netherlands suggests an anticipated growth rate of approximately 8% based on historical trends (Lokale Energie Monitor, 2022). However, this figure serves as a broad approximation, and the projection of the growth percentage in a five-year time span is based on the assumption of steady compound annual increase.

A crucial limitation of relying solely on such an approach for projections lies mainly in its inability to capture the dynamic nature of energy communities’ diffusion and expansion, which should be taken into consideration during the design of policy schemes that aim at the support and integration of energy communities into the existing grid.

For example, in a scenario where a rapidly growing community surpasses initial projections for on-site solar power generation, further growth could be met with inability to be realized due to the unpreparedness of the existing infrastructure.

By gauging the potential rate of community growth based on simulations such as this, informed and proactive infrastructure investment decisions are possible. This can prompt policymakers and planners to ensure that the current infrastructure can accommodate the projected increase in population, which, in turn, can save valuable resources and reduce the time until carbon neutrality is achieved.

This forward-thinking approach can be applied not only when grid integration matters but also in other infrastructure issues. This can be somewhat showcased in the Irish case study, in which the feedback we received via direct communication with members of the community, revealed the critical role of infrastructure planning in enabling growth. While the project demonstrates success in certain sustainability metrics, further expansion has remained stagnant and dependent on resolving limitations within the existing wastewater treatment system.

More specifically, according to project leaders there is currently an embargo on planning permissions in “Cloughjordan Ecovillage” because the local town wastewater treatment plant is at capacity. This has resulted in a number of dwellings and residents in the village remaining static for the last 14 years, pointing to the fact that if the situation remains as is, there will be no further growth.

The case of the “Cloughjordan Ecovillage” is a prime example of how unforeseen hurdles, particularly infrastructure constraints, can impede the progress of otherwise well-designed sustainable community structures. This underlines the importance of collaborative efforts between CEIs, local authorities, and relevant stakeholders combined with a strategic approach to ensure that infrastructure keeps pace with sustainable development plans.

Moving a step further with the exploration of the “Band Together” storyline through this modelling exercise, we turn our attention to the emission reduction (decarbonization) potential from the expected growth of CEIs like the case studies analyzed in this section. Making use of the projections on the growth potential of the CEIs under study, we pair these insights with data regarding the anticipated decarbonization in the residential sector of the selected country case studies.

To this end, to gather the necessary data, we rely on the EU Reference Scenario 2020, an analytical tool of the EC, vital in energy and climate action planning, which provides projections on key energy sector indicators for Member States until 2050 (European Commision, 2020). It is noteworthy that in the case of the “Belica Energy Community” in North Macedonia, there were no available data in the database, since North Macedonia is not an EU member state. In pursuit of diversity and inclusivity in our case studies, we address this issue by aggregating the total GHG emissions of all EU Member States.

Figure 64, **Figure 65**, and **Figure 66** present the projected levels of the CO_2 emissions avoided in the selected cases studies resulting from the potential further growth of the CEIs under study by 2030 based on the simulation results of the ANIMO framework.

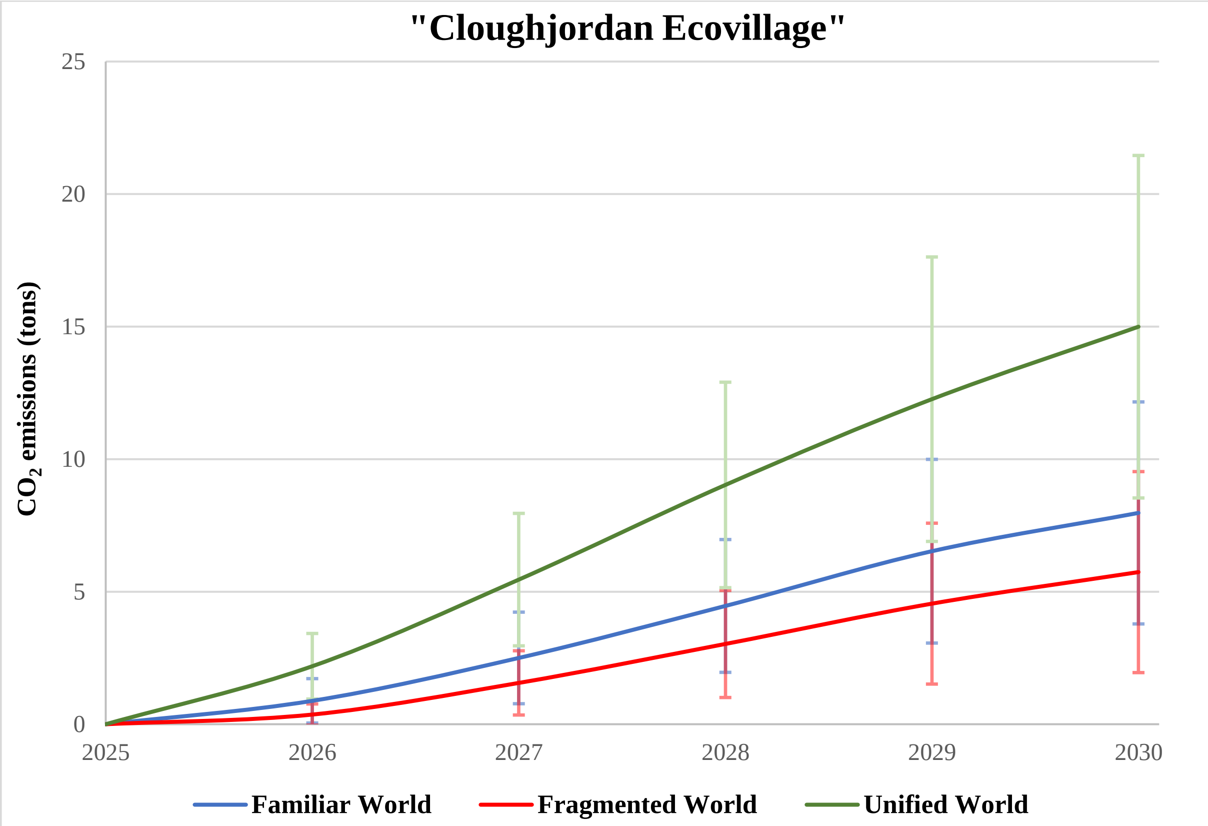


Figure 64. Projected levels of the CO_2 emissions avoided in Ireland resulting from the potential further growth of "*Cloughjordan Ecovillage*" by 2030 based on the simulation results of the ANIMO framework.

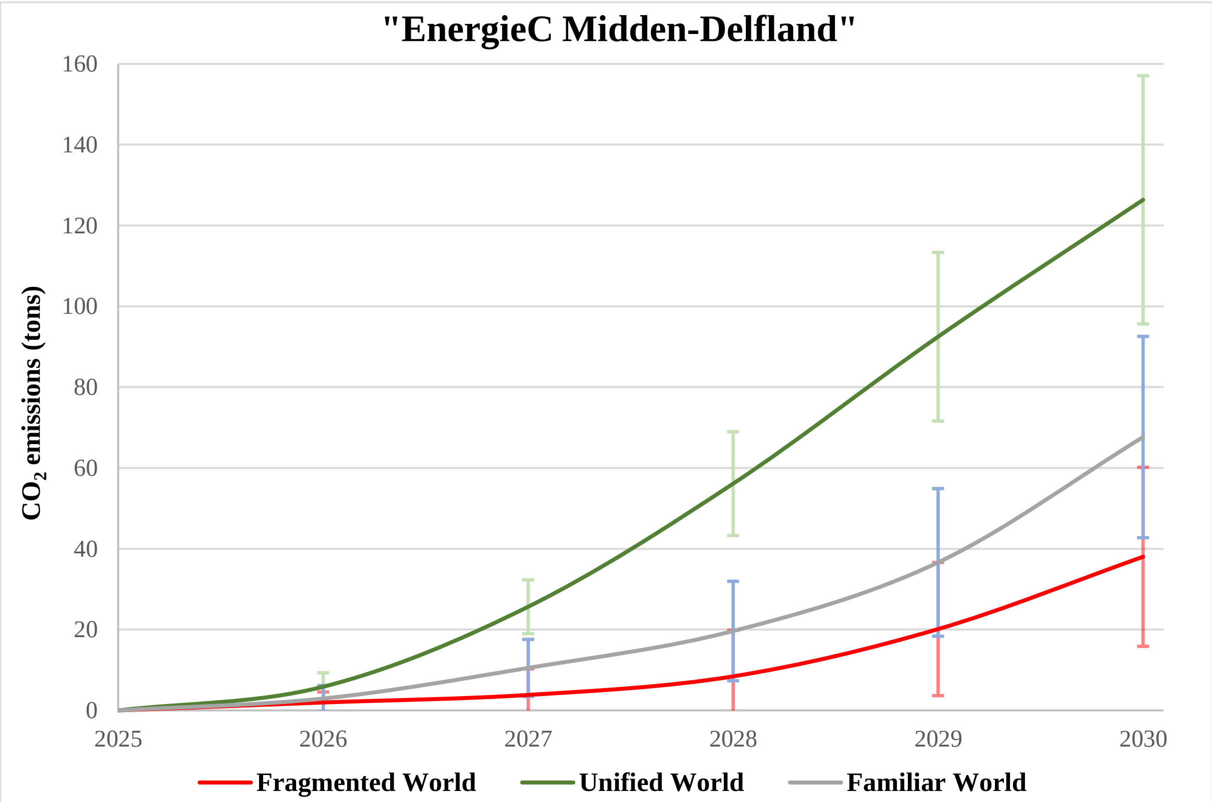


Figure 65. Projected levels of the CO_2 emissions avoided in the Netherlands resulting from the potential further growth of the "*EnergieC Midden-Delfland*" energy community by 2030 based on the simulation results of the ANIMO framework.

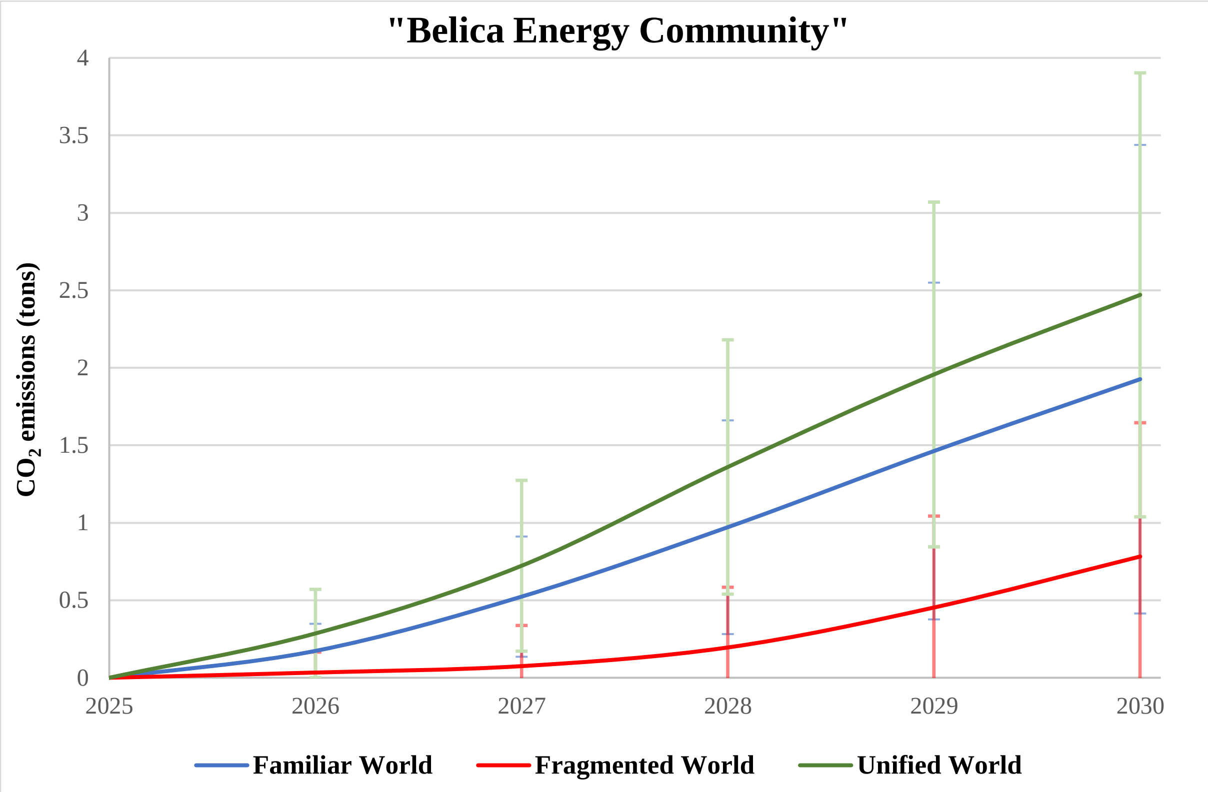


Figure 66. Projected levels of the CO_2 emissions avoided in North Macedonia resulting from the growth of the "*Belica Energy Community*" by 2030 based on the simulation results of the ANIMO framework.

As expected, the most significant emission reduction (decarbonization) potential is correlated with increased participation in energy communities, highlighting the positive impact of collective expressions of energy citizenship on advancing energy transition endeavors. Having utilized country specific data, these outcomes produce insights not only for the CEIs under study, but also the countries that host them.

In this context, the "EnergieC Midden-Delfland" energy community showcases the highest capacity for reducing carbon emissions, which also highlights the efficacy of the energy-related Dutch policy framework. On the other hand, "Cloughjordan Ecovillage", while exhibiting substantial promise for decarbonization, as discussed earlier local infrastructure constraints stand in the way of further progress, despite its notable contributions to the carbon footprint reduction in the region during past years.

Lastly, the North Macedonian case study showcases the lowest emission reduction (decarbonization) potential compared to the other case studies. This phenomenon, however, is possibly owed less so to the weak regulatory frameworks in place, but rather is attributable to factors such as social cohesion, demographic shifts, and a declining population in the region.

Nonetheless, even in instances where the impact may seem marginal, the efforts of these local initiatives are noteworthy and warrant further encouragement and support. This underscores the importance of operationalizing their activities through targeted research and policy initiatives to maximize their potential in driving sustainable energy transitions and implementing collective energy citizenship practices at the local level.

Concluding, through our modeling analysis under the "Band Together" storyline we provided insights into resident motivations and the impact that social, cultural, and demographic factors can potentially have on the expansion of CEIs. Building further on the derived insights, we also made projections on the potential decarbonization effect the expansion of the CEIs in question can have on the energy system.

Thus, we empower policymakers and community organizers to develop effective strategies that promote widespread adoption and accelerate the energy transition. As research continues, further refinement of the ANIMO modeling framework based on additional data and complexities can offer even more robust predictions and decision-making support, optimally paving the way for a sustainable future fostered by collaborative citizen community structures.

7.3. A "green" rebranding of a Coal and Carbon Intensive Region into a city of the people, by the people, for the people

Simulation results of DREEM provide us with useful insights on the different energy transition pathways under study in the Megalopolis' residential sector.

Figure 67 presents the evolution of energy consumption by 2050 in Megalopolis under the three (3) "*future-world*" narratives. Findings indicate that in both the "*Familiar World*" and the "*Unified World*" narratives, we reach almost at the same levels of final energy consumption by 2050 (around 65.5% of the initial consumption levels). On the contrary, the "*Fragmented World*" leads to the least reduction of the final energy consumption (48.5% of the initial consumption levels).

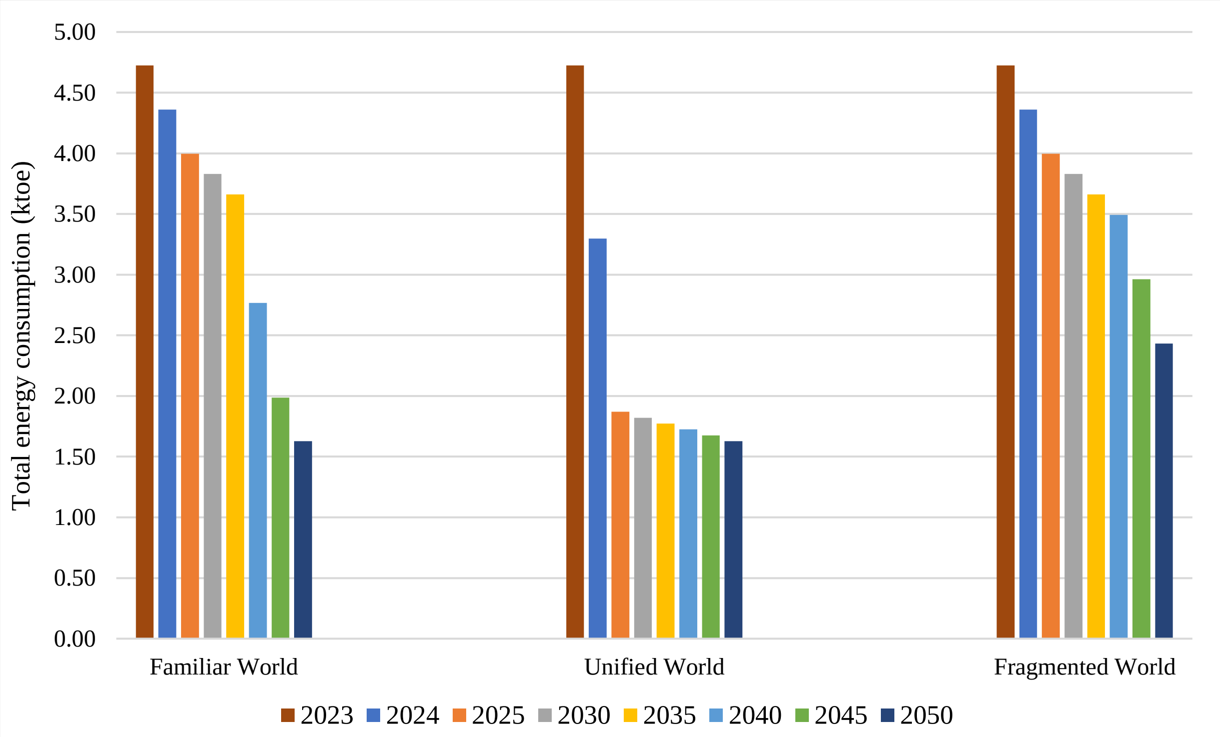


Figure 67. Total energy consumption (ktoe) by 2050 in the residential sector of Megalopolis for each "*future-world*" narrative under study.

In addition, Figure 68, Figure 69, and Figure 70 present the projected evolution of the final energy mix and total energy savings by 2050 in the residential sector of Megalopolis.

It becomes apparent that a potential future transition pathway in which citizens come together united in the battle against climate change and decide to invest in green solutions (energy renovation measures and heat pumps) as soon as possible, while they are also willing to adopt behavioral and lifestyle changes when it comes to managing their energy consumption patterns (i.e., "*Unified World*") leads to a rapid and complete phase out of fossil fuels from the final energy mix of the municipality of Megalopolis by 2050.

Similarly, under a potential future transition pathway in which citizens follow the current rates of decarbonization efforts and decide to invest in the technological solutions, as foreseen each time by current policymaking at the EU and the national level (i.e., "*Familiar World*") total decarbonization in the residential sector in Megalopolis by 2050 is attained. Nevertheless, in this case decarbonization occurs at a significantly slower pace compared to the case of a "*Unified World*". Specifically, there is no notable downward trend in fossil fuel usage by 2035; only thereafter do citizen investments in natural gas begin to decline based on the evolution of the final energy mix.

On the other hand, under a potential future transition pathway in which individuals are characterized by distrust and skepticism and are mainly concerned about their energy security and lower bills rather than combating climate crisis (i.e., "*Fragmented World*"), the use of fossil fuels is retained in the evolution of the final energy mix, persisting even by 2050, and thus, the vision of decarbonization cannot be achieved.

This underscores how the lack of energy citizenship practices, and the accompanied diminishing collectivistic values hinder the energy transition process, impeding progress toward climate neutrality and obstructing the creation of new decarbonization pathways.

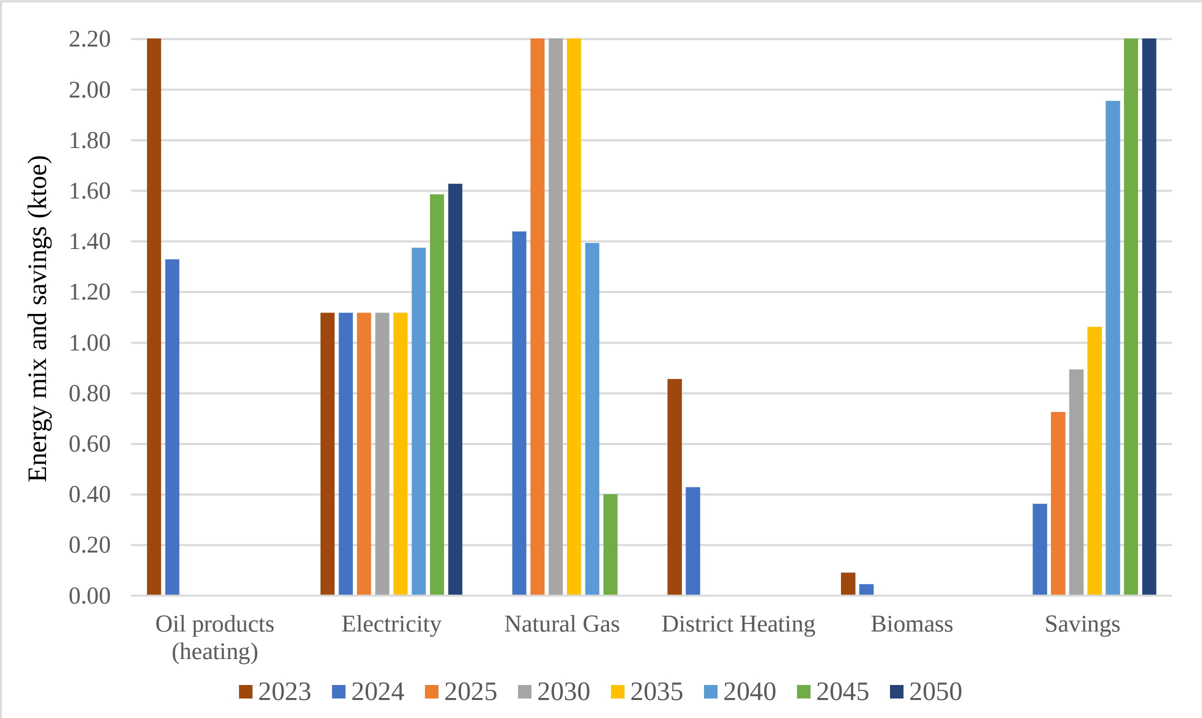


Figure 68. Evolution of the final energy mix and total energy savings (ktoe) by 2050 in the residential sector of Megalopolis under the "*Familiar World*" narrative.

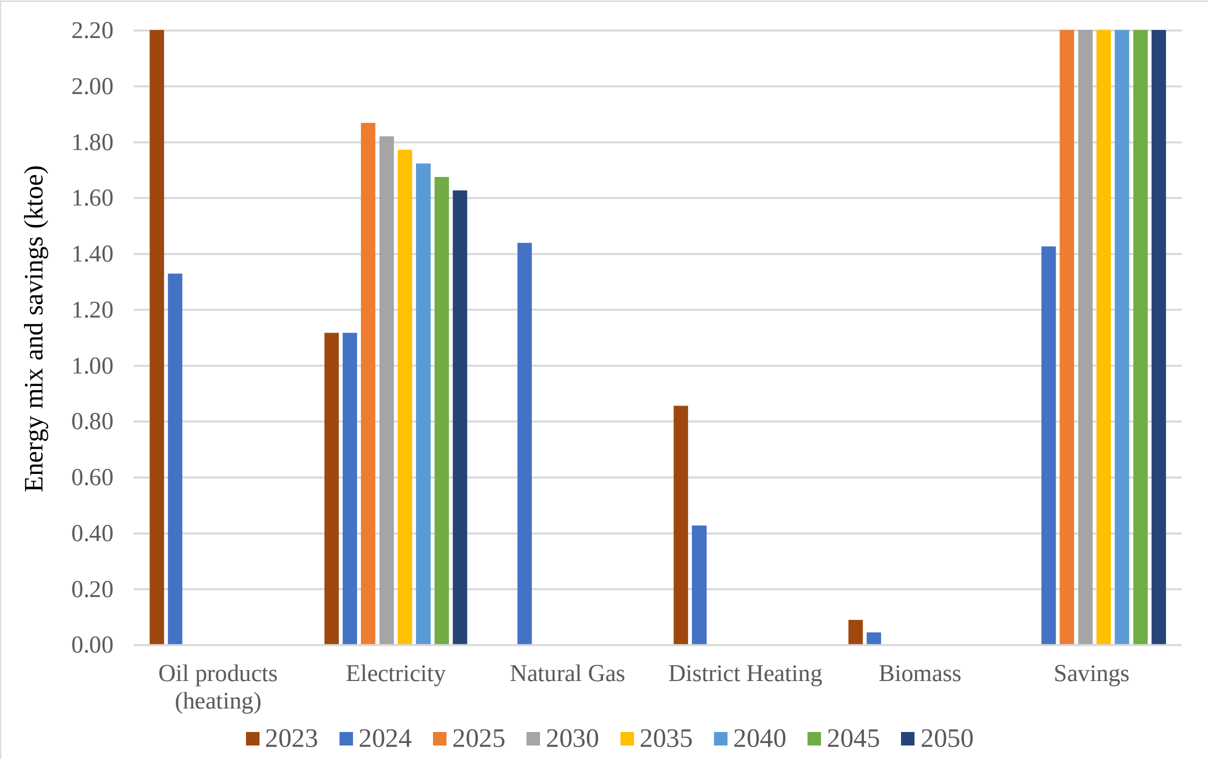


Figure 69. Evolution of the final energy mix and total energy savings (ktoe) by 2050 in the residential sector of Megalopolis under the "*Unified World*" narrative.

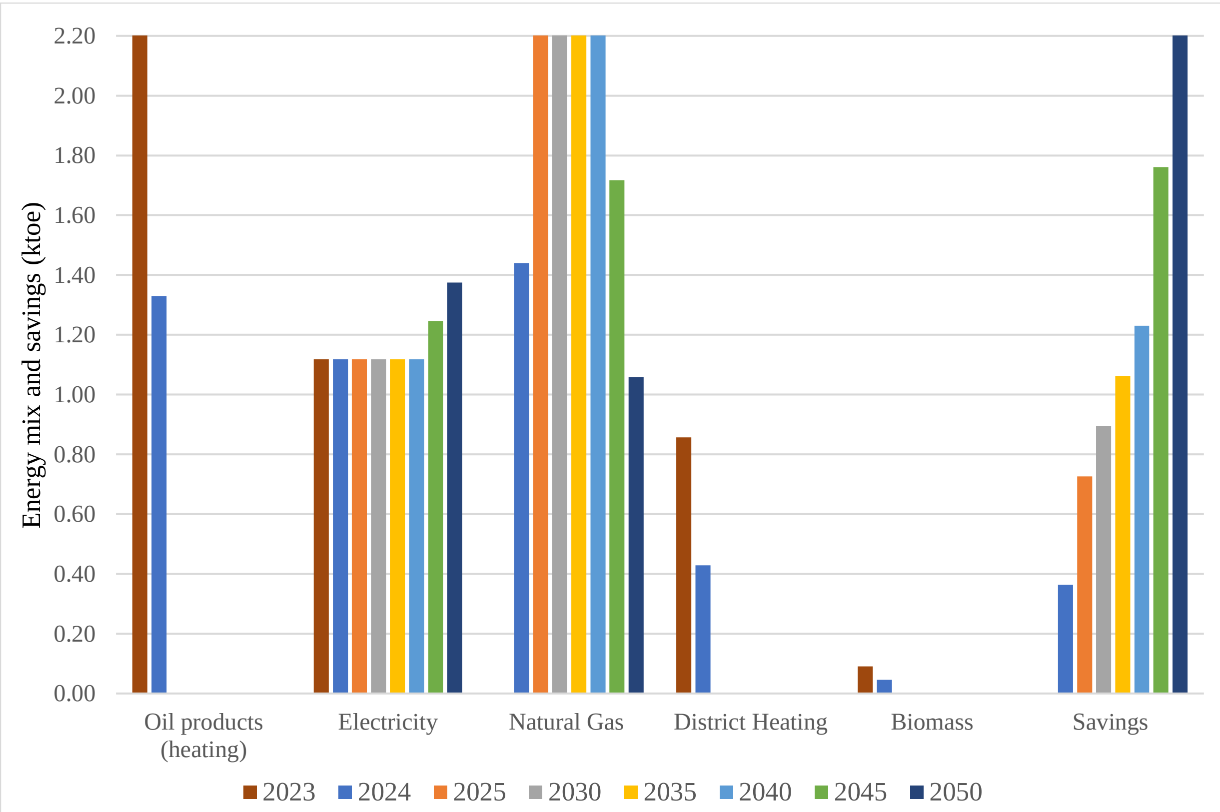


Figure 70. Evolution of the final energy mix and total energy savings (ktoe) by 2050 in the residential sector of Megalopolis under the "*Fragmented World*" narrative.

When considering the environmental impact within decarbonization pathways under the "future-world" narratives under study, projections on CO_2 emissions serve as a key metric. Figure 71 and Figure 72 illustrate that under both the "*Familiar World*" and the "*Unified World*" narrative total decarbonization by 2050 is achieved. Notably, under the "*Unified World*" narrative a faster decarbonization rate is achieved, highlighting the importance of a citizen-led transition based on energy efficiency investments and lifestyle and behavioral changes.

Although both narratives ultimately achieve similar emission reduction, the "*Unified World*" narrative achieves CO_2 emission reduction levels by 2030 that are attained more than a decade later under the "*Familiar World*" narrative; this highlights the decarbonization potential of transition pathways under a joint "*Power to the People*" and "*Habitual Creatures*" storylines at the municipality level.

Finally, transition pathways under the "*Fragmented World*" narrative fail to achieve complete phase out of fossil fuel usage by 2050, as expected. This highlights how a future marked by crises and disparities among nations and individuals hinders the adoption of energy citizenship-related social innovations, resulting in limited progress towards decarbonization targets and emissions' reduction.

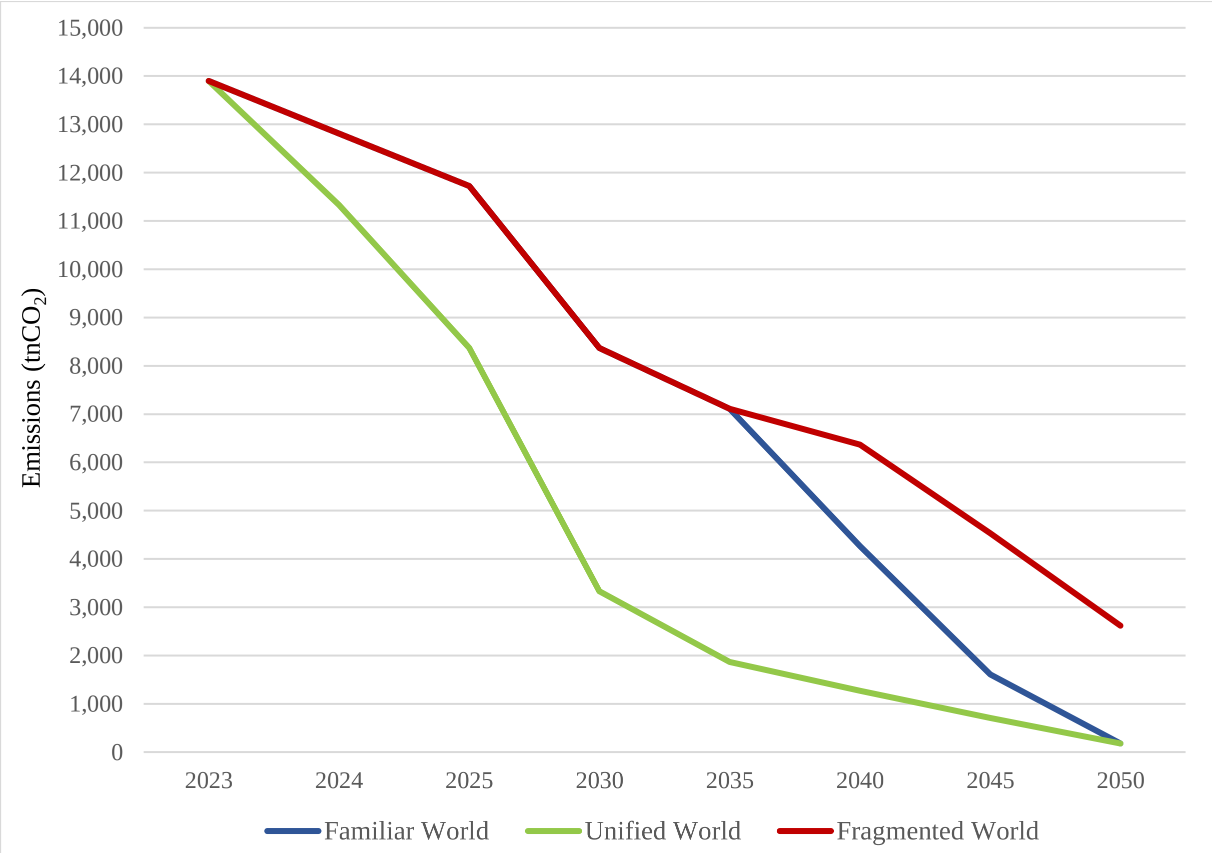


Figure 71. Evolution of the CO_2 emissions ($tnCO_2$) in the residential sector of Megalopolis by 2050 for the different "*future-world*" narratives under study.

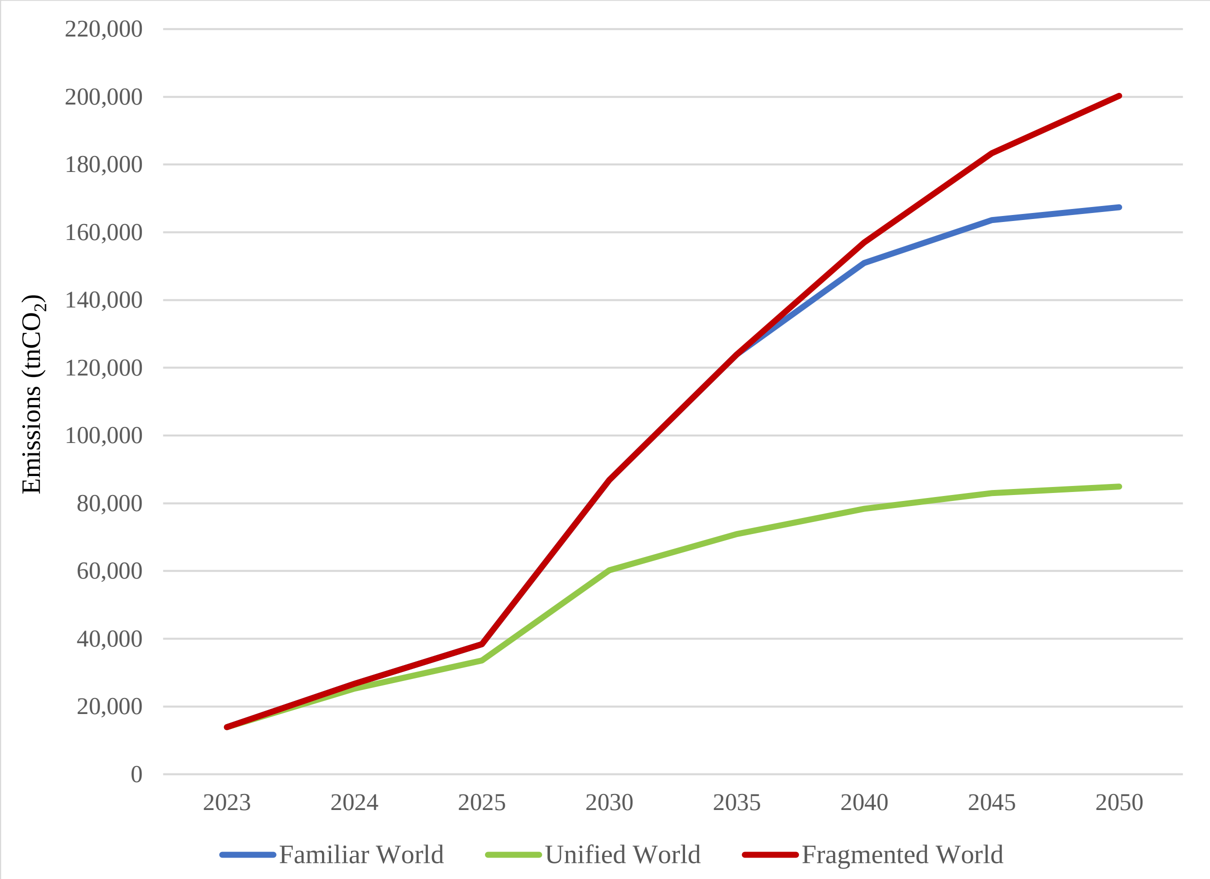


Figure 72. Evolution of the cumulative levels of CO_2 emissions avoided ($tnCO_2$) in the residential sector of Megalopolis by 2050 for the different "*future-world*" narratives under study.

When it comes to the economic implications of the transition pathways under the different "*future-world*" narratives analyzed, we consider costs and other charges for citizens by 2050, relevant to investment costs in the technological solutions selected under each narrative, and charges relevant to energy carriers and the expected introduction of a parallel ETS in the building sector.

Following the trend evolution of ETS prices, Figure 73 illustrates the evolution of the total ETS-related charges by 2050 in the residential sector of Megalopolis for the three (3) "future-world" narratives under study.

As expected, a potential future transition pathway in which citizens come together united in the battle against climate change and decide to invest in green solutions (energy renovation measures and heat pumps) as soon as possible, while they are also willing to adopt behavioral and lifestyle changes when it comes to managing their energy consumption (i.e., "*Unified World*") results in total phase out of lignite and to the elimination of ETS costs.

Furthermore, under the "*Familiar World*" narrative, ETS costs follow a plausible decreasing trend over the coming decades. On the other hand, a potential future transition pathway in which individuals are characterized by distrust and skepticism and are mainly concerned about their energy security and lower bills rather than combating climate crisis (i.e., "*Fragmented World*"), and in which the use of fossil fuels is retained in the evolution of the final energy mix by 2050, results in persistently increased ETS costs compared to present levels.

However, while costs are ultimately eliminated upon achieving total electrification by 2050, a notable initial spike in the overall declining trend is observed, potentially reflecting the emergence of possible energy crises. Specifically, the "*Familiar World*" narrative shows an 85% decrease in ETS costs, whereas the "*Fragmented World*" narrative exhibits only an 18.4% decrease by 2050.

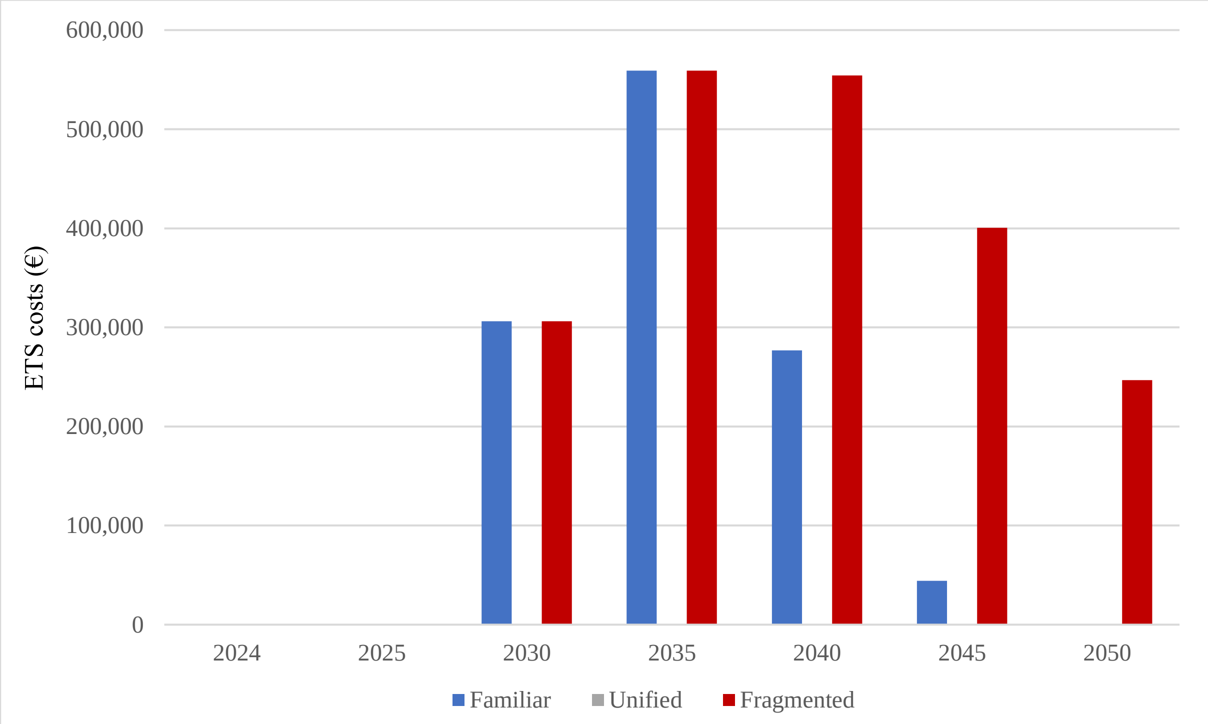


Figure 73. Evolution of the total ETS-relevant costs by 2050 in the residential sector of Megalopolis for the three (3) "future-world" narratives under study and the second case of ETS price evolution (ETS ranges from 30 to 100 €/tnCO_2).

Except for the ETS-related costs, each "future-world" narrative under study includes different fuel and renovation costs. As shown in Table 20, the prompt adoption of citizen investments in green solutions ("*Unified World*") in contrast to sole reliance on fossil fuels for energy security ("*Fragmented World*") leads to lower annual and total fuel costs by 2050.

Table 20. Evolution of total fuel costs per household by 2050 in Megalopolis for the three (3) "future-world" narratives under study (€/household).

Time horizon	2023	2024	2025	2030	2035	2040	2045	2050	Total
"***Familiar World***"	1,871	6,085	10,081	17,990	26,181	35,821	44,032	51,449	**51,449**
"***Unified World***"	1,347	8,426	15,129	20,637	25,897	30,850	35,539	39,999	**39,999**
"***Fragmented World***"	2,197	7,759	14,122	34,109	54,549	74,609	93,322	108,591	**108,591**

Regarding renovation costs, as shown in Figure 74, the transition pathway under the "*Unified World*" narrative leads to higher initial costs, as expected. In fact, the earlier the phase out of natural gas, the greater the annual costs.

In particular, transition under the "*Unified World*" narrative proves considerably more expensive than the transition under both the "*Familiar World*" and the "*Fragmented World*" narratives, especially during the early stages of the transition, which is marked by drastic changes in the energy mix.

However, it is important to remember that renovation costs represent just one facet of the total costs attributed to the energy transition in the residential sector of Megalopolis and of the citizen-related charges. The latter speaks of the necessity to design and implement renovation programs that focus on supporting wider citizen inclusion, especially of the most vulnerable groups, towards the implementation of measures that lead to increased overall benefits (e.g., enhanced comfort, reduced energy expenses, achievement of climate targets).

It should also be noted that infrastructure and other indirect costs are not included in the renovation costs calculated by the DREEM model. Only costs to be paid by citizens/ households are included. The latter implies that renovation costs under both the "*Familiar World*" and the "*Fragmented World*" narratives are expected to be higher than the ones projected.

In addition, despite the current high capital costs of heat pumps, these results should also be considered in the context of the expected decrease of the heat pump capital costs due to the learning curve effect, which will radically decrease capital costs after 2030, as also indicated by forecasts published by the European Heat Pump Association (Renewable Heating Hub, 2021).

Finally, **Figure 75** also presents total renovation costs in 2050 in the residential sector of Megalopolis for the three (3) "future-world" narratives under study.

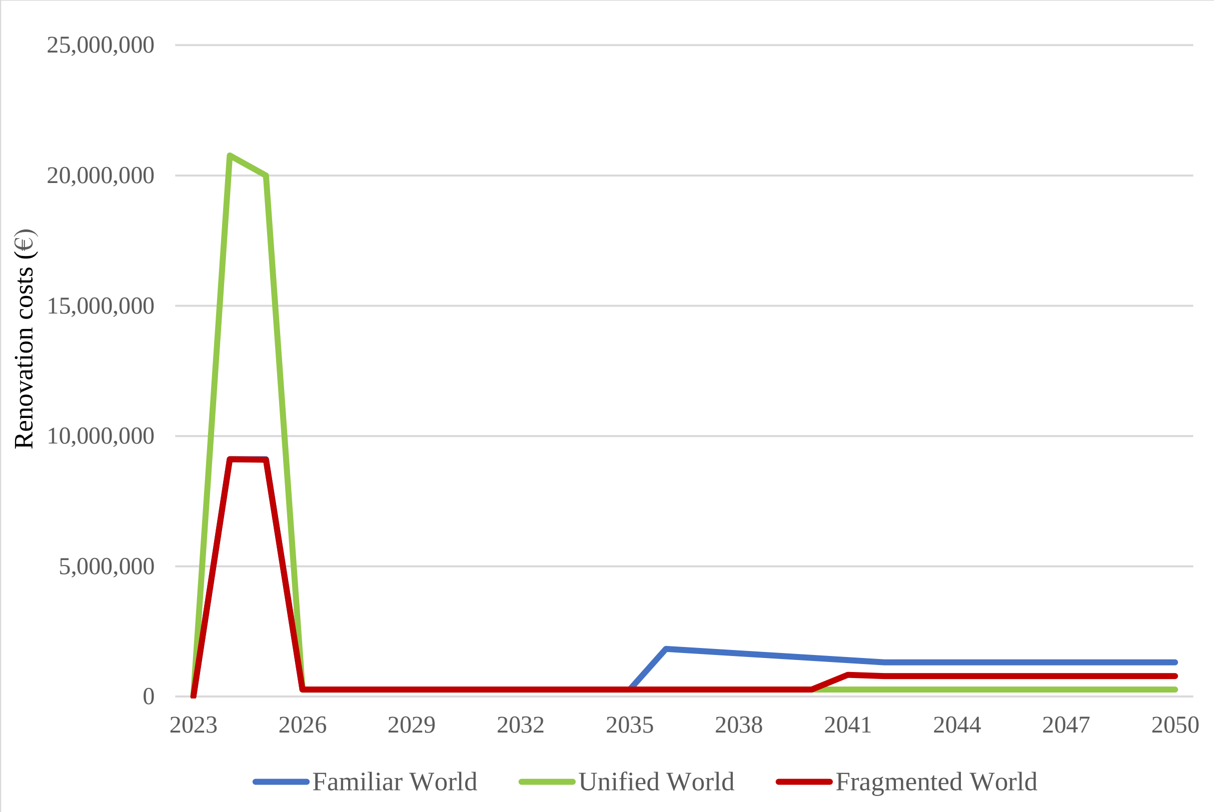


Figure 74. Evolution of the total renovation costs in the residential sector of Megalopolis by 2050 for the three (3) "*future-world*" narratives under study.

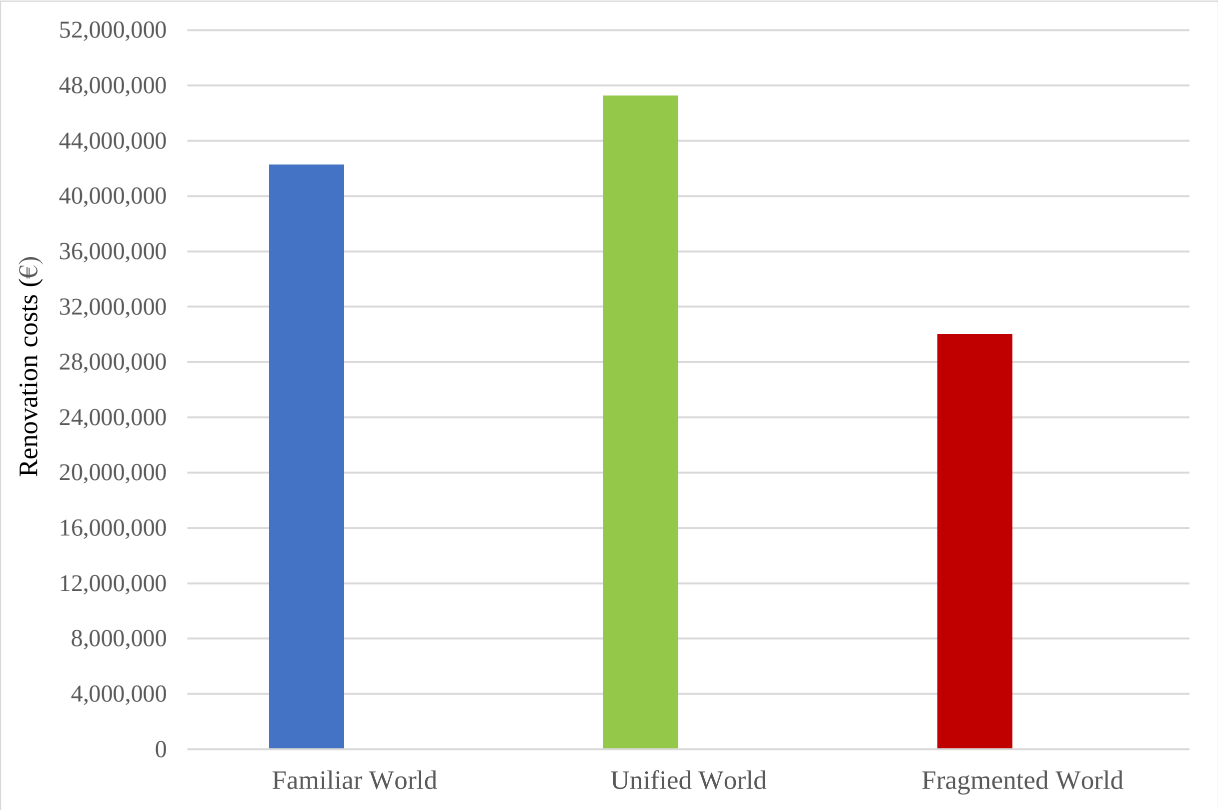


Figure 75. Total renovation costs in 2050 in the residential sector of Megalopolis for the three (3) "*future-world*" narratives under study.

Lastly, to extract a robust and meaningful evaluation of the economic implications and the economic viability of the different transition pathways under study in the residential sector of Megalopolis, we aggregated the individual costs (ETS, fuel, and renovation costs), at both the household and the municipality level, to extract the costs to be shouldered by the municipality citizens/ households. It is assumed that the total cost is equally divided in each household.

Figure 76 and **Figure 77** present the evolution of the charges to be borne at the household level by 2050. It is noteworthy to mention that except for the "*Fragmented World*" narrative, transition pathways under the two (2) other "*future-world*" narratives lead to reduced annual costs, showing the viability of investing in green solutions. Particularly in the case of the "*Unified World*" narrative, annual costs seem to drop under the 1,000€/household threshold around 2030.

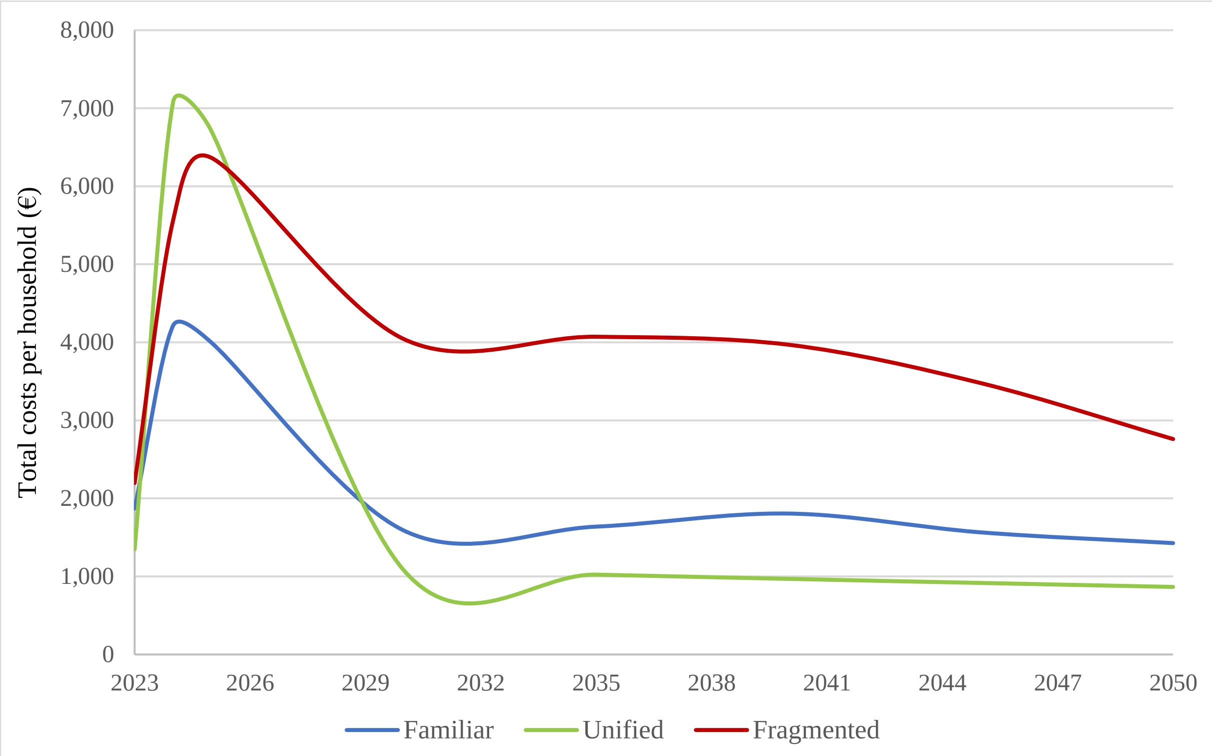


Figure 76. Evolution of the total costs per household by 2050 in the municipality of Megalopolis for the transition pathways and the three (3) “future-world” narratives under study (€/household).

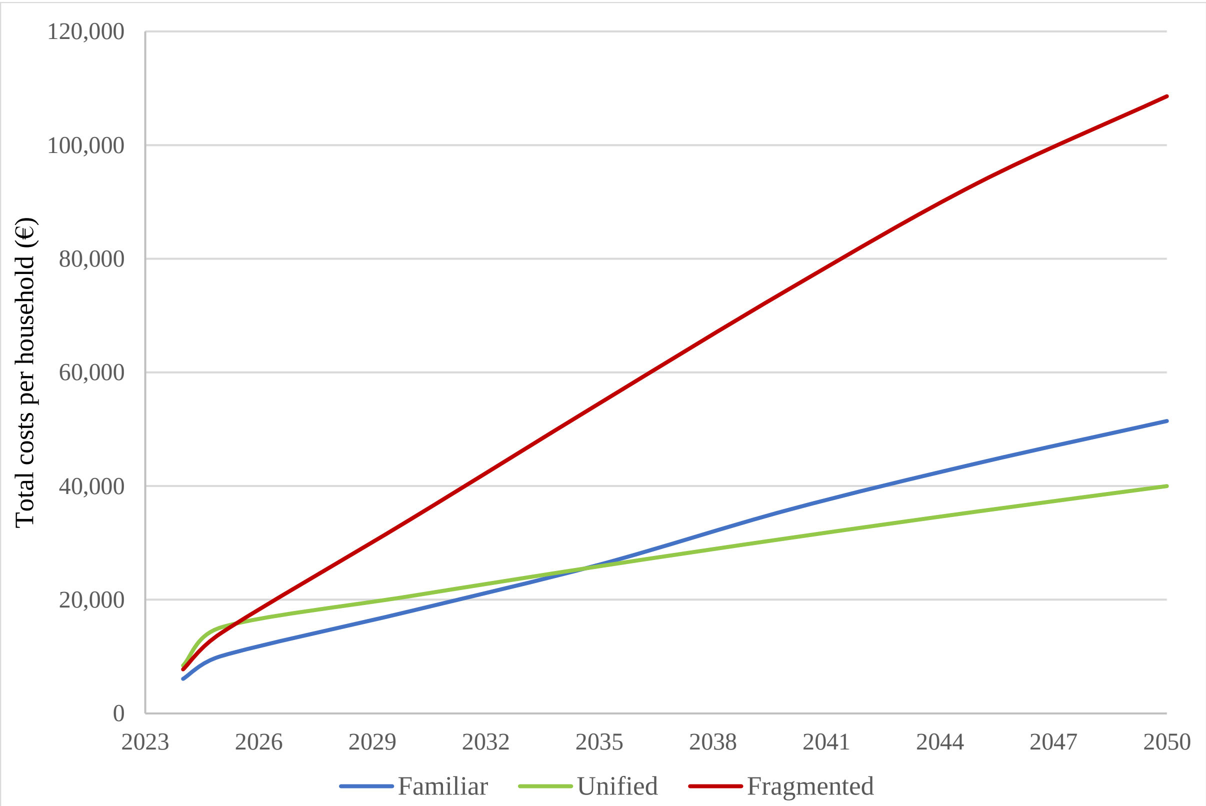


Figure 77. Evolution of the cumulative total costs per household by 2050 in the municipality of Megalopolis for the transition pathways and the three (3) “future-world” narratives under study (€/household).

Similarly to the household-level, Figure 78 and Figure 79 present results on the evolution of the total costs of the energy transition by 2050 at the municipality level of Megalopolis for the transition pathways and the three (3) “*future-world*” narratives under study.

It is noteworthy that transition pathways under the "*Fragmented World*" narrative proves unsustainable in the long term, as potential disadvantageous future developments are projected to steadily escalate costs, while return on investment is evidently absent.

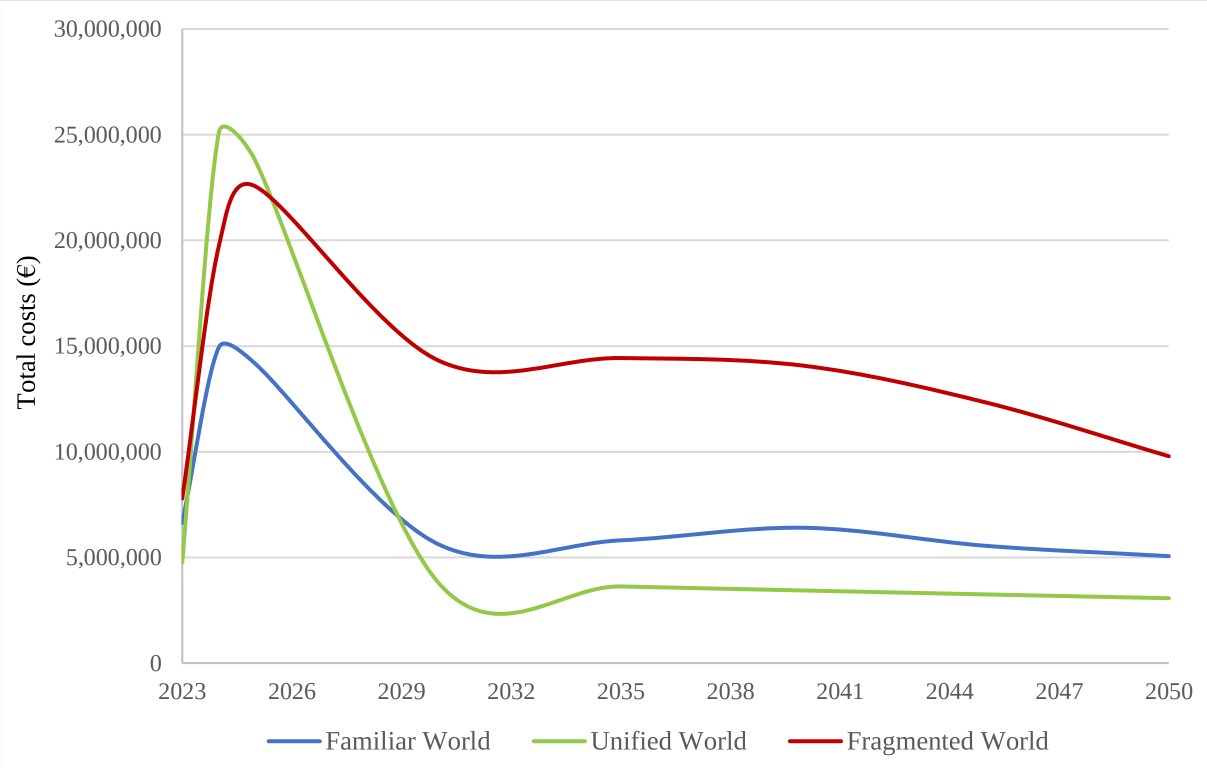


Figure 78. Evolution of the total costs by 2050 at the municipality level of Megalopolis for the transition pathways and the three (3) “future-world” narratives under study (€).

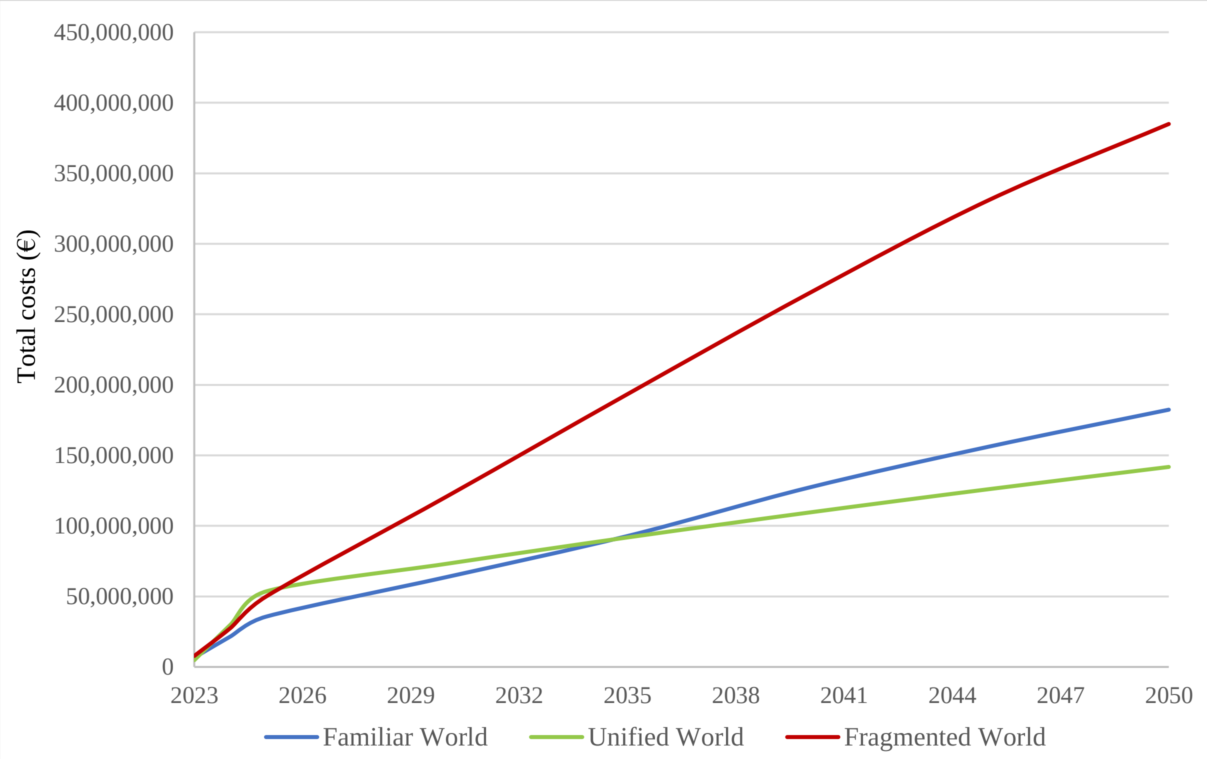


Figure 79. Evolution of the cumulative total costs by 2050 at the municipality level of Megalopolis for the transition pathways and the three (3) “future-world” narratives under study (€).

Overall, our findings indicate that a citizen-led transition based on energy efficiency investments and lifestyle and behavioral changes ("*Unified World*") in a European CCIR, as is the municipality of Megalopolis, results in lower total (ETS, fuel, and renovation) costs at both the household and the municipality level, compared to continuing the reliance and the dependence on fossil fuels and gas ("*Fragmented World*").

Our results also showed that such a transition is also the most efficient pathway in terms of energy demand reduction, environmental footprint, and potential extra charges on household bills. Moreover, in the long run, households' extra charges from the replacement of existing oil boilers with gas boilers will amplify the energy poverty phenomenon in the region as it results in increased costs.

Tailored energy support programs for such regions in transition, promoting the green solutions like renovations and heat pumps, and promotional campaigns focusing on the benefits of behavioral and lifestyle changes towards energy savings and lower bills, could directly contribute to the reduction of household energy costs and indirectly to the labor market and economic growth, especially in the short-term transition.

8. Conclusions, recommendations, and further research

Until now, the primary focus on climate change mitigation has centered on the technical and infrastructural aspects of transitioning energy systems. While technological advancements are undoubtedly crucial, it's imperative to recognize that technology alone cannot effectively address climate crisis. The complex interplay of societal systems serves as the underlying cause of the problem. Understanding how society and individuals evolve is less certain, given the ever-changing nature of behaviors and lifestyles, which are anticipated to undergo substantial shifts in the future.

However, projecting or envisioning these changes poses a challenge and remains largely unexplored within the realm of climate change mitigation. To achieve the vision of a green, inclusive, and equitable transition by 2050, the pivotal role of citizens and other societal actors, along with their empowerment and engagement, has been duly acknowledged within the recent EU's strategic and legislative frameworks.

In this context, citizens are anticipated to expand their role as self-consumers and contributors within energy communities, actively shaping alterations in the energy landscape, impacting both demand and supply. Consequently, transitions must not only be technologically viable and economically feasible but also socially and politically acceptable, considering individual preferences, levels of acceptance, and shifts in behavior and lifestyle.

As citizens and other societal actors are anticipated to have a more active role in shaping future energy systems, the concept of *energy citizenship* has gained prominence in recent literature, indicating its compatibility with and significant contribution to scenario-based analyses aimed at devising transition pathways toward envisioned energy futures and the goal of climate neutrality.

Nevertheless, merely developing such scenarios and pathways is insufficient, as policymakers require decision and support tools capable of exploring the quantitative interaction between economic decision-making and behavioral heterogeneity, i.e., modeling tools.

Despite the growing significance and utilization of modeling tools, socio-technical aspects are inadequately represented within them. Specifically, most modeling tools adopt a technoeconomic or cost optimization approach or treat the social dimension of the energy transition as an auxiliary layer of analysis, viewing society merely as a broader social context and constraining their capacity to incorporate the dynamics of socio-technical factors, such as policy preferences, behavioral patterns, or social acceptance of specific technologies. As a result, they fail to fully account for the intricate interplay between socio-technical factors and other critical elements like energy, economy, and environment.

Such socio-technical factors can exert a substantial influence on expediting or hindering processes within the energy transition, highlighting an increasing recognition of the significance of their dynamics, and thus are crucial in crafting modeling tools. Consequently, to explore socio-technical pathways leading to climate neutrality in Europe by 2050, it is imperative to either create new or refine existing modeling tools to align with current requirements.

8.1. Modeling of energy citizenship at the local level

Considering the wide array of manifestations associated with energy citizenship, it is evident that it can significantly influence decarbonization endeavors across various EU contexts and scales. Particularly concerning the local scale, it is crucial to better comprehend how different facets of energy citizenship have thus far been examined.

A recurring challenge identified in recent literature pertains to the underutilization of modeling tools, while research has mostly relied on field studies, surveys, and interviews. While these methods offer certain advantages and lay the groundwork for further exploration, they tend to yield general trends and implications that may lack the precision necessary for informing policymaking effectively.

In this deliverable, we aimed at adding a quantitative dimension to the research around the concept of energy citizenship and its expressions at the local level by using the capacities of two modeling tools to explore the relationship between the various forms of energy citizenship and their emission reduction (decarbonization) potential in micro-scale energy systems. To reach this objective, we followed a multi-method approach, coupling the strengths of energy system modeling with qualitative and semi-quantitative techniques.

Our overarching approach comprised five (5) main methodological steps, guiding us from the initial identification of patterns and trends of energy citizenship (as outlined in **Deliverable 5.1**) and the ENCLUDE's "*people-centered*" storylines and "*future-world*" narratives (as developed in **Deliverable 5.2**) to the eventual development of the ENCLUDE scenario space and formulation of case-specific decarbonization pathways, which were then simulated and presented within this report.

With the intention of applying the ENCLUDE modeling ensemble to the creation of case-specific decarbonization pathways at the local level, we conducted an updated gap analysis to uncover new patterns and trends of energy citizenship that had not yet been addressed by our modeling tools. This exploration considered the already developed "*people-centered*" storylines and the "*future-world*" narratives, insights gleaned from the efforts in **WP3** and **WP6** (including the ENCLUDE Academy), and feedback from relevant end-users and stakeholders.

Through this process, we not only identified further necessary model developments, modifications, and adjustments, but we also gained a comprehensive understanding of the relationship between patterns and trends of energy citizenship (both at the individual and the collective level), socio-technical decarbonization pathways, and the capabilities of the ENCLUDE modeling ensemble.

By building upon the groundwork laid out in previous deliverables and adhering to the overarching framework established within **WP5**, we focused on developing transition scenarios and decarbonization pathways across various real-world micro-scale case studies across different geographical contexts and socioeconomic environments, also drawn from the comprehensive and meticulously detailed pool developed under **WP3**.

To tailor our approach to the unique characteristics of the analyzed case studies and to align with the identified patterns and trends of energy citizenship, we expanded upon the previously established modeling ensemble introduced in **Deliverable 5.1**. This expansion included the incorporation of two (2) new modeling tools. Within this report, we introduced one of these additions: the ANIMO modeling framework. This new framework enhances the capabilities of the ENCLUDE modeling ensemble, facilitating a more comprehensive and in-depth exploration of the diverse expressions of energy citizenship.

Specifically, we expanded upon the existing architecture of the ATOM model, originally designed for national-level analysis, to develop a new modeling framework conceptualized and created within the ENCLUDE project, called "**ANIMO**".

ATOM primarily focused on examining the dynamics of technology diffusion, particularly concerning solar PV and residential battery energy storage systems, which represent investments in equipment, products, and infrastructure. Consequently, economic factors played a pivotal role in each agent's decision-making process, encompassing factors like investment resistance, associated risks, costs, payback periods, and household income.

While economic factors also influence participation in CEIs within the ANIMO model, additional and somewhat disparate factors intertwined with social values, orientations, and perspectives have been included in the model. These factors include sensitivity to and perception of environmental and climate issues, preferences regarding autonomy as an energy producer (i.e., prosumer) versus reliance on traditional grids, and the level of cooperation and altruism inherent in individuals within a specific area.

To address this complexity, ANIMO introduces a set of new agent-related parameters aimed at capturing these attributes. These attributes are specific to each case, as they depend on the nature and structure of the real-life application under study. The process of selecting and designing these agent-related parameters, as well as informing them based on real-life data, can significantly impact the plausibility and accuracy of modeling results. By concentrating on specific locales, ANIMO can explore the intricate interactions and dynamics within communities, offering a framework for modeling and comprehending the complexities of energy citizenship at the grassroots level.

In this deliverable, ANIMO simulated the propagation of social and grassroot innovations, particularly focusing on the establishment of and involvement in CEIs. It investigated the adoption and dissemination of envisioned social progressions among a diverse network of individuals, encompassing various socioeconomic backgrounds, behaviors, and lifestyles, and delved into the intricacies of citizens' choices within a structured social framework, particularly regarding their decision to participate or refrain from involvement in CEIs.

Moreover, it examined the collective decision-making processes between communities and how these processes influence external perceptions of the community as well as interactions among existing and potential community members.

The abovementioned features made ANIMO appropriate to address the trends and patterns of the "*Band Together*" storyline. Using data collected from the ENCLUDE case studies, ANIMO was upgraded to assess the decision-making processes of various citizen profiles, which is essential for the successful development and implementation of socio-technically informed modeling activities.

Following thorough assessment and dialogue with **WP3**, we chose the most well-documented and data-abundant case studies. Using WP3 survey data on citizen preferences, we derived insights into the fundamental beliefs held by the members and developed a population profile. This profile served as input for ANIMO, adjusting the case-specific agent-related parameters each time.

These parameters were carefully crafted and chosen to encapsulate the primary influences of human behavior and decision-making regarding the choice to participate in an energy community. The application of ANIMO simulated the expected growth rate of the community over a set time horizon. This process enabled the comparison of growth rates and decarbonization potentials among different communities, essentially examining diverse populations.

Furthermore, we illuminated and identified social values and beliefs more inclined to lead to favorable decisions, thereby supporting the continued expansion of energy communities. These insights can, in turn, aid policymakers in crafting tailored policies aimed at bolstering incentives that truly drive such social and grassroot innovations forward.

Additional enhancements, modifications, and refinements were also made to ensure that the **DREEM** model could simulate the case-specific decarbonization pathways outlined in this deliverable. To enable DREEM to assess the decarbonization potential of the "*Power to the People*" and "*Habitual Creatures*" storylines, we extended the original architecture and capabilities of the model. The new components and respective modules that were developed and integrated to the original model's structure were the "C_8: Multilevel upscaling" and the "C_9: Transition matrix".

8.2. Decarbonization potential of energy citizenship at the local level

As part of this report, our focus was to design the scenario space based on the work implemented in the context of **Deliverable 5.2**, i.e., the further expansion and adjustment of the SSPs' qualitative descriptions to formulate a new set of three (3) qualitative descriptions, the ENCLUDE *"future-world"* narratives.

More specifically, by amalgamating the "*people-centered*" storylines with the "*future-world*" narratives, we broadened our scenario range by introducing alternative scenarios that delve into the uncertainty surrounding future societal and climatic conditions. These scenarios depicted the evolution of socio-technical aspects that are challenging to quantify, such as institutional quality, political stability, and environmental consciousness, serving as a foundation for users to further develop the scenarios.

This approach enabled us to encapsulate the impact of different external systemic changes including shifts in governmental institutions, organizational dynamics, and broader societal transformations at the national scale.

8.2.1. A "Power to the People" storyline and prosumerism

In this study, we examined whether *a people-powered transition based on citizen investments in small-scale PV systems can support the transition to climate neutrality by 2050 in the European Union's residential sector*. To prove that citizens can actually have benefits at the individual level from these investments, we first used the DREEM model to project the annual electricity demand and electricity production from PV at the city level in different Member States (i.e., Aalborg and Copenhagen in Denmark, Marseille and Paris in France, Athens and Thessaloniki in Greece, Lisbon and Porto in Portugal, and Bilbao, Madrid, and Malaga in Spain), considering their different climatic conditions and active policy schemes in terms of onsite generation (i.e., net metering, net billing, and FiT).

Based on modeling results, we then analyzed the profitability and decarbonization potential of small-scale PV investments as key drivers for citizens to actively participate in the energy transition, and, specifically, we calculated the economic benefits in terms of NPV and PBP for potential prosumers.

We identified *the economic benefits of different policy schemes* and compared *their potential benefits of prosumerism for EU citizens under different potential evolutions of the future.* Specifically, by comparing the economic benefits of the net metering and FiT policy schemes for smaller capacities (3 kW_p) like in the cases of Denmark, France, and Greece, we find that net metering seems to be more attractive in terms of profitability since citizens have no motive to produce excess electricity and feed it into the grid.

On the contrary, FiT can provide citizens with larger profitability when the installed capacity of the PV system is significantly larger and thus citizens have a strong motivation to produce larger amounts of electricity and provide it to the grid.

Our results also show that the fixed price under which citizens are compensated for the case of FiT is considered the most important factor for the profitability of the investment. Furthermore, we observe that economic parameters like the retail price of electricity and the capital costs of the PV system are the main drivers for the economic efficiency of investments in solar PV systems.

For example, despite the significantly lower solar potential of Denmark contrary to Greece, it is noteworthy that the discounted payback period of the investment of a 3 kW_p solar PV system is ~34% lower than the respective investment in Greece. This is attributed to the extremely high retail electricity prices in Denmark (the highest in the total of EU) alongside with the lower PV capital costs in Denmark, contrary to Greece.

Finally, we estimated *the emission reduction (decarbonization) potential of different transition pathways under a "Power to the People" storyline at the local level across the different Member States.* We observe that the decarbonization potential of prosumerism is dependent on countries' existing electricity mix, i.e., higher utilization of fossil fuels for electricity generation results in higher decarbonization potential.

For instance, while rooftop solar PV investments can contribute to the decarbonization efforts in Denmark and France, their existing reliance on wind and nuclear energy, respectively, results in a lower decarbonization potential compared to Greece, which has greater decarbonization potential since the carbon intensity of its electricity mix is comparatively larger.

8.2.2. A "Band Together" storyline and the further diffusion of Collective Energy Initiatives

In the context of the ENCLUDE "*Band Together*" storyline we asked ourselves: "*How can social and grassroot innovations, like CEIs, around Europe be further diffused and grow in the context of the short-term energy transition by 2030?*".

To answer this overarching question, we tested a set of diverse case studies using a common methodological framework. Specifically, we explored three (3) case studies, i.e., (i). the "*Cloughjordan Ecovillage*" in Ireland, (ii). the "*EnergieC Midden-Delfland*" energy community in the Netherlands, and (iii). the "*Belica Energy Community*" in North Macedonia.

For each case study, we followed a systematic process designed to collect, calibrate, and utilize the available data, simulate a community of agents working together to shape energy behavior and lifestyle within the community as well as disseminate it to non-members aiding in the growth of the community, all while taking into consideration elements such as individual temperaments and community values, ultimately aiming to realistically depict the development and growth of CEIs.

Our first step was to process community-specific data acquired through questionnaire surveys conducted in the context of **WP3** on crucial aspects of individual and collective citizen behaviors and lifestyles to parameterize the ANIMO framework.

To streamline the information, survey questions were categorized based on their influence on key character attributes deemed significant in the decision-making process regarding participation to a CEI. As a result, four (4) key character attributes were integrated as agent-related parameters into the ANIMO modeling framework, i.e., *financial concern*, *environmental awareness*, *energy independence*, and *sense of community*.

This process provided a holistic view of the community's preferences and priorities as well as depicted the degree to which these attributes are prevalent within each community, offering a nuanced understanding of the key factors influencing each community members' decision-making process.

Specifically, we observed similar trends in terms of the prevalence between the agent-related parameters in each of the three (3) selected case studies; however, the citizens of "*Belica Energy Community*" showcased lower sense of environmental awareness, energy independence, and sense of community compared to the citizens of the "*EnergieC Midden-Delfland*" energy community and the "*Cloughjordan Ecovillage*".

Based on the previous step, we parameterized the agents within ANIMO by assigning values to the agent-related parameters based on the community data. Different combinations of primary characteristics for each agent were formulated using varying distributions for each of the agent-related parameters.

The characteristics incorporated various levels of financial concerns, environmental awareness, desire for energy independence, and sense of community, and as a result, agents were further categorized based on their primary motivations for joining and operating within a community.

This led to the creation of six (6) "**Personas**" (archetypes) representing possible real-life incentives for participating to a CEI in the case of existing community members, as well as the reasoning behind the decision to join a CEI for prospective members:	
"***Eco-Conscious Savers***"	"*Environmentally conscious individuals that are financially savvy. Joining an energy community is a way to reduce their carbon footprint while also saving money on energy bills, or even generating income through participation in renewable energy production. Clear demonstrations of cost savings and potential financial benefits associated with RES can sway their decision*".
"***Tech Trailblazers***"	"*Excited about the innovative aspects of an energy community, they value the potential for smart home integration and increased energy independence through community-managed*

	systems. Additionally, they enjoy the sense of community and collaboration that comes with working towards shared goals".
"***Self-Reliant Savers***"	"*Driven by a desire for self-sufficiency, these individuals prioritize both energy independence and financial savings. They are interested in reducing reliance on the traditional grid and potentially generating their own energy through community renewable sources. Lower energy bills and shared investment opportunities further incentivize them to join*".
"***Security-Minded Sceptics***"	"*These individuals are drawn to the financial benefits offered by an energy community. They place value on a strong sense of community and trust the recommendations of neighbors who have already joined. Positive experiences shared within the community can convince them of the financial advantages and encourage them to adopt this innovative approach to energy management*".
"***Eco-Collaborators***"	"*Community-oriented individuals that value collective action and believe it is essential for addressing climate change. The opportunity to contribute to a larger environmental movement alongside like-minded neighbors is a significant motivator. Additionally, they appreciate the community's focus on renewable energy sources, which aligns with their desire to reduce their environmental impact*".
"***Green Guardians***"	"*Environmentalists that prioritize both a sustainable lifestyle and achieving energy independence. They're deeply concerned about the impact of traditional energy production and actively seek ways to reduce their carbon footprint. In addition, on-site renewable energy generation and reduced reliance on the grid align perfectly with their desire for energy independence, empowering them to take control of their energy consumption*".

These combinations provided us with a richer picture of different types of individuals within the energy community, while also helping us to model discrete types of agents within ANIMO. After processing the key data that were used as input into the ANIMO framework to calibrate the agent-related parameters, we turned to specifying the remaining model's parameters affecting the design and structure of the social network of agents, drawing from the scenario space and the descriptions of the "*future-world*" narratives.

With regards to our scenario design, we assumed the traditional adoption curve to simulate baseline transition pathways under the "*Familiar World*" narrative, as this curve describes the typical attitude of individuals towards innovation.

However, to portray the differences between the different "*future-world*" narratives, we further informed and differentiated the scenario space by incorporating various degrees of social acceptance and behavior adoption related to the decision-making process of joining a CEI. Therefore, the adoption curve was adapted to the needs of each narrative, by assuming a skewed distribution of the adoption curve and, thus, different percentages for the adopter groups.

As a result, we developed two (2) new adoption curves with the respective percentages for the different adopter groups; one (1) correlating to positive systemic changes (i.e., "*Unified World*"), that drive cooperation forward and assumes widespread early adoption of sustainable practices, and one describing a world in which growing disbelief is prevalent, which deters individuals from incorporating such practices into their lifestyle and in which adoption of innovations is delayed (i.e., "*Fragmented World*").

To identify *the key driving factors that could support the further growth of social and grassroot innovations, like CEIs, in Europe by 2030*, we employed the ANIMO model to simulate the different scenarios deriving from the "*future-world*" narratives. Our modeling results showed that *population density* and *social connectivity* are *key drivers of further CEI growth*. Remote locations, like the cases of Ireland and even more of North Macedonia, face inherent limitations due to lower population density. Contrastingly, densely populated areas facilitated faster CEI expansion, likely due to the enhanced effect of the "word-of-mouth" phenomenon.

Our findings also clearly demonstrated the cascade effect of mass participation that is encouraged by dense areas in terms of population, highlighting a "*ripple effect*" that can significantly accelerate the energy transition. This is clearly demonstrated in the case of the “*EnergieC Midden-Delfland*” energy community, which is the most densely populated area out of the selected case studies. This trend is further supported when comparing case study results across the “*future-world*” narratives.

Furthermore, we estimated *the emission reduction (decarbonization) potential of the transition pathways* under study. As expected, we find that higher emission reduction (decarbonization) potential is correlated with increased participation in energy communities, highlighting the positive impact of collective expressions of energy citizenship on advancing a green transition.

Particularly, the case of the “*EnergieC Midden-Delfland*” energy community showcases the highest capacity for reducing carbon emissions, and the case of “*Cloughjordan Ecovillage*" exhibits substantial promise for decarbonization, while “*Belica Energy Community*” contributes the least to avoided CO_2 emissions compared to the other case studies. As such, we believe that banding together holds high potential for achieving the ambitious decarbonization goals of the EU, particularly when combined with targeted policy actions designed to achieve widespread adoption of CEIs.

Of course, future projections of CEIs’ growth and targeted policy interventions to achieve it should also consider external conditions capturing the dynamic nature of CEIs’ diffusion and expansion.

For example, we received feedback from members of the Irish case study revealing the critical role of infrastructure planning in enabling future growth of the ecovillage. While the project demonstrates success in certain sustainability metrics, further expansion has remained stagnant and dependent on resolving limitations within the existing wastewater treatment system.

The case of the “Cloughjordan Ecovillage” is a prime example of how unforeseen hurdles, particularly infrastructure constraints, can impede the progress of otherwise well-designed sustainable community structures. This underlines the importance of collaborative efforts between CEIs, local and regional authorities, and other relevant stakeholders combined with a strategic approach to ensure that infrastructure keeps pace with sustainable development plans.

Overall, we believe that our insights regarding the “*Band Together*” storyline can be a steppingstone for policymakers and community organizers to better understand how social and grassroot innovations can be further diffused at the local level and thus further improve their capacity in terms of developing effective strategies that promote socio-technical transitions at the micro scale.

8.2.3. A tale of “Power to the People” and “Habitual Creatures”: A “green” rebranding of a Coal and Carbon Intensive Region into a city of the people, by the people, for the people

With regards to the case study application under a combined “*Power to the People*” and “*Habitual Creatures*” storyline, we tested the hypothesis of *a citizen-led transition based on energy efficiency investments and lifestyle and behavioral changes leading to a just and inclusive transition in the CCIR of Megalopolis.* Of course, this vision can only be realized if citizens and local agents have the willingness and the capacities to collaborate actively in transformative governance processes, ultimately resulting in collectively investing in the technological capabilities required.

However, before citizens decide to proceed with investing in energy efficiency, they need to be aware of the both the economic and the environmental value stemming from their investments, as it is unlikely to invest in new technological capabilities having only environmental or other ancillary benefits for the energy system, e.g., demand flexibility, grid stabilization, as their primary goals.

In this regard, we sought to find *the post-lignite development trajectory and the potential benefits of a people-powered transition in the residential sector of Megalopolis that does not rely on traditional fossil fuels, i.e., oil and natural gas.* Based on our findings, we observe that investing in electrification right from the start (i.e., "*Unified World*" scenario) is the most efficient scenario in terms of energy consumption reduction, environmental footprint, and potential extra charges on household bills.

This result complies with the intension of the REPowerEU plan to double the diffusion rate of heat pumps and reach ten (10) million installations by the next five (5) years (European Commission, 2022a). Regarding costs, our findings indicate that citizen investments in energy efficiency solutions along with adopting behavioral and lifestyle changes when it comes to managing energy consumption patterns lead to lower total costs in the long run at both the household and the municipality level.

Specifically, Megalopolis could save a cumulative amount of around €300 million if citizens collectively decide to directly invest in energy efficiency solutions and electrification. Downscaling from the municipality to the household level, this is translated to a cumulative cost saving of around 60,000 € per household (i.e., ~3 times the current GDP per capita of Greece) until 2050, showing the high economic potential of this socio-technical transition.

Considering that the economy of Megalopolis, which is mainly based on the energy and mining sector, will undergo an abrupt pathway towards the phase out of lignite, and that by 2025 (when the lignite-fired units will close), its gross domestic product, employment, and income could be significantly reduced, such building energy upgrades could decrease citizen' energy costs, limiting the effect of wage decreases and thus providing a significant helping hand to the most vulnerable citizens of Megalopolis.

Last but not least, we quantified *the emission reduction (decarbonization) potential in the residential sector of Megalopolis for the different* "*future-world*" *transition pathways under a combined* "*Power to the People*" *and* "*Habitual Creatures*" *storyline.* Aside from cost benefits, we observe that collective citizen action can also bring about significant environmental benefits highlighting the positive correlation between energy citizenship and decarbonization.

Considering the above, the Greek government should provide tailored energy efficiency support programs for such regions in transition, raising awareness in terms of the positive impacts of energy efficiency solutions on the reduction of household energy costs and to the labor market and economic growth.

Thus, while technological infrastructure is already in place, exploratory analyses focusing on new and innovative business models and legal frameworks are required to maximize the value of the technological capabilities required to inform and convince citizens of the potential benefits.

According to current planning at the national level, Megalopolis may miss the opportunity for just transition, as the installation of gas boilers is underway free of charge for all households through the Just Transition Fund.

As shown in our results, households' extra charge from citizen investments in gas boilers will only amplify the energy poverty phenomenon in the region as it results in increased costs in the long run. Therefore, our analysis suggests that citizens following the existing policy plan may result in a natural gas lock-in effect, at least in the residential sector, exposing citizens to costly energy bills for decades.

In general, we value that the Greek government should not only inject structural funds to trigger technology innovations in CCIRs but also further harmonize its policies considering the cultural and perceptual background of their local communities to foster the potential of energy citizenship as a lever of systemic change and more active citizen participation in these regions, which may eventually lead to more diversified, inclusive, and resilient transition pathways.

8.3. Limitations, exploitation, and further research

An important gap identified in the context of further developing and adjusting the ENCLUDE modeling ensemble to address the ENCLUDE "people-centered" storylines, lies in the capabilities of computational tools to address the "*People to the Streets*" storyline.

Considering that this storyline revolves around political activism and citizen engagement in sociopolitical movements, either supporting or opposing green transitions, we will use our modeling ensemble to assess the socio-technical dimensions of energy transition regarding the issue of local acceptance from the macro-perspective (i.e., national or supranational level) by reducing the technology potential, or even setting upper and lower limits in the models to consider the accepted technology saturation, which can be quantified based on empirical studies. The "saturation" may depend on personal factors such as attitudes and norms as well as regional conditions and can be very heterogeneous.

For technologies with considerable local acceptance issues, we will also consider technology exclusion within our modeling tools. This study will be part of **Deliverable 5.4**, as part of which, we will also examine how energy citizenship may aid in the shift to a decarbonized energy system at the national and supranational level.

To this end, we will incorporate a range of national and supranational case studies across different geographical contexts and socioeconomic environments and utilize several models from the expanded ENCLUDE modelling ensemble to simulate various scenarios incorporating a multitude of energy citizenship trends.

Indicatively, we will aim at defining how citizen behavior regarding the adoption of small-scale solar PV systems can impact decarbonization, examining the influence of social and political movements in the energy transition and the potential impact of prosumerism in the future electricity system, and exploring the scaled-up decarbonization potential stemming from the combination of multiple people-centric narratives at the national and supranational level.

Finally, selected results realized within **Deliverable 5.3** will be utilized to feed into the strategic citizen clusters developed under the work conducted in the context of **WP4**. Results from this application will be presented in the context of **Deliverable 5.5**.

Overall, we believe that our work can be exploited both within and outside of ENCLUDE by policymakers and other relevant end-users from the field of policy and practice, using our findings to derive interesting and policy-relevant implications and recommendations, and by researchers and other end-users from the field of academia that are interested in the ways that different patterns and trends of energy citizenship at the local level can be integrated into the design of decarbonization pathways and simulated through the use of energy system models.

Finally, to support efforts across Europe on transparency, associate source code, datasets, and detailed documentations, along with suitable open licenses (where possible) to enable the models' use, modification, and republication, will be uploaded on the TEESlab UPRC's GitHub page, while case study results will be made available on the ENCLUDE Interactive Policy Platform (as developed in the context of the **WP7**).

References

Ahsan Kabir, M., Farjana, F., Choudhury, R., Imrul Kayes, A., Sawkat Ali, M., & Farrok, O. (2023). Net-metering and Feed-in-Tariff policies for the optimum billing scheme for future industrial PV systems in Bangladesh. *Alexandria Engineering Journal*, *63*, 157–174. https://doi.org/10.1016/j.aej.2022.08.004

Arnfield, A. J. (2023). Köppen climate classification. In *Encyclopedia Britannica*.

Aruta, G., Ascione, F., Bianco, N., & Mauro, G. M. (2023). Sustainability and energy communities: Assessing the potential of building energy retrofit and renewables to lead the local energy transition. *Energy*, *282*, 128377. https://doi.org/https://doi.org/10.1016/j.energy.2023.128377

Ash, N., Blanco, H., Garcia, K., & Brown, C. (2010). *Ecosystems and human well-being: a manual for assessment practitioners*. Island Press.

Axon, S., Morrissey, J., Aiesha, R., Hillman, J., Revez, A., Lennon, B., Salel, M., Dunphy, N., & Boo, E. (2018). The human factor: Classification of European community-based behaviour change initiatives. *Journal of Cleaner Production*, *182*, 567–586. https://doi.org/10.1016/j.jclepro.2018.01.232

Ayoub, A., & Sornette, D. (2023). The power of precursors: An empirical assessment of nuclear power risks. *Progress in Nuclear Energy*, *164*. https://doi.org/10.1016/j.pnucene.2023.104878

Batty, M., & Torrens, P. M. (2005). Modelling and prediction in a complex world. *Futures*, *37*(7 SPEC.ISS.), 745–766. https://doi.org/10.1016/j.futures.2004.11.003

Bellini, E. (2024). France announces new FIT rates for PV systems up to 500 kW. *PV Magazine*. https://www.pv-magazine.com/2024/01/04/france-announces-new-fit-rates-for-pv-systems-up-to-500-kw/

Bjerkan, K. Y., Ryghaug, M., & Skjølsvold, T. M. (2021). Actors in energy transitions. Transformative potentials at the intersection between Norwegian port and transport systems. *Energy Research and Social Science*, *72*. https://doi.org/10.1016/j.erss.2020.101868

Bódis, K., Kougias, I., Jäger-Waldau, A., Taylor, N., & Szabó, S. (2019). A high-resolution geospatial assessment of the rooftop solar photovoltaic potential in the European Union. *Renewable and Sustainable Energy Reviews*, *114*(16). https://doi.org/10.1016/j.rser.2019.109309

Bonabeau, E., Dorigo, M., & Theraulaz, G. (2000). Inspiration for optimization from social insect behaviour. In *Nature* (Vol. 406, Issue 6791, pp. 39–42). https://doi.org/10.1038/35017500

Bowles, S., & Gintis, H. (2004). The evolution of strong reciprocity: Cooperation in heterogeneous populations. *Theoretical Population Biology*, *65*(1), 17–28. https://doi.org/10.1016/j.tpb.2003.07.001

Boyer, R. H. W. (2018a). Intermediacy and the diffusion of grassroots innovations: The case of cohousing in the United States. *Environmental Innovation and Societal Transitions*, *26*, 32–43. https://doi.org/10.1016/j.eist.2017.08.001

Boyer, R. H. W. (2018b). Intermediacy and the diffusion of grassroots innovations: The case of cohousing in the United States. *Environmental Innovation and Societal Transitions*, *26*, 32–43. https://doi.org/10.1016/j.eist.2017.08.001

Bradshaw, J., Uszok, A., Jeffers, R., Suri, N., Hayes, P., Burstein, M., Acquisti, A., Benyo, B., Breedy, M., Carvalho, M., Diller, D., Johnson, M., Kulkarni, S., Lott, J., Sierhuis, M., & Van Hoof, R. (2003). Representation and reasoning for DAML-based policy and domain services in KAoS and nomads. *Proceedings of the Second International Joint Conference on Autonomous Agents and Multiagent Systems*, 835–842. https://doi.org/10.1145/860575.860709

Brandoni, C., & Polonara, F. (2012). The role of municipal energy planning in the regional energy-planning process. *Energy*, *48*(1), 323–338. https://doi.org/https://doi.org/10.1016/j.energy.2012.06.061

Brenner-Fliesser, M., Matowska, M., Schwarzinger, S., & Blaettner, D. (2023). *WP3-Contextualising the emergence and consolidation of energy citizen-ship D3.1-Report on survey and structured interview results for identifying potential emergence and consolidation factors*. www.encludeproject.eu

Bünning, F., Sangi, R., & Müller, D. (2017). A Modelica library for the agent-based control of building energy systems. *Applied Energy*, *193*, 52–59. https://doi.org/10.1016/j.apenergy.2017.01.053

Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P. W., Trisos, C., Romero, J., Aldunce, P., Barrett, K., Blanco, G., Cheung, W. W. L., Connors, S., Denton, F., Diongue-Niang, A., Dodman, D., Garschagen, M., Geden, O., Hayward, B., Jones, C., … Ha, M. (2023a). *IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.* (P. Arias, M. Bustamante, I. Elgizouli, G. Flato, M. Howden, C. Méndez-Vallejo, J. J. Pereira, R. Pichs-Madruga, S. K. Rose, Y. Saheb, R. Sánchez Rodríguez, D. Ürge-Vorsatz, C. Xiao, N. Yassaa, J. Romero, J. Kim, E. F. Haites, Y. Jung, R. Stavins, … C. Péan, Eds.). https://doi.org/10.59327/IPCC/AR6-9789291691647

Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P. W., Trisos, C., Romero, J., Aldunce, P., Barrett, K., Blanco, G., Cheung, W. W. L., Connors, S., Denton, F., Diongue-Niang, A., Dodman, D., Garschagen, M., Geden, O., Hayward, B., Jones, C., … Ha, M. (2023b). *IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.* (P. Arias, M. Bustamante, I. Elgizouli, G. Flato, M. Howden, C. Méndez-Vallejo, J. J. Pereira, R. Pichs-Madruga, S. K. Rose, Y. Saheb, R. Sánchez Rodríguez, D. Ürge-Vorsatz, C. Xiao, N. Yassaa, J. Romero, J. Kim, E. F. Haites, Y. Jung, R. Stavins, … C. Péan, Eds.). https://doi.org/10.59327/IPCC/AR6-9789291691647

Campos, I., & Marín-González, E. (2020). People in transitions: Energy citizenship, prosumerism and social movements in Europe. *Energy Research and Social Science*, *69*(July), 101718. https://doi.org/10.1016/j.erss.2020.101718

Caramizaru, Aura., & Uihlein, Andreas. (2020). *Energy communities: an overview of energy and social innovation*. Publications Office of the European Union. https://doi.org/doi:10.2760/180576, JRC119433

Carlsen, H., Eriksson, E. A., Dreborg, K. H., Johansson, B., & Bodin, Ö. (2016). Systematic exploration of scenario spaces. *Foresight*, *18*(1), 59–75. https://doi.org/10.1108/FS-02-2015-0011

Cebecauer, T., & Suri, M. (2015). Typical Meteorological Year Data: SolarGIS Approach. *Energy Procedia*, *69*, 1958–1969. https://doi.org/10.1016/J.EGYPRO.2015.03.195

Chakraborty, D., Alam, A., Chaudhuri, S., Başağaoğlu, H., Sulbaran, T., & Langar, S. (2021). Scenario-based prediction of climate change impacts on building cooling energy consumption with explainable artificial intelligence. *Applied Energy*, *291*(August 2020), 116807. https://doi.org/10.1016/j.apenergy.2021.116807

Chatterjee, S., Stavrakas, V., Oreggioni, G., Süsser, D., Staffell, I., Lilliestam, J., Molnár, G., Flamos, A., & Ürge-Vorsatz, D. (2022). Existing tools, user needs and required model adjustments for energy demand modelling of a carbon-neutral Europe. *Energy Research & Social Science*.

Chatterjee, S., Stavrakas, V., Oreggioni, G., Süsser, D., Staffell, I., Lilliestam, J., Molnar, G., Flamos, A., & Ürge-Vorsatz, D. (2022). Existing tools, user needs and required model adjustments for energy demand modelling of a carbon-neutral Europe. *Energy Research & Social Science*, *90*(December 2021), 102662. https://doi.org/10.1016/j.erss.2022.102662

Chatzisideris, M., Laurent, A., Christoforidis, G., & Krebs, F. (2017). Cost-competitiveness of organic photovoltaics for electricity self-consumption at residential buildings: A comparative study of Denmark and Greece under real market conditions. *Applied Energy*, *208*(26), 471–479. http://dx.doi.org/10.1016/j.apenergy.2017.10.003

Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., & Sovacool, B. (2018). Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. *Energy Research and Social Science*, *37*(January 2017), 175–190. https://doi.org/10.1016/j.erss.2017.09.015

City Population official webpage. (2023). Belica in Kicevo (North Macedonia). https://www.citypopulation.de/en/northmacedonia/jugozapaden/ki%C4%8Devo/405833__belica/

Clarke, L., Jiang, K., Akimoto, K., Babiker, M., Blanford, G., Fisher-Vanden, K., Hourcade, J.-C., Krey, V., Kriegler, E., Löschel, A., & others. (2014). *Assessing transformation pathways*.

Climate Action Network. (2024a). *Rooftop Solar PV Country Profiles*. https://caneurope.org/rooftop-solar-pv-comparison-report/

Climate Action Network. (2024b). *Rooftop Solar PV Country Profiles*.

Cloughjordan Ecovillage. (2023). Cloughjordan Ecovillage Official Website. https://www.thevillage.ie/

Cooper, A. (1999). *The Inmates are Running the Asylum*.

Country Economy. (2024a). *Denmark - Household Electricity Prices*. https://countryeconomy.com/energy-and-environment/electricity-price-household/denmark?year=2017

Country Economy. (2024b). *France - Household Electricity Prices*. https://countryeconomy.com/energy-and-environment/electricity-price-household/france?year=2017

Country Economy. (2024c). *Portugal - Household Electricity Prices*. https://countryeconomy.com/energy-and-environment/electricity-price-household/portugal

Country Economy. (2024d). *Spain - Household Electricity Prices*. https://countryeconomy.com/energy-and-environment/electricity-price-household/spain

Csereklyei, Z., & Stern, D. I. (2015). Global energy use: Decoupling or convergence? *Energy Economics*, *51*, 633–641. https://doi.org/https://doi.org/10.1016/j.eneco.2015.08.029

Dana, L. P., Gurău, C., Hoy, F., Ramadani, V., & Alexander, T. (2021). Success factors and challenges of grassroots innovations: Learning from failure. *Technological Forecasting and Social Change*, *164*. https://doi.org/10.1016/j.techfore.2019.03.009

Daniel Huppmann, Elmar Kriegler, Volker Krey, Keywan Riahi, Joeri Rogelj, Katherine Calvin, Florian Humpenoeder, Alexander Popp, Steven K Rose, John Weyant, Nico Bauer, Christoph Bertram, Valentina Bosetti, Jonathan Doelman, Laurent Drouet, Johannes Emmerling, Stefan Frank, Shinichiro Fujimori, David Gernaat, … Runsen Zhang. (2019). *IAMC 1.5°C Scenario Explorer and Data hosted by IIASA*.

Danish Government Gazette. (2016). *BEK no. 999 of 29/06/2016* .

DAPEEP SA. (2022). *RES & CHP summary information sheet*. https://www.dapeep.gr/energeia/apesithia/deltio-ape/

De Vita, A., Kielichowska, I., Mandatowa, P., Capros, P., Dimopoulou, E., Evangelopoulou, S., Fotiou, T., Kannavou, M., Siskos, P., Zazias, G., De Vos, L., Dadkhah, A., & Dekelver, G. (2018). *ASSET Study on Technology pathways in decarbonisation scenarios*.

Defard, C. (2023). Energy Union 2.0. to deliver the European Green Deal: stronger governance, common financing and democratic tools. In *Jacques Delors Institute*. https://doi.org/10.4324/9781003246985-3

Dufo-López, R., & Bernal-Agustín, J. L. (2015). A comparative assessment of net metering and net billing policies. Study cases for Spain. *Energy*, *84*, 684–694. https://doi.org/10.1016/j.energy.2015.03.031

Dunphy, N. P., Lennon, B., Quinlivan, L., Revez, A., & Brenner-Fließer, M. (2023). *www.encludeproject.eu WP2-Characterizing and conceptualizing both individual and collective expressions of energy citizenship D2.1 Report on intersectional analysis of emerging examples of energy citizenship*. www.encludeproject.eu

Egert, R., Gerber, N., Haunschild, J., Kuehn, P., & Zimmermann, V. (2021). Towards Resilient Critical Infrastructures - Motivating Users to Contribute to Smart Grid Resilience. *I-Com*, *20*(2), 161–175. https://doi.org/10.1515/icom-2021-0021

Ellenbeck, S., & Lilliestam, J. (2019). How modelers construct energy costs: Discursive elements in Energy System and Integrated Assessment Models. *Energy Research and Social Science*, *47*(August 2018), 69–77. https://doi.org/10.1016/j.erss.2018.08.021

EnergieC Midden-Delfland. (2023). EnergieC Midden-Delfland Official Webpage. https://www.energiecmiddendelfland.nl/

Energy Press. (2024, February). *HEATING FUEL*.

EU. (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. *Official Journal of the European Union*, *2018*(L 328), 82–209.

European Commision. (2020). *EU Reference Scenario 2020*.

European Commission. (2019a). *Clean energy for all Europeans package*.

European Commission. (2019b). *The European Green Deal*. https://doi.org/10.1128/AAC.03728-14

European Commission. (2020). *EU Reference Scenario 2020*. https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

European Commission. (2021). *Energy union*.

European Commission. (2022a). REPowerEU Plan. *Https://Ec.Europa.Eu/Commission/Presscorner/Detail/En/IP_22_3131*.

European Commission. (2022b, March 8). *REPowerEU: Joint European action for more affordable, secure and sustainable energy*.

EUROPEAN COMMISSION. (2023). *Assessment of progress towards the objectives of the Energy Union and Climate Action*.

European Commission. (2023). *Renewable energy targets*.

European Parliament, & Council of the European Union. (2018). Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action. *Official Journal of the European Union*, *2018*(1), 1–77.

European, & Regions, C. of the. (2018). The Green Deal goes local ! 300+ best practices from the Members of the European Committee of the Regions. In *Official Journal of the European Communities*.

Evans, R. (2000). Economic Models and Economic Policy: What Economic Forecasters Can Do for Government. In F. A. G. Den Butter & M. S. Morgan (Eds.), *Empirical Models and Policy-Making* (pp. 206–280).

Fina, B., & Monsberger, C. (2023). Measures and business model approaches to facilitate the diffusion and integration of energy communities—A special focus on the Austrian case. *Energy Strategy Reviews*, *49*. https://doi.org/10.1016/j.esr.2023.101161

Forni, L. G., Galaitsi, S. E., Mehta, V. K., Escobar, M. I., Purkey, D. R., Depsky, N. J., & Lima, N. A. (2016). Exploring scientific information for policy making under deep uncertainty. *Environmental Modelling & Software*, *86*, 232–247. https://doi.org/https://doi.org/10.1016/j.envsoft.2016.09.021

French Government Gazette. (2017). *Art. 14/Order of May 9 for solar/2017* .

Fröding, V., & Gasne, S. (2024). *Renewable Energy Laws and Regulations*. https://iclg.com/practice-areas/renewable-energy-laws-and-regulations/france

Gautier, A., Jacqmin, J., & Poudou, J.-C. (2017). *The Prosumers and the Grid The Prosumers and the Grid **. https://www.researchgate.net/publication/304246432

German Association of Engineers. (2012). *Calculation of transient thermal response of rooms and buildings - Modelling of rooms* .

Gilbert, N., Ahrweiler, P., Barbrook-Johnson, P., Narasimhan, K. P., & Wilkinson, H. (2018). Computational modelling of public policy: Reflections on practice. *Jasss*, *21*(1). https://doi.org/10.18564/jasss.3669

Gjorgievski, V. Z., Cundeva, S., & Georghiou, G. E. (2021). Social arrangements, technical designs and impacts of energy communities: A review. In *Renewable Energy* (Vol. 169, pp. 1138–1156). Elsevier Ltd. https://doi.org/10.1016/j.renene.2021.01.078

Global Solar Atlas. (2024, January).

Greece - Household electricity prices. (2023, December).

Greek Government Gazette. (2016). *Article 4/L.4414/2016.A'149* .

Greek Government Gazette. (2023). *Law 5037/2023.OFG 78/28.03.2023*.

Grigoriou, R., Mayer, J., & Pallicska, J. (2022). *Household Energy Price Index (HEPI) for Europe Significant electricity price*.

Grubler, A., Johansson, T. B., Mundaca, L., Nakicenovic, N., Pachauri, S., Riahi, K., Rogner, H.-H., Strupeit, L., Kolp, P., Krey, V., Macknick, J., Nagai, Y., Rogner, M. L., Smith, K. R., Steen-Olsen, K., Weinzettel, J., & Davidson, O. (2012). Energy Primer. In T. B. Johansson, N. Nakicenovic, A. Patwardhan, & L. Gomez-Echeverri (Eds.), *Global Energy Assessment (GEA)* (pp. 99–150). Cambridge University Press. https://doi.org/10.1017/CBO9780511793677.007

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, *23*(2), 485–498. https://doi.org/10.1016/j.gloenvcha.2012.12.006

Hansen, A. R., Jacobsen, M. H., & Gram-Hanssen, K. (2022). Characterizing the Danish energy prosumer: Who buys solar PV systems and why do they buy them? *Ecological Economics*, *193*. https://doi.org/10.1016/j.ecolecon.2021.107333

Harish, V. S. K. V., & Kumar, A. (2016). Reduced order modeling and parameter identification of a building energy system model through an optimization routine. *Applied Energy*, *162*, 1010–1023. https://doi.org/10.1016/J.APENERGY.2015.10.137

Helbing, D. (2012). Agent-Based Modeling. In *Social Self-Organization. Understanding Complex Systems* (pp. 25–70). Springer, Berlin, Heidelberg.

Hellenic Ministry of Development, C. and S. (2021). *Εβδομαδιαιο δελτιο επισκοπησης τιμων καυσιμων*.

Hellenic Ministry of Development, C. and S. (2022a). *Εβδομαδιαίο δελτίο επισκόπησης τιμών καυσίμων (14/10/2022)*.

Hellenic Ministry of Development, C. and S. (2022b). *Εβδομαδιαίο δελτίο επισκόπησης τιμών καυσίμων (21/10/2022)*.

Hellenic Ministry of Development, C. and S. (2022c). *Εβδομαδιαίο δελτίο επισκόπησης τιμών καυσίμων (28/10/2022)*.

Hellenic Ministry of Environment and Energy. (2019). *Long Term Strategy for 2050*.

Hellenic Statistical Authority. (2022). *Census results of Population and Housing ELSTAT 2021*.

Hellenic Statistical Authority (ELSTAT). (2020). *Household Budget Survey* .

Heppenstall, A., Crooks, A., Malleson, N., Manley, E., Ge, J., & Batty, M. (2021). Future Developments in Geographical Agent-Based Models: Challenges and Opportunities. *Geographical Analysis*, *53*(1), 76–91. https://doi.org/10.1111/gean.12267

IEA. (2018). *National Survey Report of PV Power Applications in Denmark*. https://iea-pvps.org/wp-content/uploads/2020/01/NSR_Denmark_2018.pdf

IEA. (2022). *National Survey Report of PV Power Applications in France*. https://iea-pvps.org/wp-content/uploads/2023/08/National-Survey-Report-of-PV-Power-Applications-in-FRANCE-2022-v3.pdf

IEA. (2023). *Greece 2023: Energy Policy Review*. https://iea.blob.core.windows.net/assets/5dc74a29-c4cb-4cde-97e0-9e218c58c6fd/Greece2023.pdf

Indoor environmental input parameters for design and assessment of energy performance of buildings-addressing indoor air quality, thermal environment, lighting and acoustics. (2006).

Intergovernmental Panel on Climate Change (IPCC). (2022). Climate Change 2022, Mitigation of Climate Change Summary for Policymakers (SPM). In *Intergovernmental Panel on Climate Change.* (Issue 1).

International Energy Agency. (2017). *World Energy Outlook 2017*. https://doi.org/10.1787/weo-2017-en

Jackson, M. O., & Yariv, L. (2006). Diffusion on Social Networks. *Économie Publique/Public Economics*, *16*. https://doi.org/10.4000/economiepublique.1721

Jakob, M., Haller, M., & Marschinski, R. (2012). Will history repeat itself? Economic convergence and convergence in energy use patterns. *Energy Economics*, *34*(1), 95–104. https://doi.org/https://doi.org/10.1016/j.eneco.2011.07.008

Jones, R., Patwardhan, A., Cohen, S., Dessai, S., Lammel, A., Lempert, R., Mirza, M. M. Q., & von Storch, H. (2014). *Foundations for decision making*.

Karamaneas, A., Koasidis, K., Frilingou, N., Xexakis, G., Nikas, A., & Doukas, H. (2023). A stakeholder-informed modelling study of Greece's energy transition amidst an energy crisis: The role of natural gas and climate ambition. *Renewable and Sustainable Energy Transition*, *3*. https://doi.org/10.1016/j.rset.2023.100049

Kennedy, N., & Buckley, J. (2021). *How to mainstream sustainable consumption in Skibbereen, using learnings from Cloughjordan eco-village* [Applied Research Project]. University College Cork.

Kërçi, T., Tzounas, G., & Milano, F. (2022). A dynamic behavioral model of the long-term development of solar photovoltaic generation driven by feed-in tariffs. *Energy*, *256*(28). https://doi.org/10.1016/j.energy.2022.124506

Kirby, P. (2020). Cloughjordan Ecovillage: Community-Led Transitioning to a Low-Carbon Future. *Palgrave Studies in Media and Environmental Communication*. https://doi.org/https://doi.org/10.1007/978-3-030-47587-1_16

Kleanthis, N., Stavrakas, V., Ceglarz, A., Süsser, D., Schibline, A., Lilliestam, J., & Flamos, A. (2022). Eliciting knowledge from stakeholders to identify critical issues of the transition to climate neutrality in Greece, the Nordic Region, and the European Union. *Energy Research & Social Science, 93*, 102836. https://doi.org/https://doi.org/10.1016/j.erss.2022.102836

Koumparou, I., Christoforidis, G. C., Efthymiou, V., Papagiannis, G. K., & Georghiou, G. E. (2017). Configuring residential PV net-metering policies – A focus on the Mediterranean region. *Renewable Energy*, *113*, 795–812. https://doi.org/10.1016/J.RENENE.2017.06.051

Kress, M., Prince, S., & Gössling, S. (2023). *Exploring the Role of Eco-Communities in Fostering Environmental Stewardship: A Study of Volunteer Tourism at Cloughjordan Eco* [Master Thesis]. Linnaeus University.

Krumm, A., Süsser, D., & Blechinger, P. (2022). Modelling social aspects of the energy transition: What is the current representation of social factors in energy models? *Energy*, *239*. https://doi.org/10.1016/j.energy.2021.121706

Kühnbach, M., Bekk, A., & Weidlich, A. (2022). Towards improved prosumer participation: Electricity trading in local markets. *Energy*, *239*, 122445. https://doi.org/10.1016/J.ENERGY.2021.122445

Laakso, S., Eranti, V., & Lukkarinen, J. (2023). Practices and acts of energy citizenship. *Journal of Environmental Policy and Planning*. https://doi.org/10.1080/1523908X.2023.2251915

Lamnatou, C., Cristofari, C., & Chemisana, D. (2024). Renewable energy sources as a catalyst for energy transition: Technological innovations and an example of the energy transition in France. In *Renewable Energy* (Vol. 221). Elsevier Ltd. https://doi.org/10.1016/j.renene.2023.119600

Lempert, R., Nakicenovic, N., Sarewitz, D., & Schlesinger, M. (2004). Characterizing Climate-Change Uncertainties for Decision-Makers. An Editorial Essay. *Climatic Change*, *65*(1), 1–9. https://doi.org/10.1023/B:CLIM.0000037561.75281.b3

Levesque, A., Pietzcker, R. C., Baumstark, L., De Stercke, S., Grübler, A., & Luderer, G. (2018a). How much energy will buildings consume in 2100? A global perspective within a scenario framework. *Energy*, *148*, 514–527. https://doi.org/10.1016/j.energy.2018.01.139

Levesque, A., Pietzcker, R. C., Baumstark, L., De Stercke, S., Grübler, A., & Luderer, G. (2018b). How much energy will buildings consume in 2100? A global perspective within a scenario framework. *Energy*, *148*, 514–527. https://doi.org/10.1016/j.energy.2018.01.139

Li, K., Liu, L., Wang, F., Wang, T., Duić, N., Shafie-khah, M., & Catalão, J. P. S. (2019). Impact factors analysis on the probability characterized effects of time of use demand response tariffs using association rule mining method. *Energy Conversion and Management*, *197*(August). https://doi.org/10.1016/j.enconman.2019.111891

Liu, Y., Goodrick, S., Williams, M., & Zhang, A. (2024). Climate change and variability overview. *Future Forests: Mitigation and Adaptation to Climate Change*, 7–48. https://doi.org/10.1016/B978-0-323-90430-8.00010-1

Lokale Energie Monitor 2022. (2022). Https://Www.Hier.Nu/Lokale-Energie-Monitor-2022.

Lopion, P., Markewitz, P., Robinius, M., & Stolten, D. (2018). A review of current challenges and trends in energy systems modeling. *Renewable and Sustainable Energy Reviews*, *96*, 156–166. https://doi.org/10.1016/j.rser.2018.07.045

MacAl, C. M., & North, M. J. (2010). Tutorial on agent-based modelling and simulation. *Journal of Simulation*, *4*(3), 151–162. https://doi.org/10.1057/jos.2010.3

Mäs, M., Flache, A., & Helbing, D. (2010). Individualization as driving force of clustering phenomena in humans. *PLoS Computational Biology*, *6*(10). https://doi.org/10.1371/journal.pcbi.1000959

Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. P., S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield. (2019). *IPCC, 2018: Global Warming of 1.5°C.*

An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

Matschoss, K., Mikkonen, I., Gynther, L., Koukoufikis, G., Uihlein, A., & Murauskaite-Bull, I. (2022). Drawing policy insights from social innovation cases in the energy field. *Energy Policy*, *161*. https://doi.org/10.1016/j.enpol.2021.112728

McCollum, D. L., Krey, V., & Riahi, K. (2011). An integrated approach to energy sustainability. *Nature Climate Change*, *1*(9), 428–429. https://doi.org/10.1038/nclimate1297

McDevitt, C. (2022). *Net metering vs. Net billing explained*. Energysage. https://www.energysage.com/solar/net-metering-vs-net-billing/

McKenna, E., & Thomson, M. (2016). High-resolution stochastic integrated thermal–electrical domestic demand model. *Applied Energy*, *165*, 445–461. https://doi.org/10.1016/J.APENERGY.2015.12.089

Michas, S., Stavrakas, V., Papadelis, S., & Flamos, A. (2020). A transdisciplinary modeling framework for the participatory design of dynamic adaptive policy pathways. *Energy Policy*, *139*. https://doi.org/10.1016/j.enpol.2020.111350

Michas, S., Stavrakas, V., Spyridaki, N. A., & Flamos, A. (2019a). Identifying Research Priorities for the further development and deployment of Solar Photovoltaics. *International Journal of Sustainable Energy*, *38*(3), 276–296. https://doi.org/10.1080/14786451.2018.1495207

Michas, S., Stavrakas, V., Spyridaki, N., & Flamos, A. (2019b). Identifying Research Priorities for the further development and deployment of Solar Photovoltaics. *International Journal of Sustainable Energy*, *38:3*, 276–296. https://doi.org/10.1080/14786451.2018.1495207

Ministry of Environment and Energy. (2022). *Revised Master Plan of the just developmental transition of coal intensive regions - Επικαιροποιημένο Master Plan Δίκαιης Αναπτυξιακής Μετάβασης των λιγνιτικών περιοχών(In Greek),*.

Ministry of the Environment and Energy. (2019). *National Energy and Climate Plan (NECP)*.

Muzzarelli, A., Ma, L., Barry, M., & Heravi, B. (2023). *Education for sustainability through communities of practice. Information, meaning, identity, and the building of a 'Learning Alliance' in the Irish Ecovillage of Cloughjordan* [Doctoral Thesis]. UCD Dublin.

Nakicenovic, N., & Swart, R. (2000). *Special Report on Emissions Scenarios (SRES) – A Special Report of Working Group III of the Intergovernmental Panel on Climate Change* (Vol. 559).

Natorski, M., & Herranz Surrallés, A. (2008). Securitizing Moves To Nowhere? The Framing of the European Union's Energy Policy. *Journal of Contemporary European Research*, *4*(2), 70–89. https://doi.org/10.30950/jcer.v4i2.88

Nikas, A., Lieu, J., Sorman, A., Gambhir, A., Turhan, E., Baptista, B. V., & Doukas, H. (2020). The desirability of transitions in demand: Incorporating behavioural and societal transformations into energy modelling. *Energy Research and Social Science*, *70*(September 2020), 101780. https://doi.org/10.1016/j.erss.2020.101780

Oberthür, S. (2011). The European Union's Performance in the International Climate Change Regime. *Journal of European Integration, 33*(6), 667–682. https://doi.org/10.1080/07036337.2011.606690

O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., van Ruijven, B. J., van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., & Solecki, W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*, *42*, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

O'Neill, B. C., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., Mathur, R., & van Vuuren, D. P. (2014). A new scenario framework for climate change research: The concept of shared socioeconomic pathways. *Climatic Change*, *122*(3), 387–400. https://doi.org/10.1007/s10584-013-0905-2

Ordóñez, Á., Sánchez, E., Rozas, L., García, R., & Parra-Domínguez, J. (2022). Net-metering and net-billing in photovoltaic self-consumption: The cases of Ecuador and Spain. *Sustainable Energy Technologies and Assessments*, *53*. https://doi.org/10.1016/j.seta.2022.102434

Oriol, L. (2018). *Self-consumption framework in France*.

Osička, J., & Černoch, F. (2022a). European energy politics after Ukraine: The road ahead. *Energy Research & Social Science*, *91*(July), 102757. https://doi.org/10.1016/j.erss.2022.102757

Osička, J., & Černoch, F. (2022b). European energy politics after Ukraine: The road ahead. *Energy Research & Social Science*, *91*(July), 102757. https://doi.org/10.1016/j.erss.2022.102757

Our World In Data. (2024a). *Per capita electricity generation from solar*. https://ourworldindata.org/grapher/solar-electricity-per-capita?tab=chart&country=ESP~PRT~DNK~SWE~FRA~GRC~NLD~DEU~OWID_EU27~BEL~AUT~POL~ITA~FIN

Our World In Data. (2024b). *Per capita electricity generation from wind*. https://ourworldindata.org/grapher/wind-electricity-per-capita?tab=chart&country=DEU~NLD~DNK~GRC~FRA~ESP~AUT~BEL~OWID_EU27~FIN~ITA~SWE~IRL~PRT~POL

Our World In Data. (2024c). *Portugal: Energy Country Profile*. https://ourworldindata.org/energy/country/portugal

Our World In Data. (2024d). *Spain: Energy Country Profile*. https://ourworldindata.org/energy/country/spain

P. Shakarian, V.S. Subrahmanian, & M.L. Sapino. (2010, July). *Using Generalized Annotated Programs to Solve Social Network Optimization Problems*. https://doi.org/10.1145/0000000.0000000

Pata, U. K., & Samour, A. (2022). Do renewable and nuclear energy enhance environmental quality in France? A new EKC approach with the load capacity factor. *Progress in Nuclear Energy*, *149*. https://doi.org/10.1016/j.pnucene.2022.104249

Pearce, B. J., Djinlev, V., Delft, T. U., & Zurich, E. (2022). *ENCLUDE Academy-Action-based Online Modules*. www.encludeproject.eu

Pfenninger, S., Hawkes, A., & Keirstead, J. (2014). Energy systems modeling for twenty-first century energy challenges. *Renewable and Sustainable Energy Reviews*, *33*, 74–86. https://doi.org/10.1016/j.rser.2014.02.003

P.O. Fanger. (1970). *Thermal comfort. Analysis and applications in environmental engineering*.

Portuguese Government Gazette. (2022). *Decree-Law 15/2022*.

project GRETA. (2023). *Visualizing Energy Data for Diverse Energy Citizenship*. https://project-greta.eu/wp-content/uploads/2023/09/

Public Power Corporation. (2024). *G1/G1N 'Green' invoice for household electricity price*. https://www.dei.gr/el/gia-to-spiti/revma/g1-g1n/

Raskin, P., Monks, F., Ribeiro, T., Vuuren, D., Alonso, A., & Field, C. (2005). Global Scenarios in Historical Perspective. *Ecosystems and Human Well-Being*, *2*.

Renewable Heating Hub. (2021, April 12). *The European Heat Pump Association tells us about the future of the industry*.

Riahi, K., Dentener, F., Gielen, D., Grubler, A., Jewell, J., Klimont, Z., Krey, V., McCollum, D., Pachauri, S., Rao, S., Ruijven, B. van, van Vuuren, D. P., Wilson, C., Isaac, M., Jaccard, M., Kobayashi, S., Kolp, P., Larson, E. D., Nagai, Y., … Morgan, G. (2012). Energy Pathways for Sustainable Development. In T. B. Johansson, N. Nakicenovic, A. Patwardhan, & L. Gomez-Echeverri (Eds.), *Global Energy Assessment (GEA)* (pp. 1205–1306). Cambridge University Press. https://doi.org/10.1017/CBO9780511793677.023

Ringler, P., Keles, D., & Fichtner, W. (2016). Agent-based modelling and simulation of smart electricity grids and markets - A literature review. In *Renewable and Sustainable Energy Reviews* (Vol. 57, pp. 205–215). Elsevier Ltd. https://doi.org/10.1016/j.rser.2015.12.169

Ritchie, H., & Rosado, P. (2020). *Nuclear energy*. Our World In Data. https://ourworldindata.org/nuclear-energy

Rogers, E. M. (1983). *Diffusion of innovations*. Free Press.

Rosenow, J., Cowart, R., Bayer, E., & Fabbri, M. (2017). Assessing the European Union's energy efficiency policy: Will the winter package deliver on 'Efficiency First'? *Energy Research & Social Science*, *26*, 72–79. https://doi.org/10.1016/J.ERSS.2017.01.022

Rothman, D., Agard, J., Alcamo, J., & Ghosh Ph.D, N. (2007). The Future Today. In *International Journal of Remote Sensing - INT J REMOTE SENS* (pp. 400–454).

Roulot, J., & Raineri, R. (2018). The impacts of photovoltaic electricity self-consumption on value transfers between private and public stakeholders in France. *Energy Policy*, *122*, 459–473. https://doi.org/10.1016/j.enpol.2018.07.035

Rövekamp, P., Schöpf, M., Wagon, F., Weibelzahl, M., & Fridgen, G. (2021). Renewable electricity business models in a post feed-in tariff era. *Energy*, *216*. https://doi.org/10.1016/j.energy.2020.119228

Rubino, A. (2018). Network charges in a low CO2 world. *Nature Energy*, *March*, 2–4. https://doi.org/10.1038/s41560-018-0115-2

Ruggeri, L. (2021). *Needs and barriers of prosumerism in the energy transition era*.

Rychtár, J. and B. S. (2008). Evolutionary dynamics on small-world networks . *International Journal of Computational and Mathematical Sciences*.

Schäfer, A. (2005). Structural change in energy use. *Energy Policy*, *33*(4), 429–437. https://doi.org/https://doi.org/10.1016/j.enpol.2003.09.002

Seebauer, S., Brenner-Fliesser, M., & Tuerk, A. (2022). *Developing a tool to assess the maturity and growth of energy communities*. https://doi.org/10.13140/RG.2.2.27794.73926

Shakarian, P., Bhatnagar, A., Aleali, A., Shaabani, E., & Guo, R. (2015). The Independent Cascade and Linear Threshold Models. In *SpringerBriefs in Computer Science* (pp. 35–48). Springer, Cham.

Shakarian, P., Eyre, S., & Paulo, D. (2013). A scalable heuristic for viral marketing under the tipping model. *Social Network Analysis and Mining*, *3*(4), 1225–1248. https://doi.org/10.1007/s13278-013-0135-7

Soeiro, S., & Ferreira Dias, M. (2020). Renewable energy community and the European energy market: main motivations. *Heliyon*, *6*(7). https://doi.org/10.1016/j.heliyon.2020.e04511

Solar Power Europe. (2023). Top 10 EU Countries Solar Capacity per Capita. https://www.solarpowereurope.org/advocacy/solar-saves/fact-figures/top-10-eu-countries-solar-capacity

Spanish Government Gazette. (2019). *Royal Decree 244/2019* .

Star, S. L., & Griesemer, J. R. (1989). Amateurs and Professionals in Berkeley ' s Museum of Vertebrate Zoology , 1907-39. *Social Studies of Science*, *19*(3), 387–420.

Statista. (2022). Installed Solar Photovoltaics Capacity per Capita in the European Union (EU-27) in 2022, by Country. https://www.statista.com/statistics/612412/installed-solar-photovoltaics-capacity-eu/#:~:text=Solar%20photovoltaics%20capacity%20installed%20per,EU%2D27%202022%2C%20by%20country&text=At%201%2C071.5%20watts%20per%20inhabitant,559%20watts%20per%20inhabitant%2C%20respectively.

Statista. (2024a). *Distribution of electricity generation in Denmark in 2023, by source*. https://www.statista.com/statistics/1235360/denmark-distribution-of-electricity-production-by-source/

Statista. (2024b). *Distribution of electricity generation in Greece in 2023, by source*. https://www.statista.com/statistics/1235419/greece-distribution-of-electricity-production-by-source/

Statista. (2024c). *Distribution of electricity production in France from 2021 to 2023, by energy source*. https://www.statista.com/statistics/1263322/electrical-production-by-sector-france/

StatLine. (2020). Key Figures for Districts and Neighborhoods 2020. https://opendata.cbs.nl/statline/#/CBS/nl/dataset/84799NED/table?dl=41062

Stavrakas, V., & Flamos, A. (2020). A modular high-resolution demand-side management model to quantify benefits of demand-flexibility in the residential sector. *Energy Conversion and Management*, *205*. https://doi.org/10.1016/j.enconman.2019.112339

Stavrakas, V., & Flamos, A. (2022). *Exploring regulatory designs and product-service offerings to empower end-users and incentivise demand flexibility: A modelling framework in support to low-carbon energy systems* [Doctoral Dissertation Thesis, University of Piraeus (UniPi)]. http://dx.doi.org/10.26267/unipi_dione/1809

Stavrakas, V., Papadelis, S., & Flamos, A. (2019a). An agent-based model to simulate technology adoption quantifying behavioural uncertainty of consumers. *Applied Energy*, *255*. https://doi.org/10.1016/j.apenergy.2019.113795

Stavrakas, V., Papadelis, S., & Flamos, A. (2019b). An agent-based model to simulate technology adoption quantifying behavioural uncertainty of consumers. *Applied Energy*, *255*. https://doi.org/10.1016/j.apenergy.2019.113795

Stavrakas, V., Spyridaki, N. A., & Flamos, A. (2018). Striving towards the deployment of bio-energy with carbon capture and storage (BECCS): A review of research priorities and assessment needs. In *Sustainability (Switzerland)* (Vol. 10, Issue 7). MDPI AG. https://doi.org/10.3390/su10072206

Stephan, A., Killer, S., Axhausen, V., Eth, K. W., Zürich, Z. E., Dennis, G., & Christian, H.-R. (1970). *Understanding Regional Effects of Travel Times in Switzerland and*.

Süsser, D., Ceglarz, A., Gaschnig, H., Stavrakas, V., Flamos, A., Giannakidis, G., & Lilliestam, J. (2021). Model-based policymaking or policy-based modelling? How energy models and energy policy interact. *Energy Research and Social Science*, *75*(February), 101984. https://doi.org/10.1016/j.erss.2021.101984

Süsser, D., Gaschnig, H., Ceglarz, A., Stavrakas, V., Flamos, A., & Lilliestam, J. (2022). Better suited or just more complex? On the fit between user needs and modeller-driven improvements of energy system . *Energy*, *239*.

Süsser, D., Pickering, B., Chatterjee, S., Oreggioni, G., Stavrakas, V., & Lilliestam, J. (2021). *Topic : LC-SC3-CC-2-2018 of the Horizon 2020 work program : Modelling in support to the transition to a Low-Carbon Energy System in Europe Project number : 837089*. https://doi.org/https://doi.org/10.48481/iass.2021.030

The European Heat Pump Association tells us about the future of the industry - Renewable Heating Hub. (2022). Retrieved 17 October 2022, from https://renewableheatinghub.co.uk/european-heat-pump-association-interview-thomas-nowak

Trading Economics. (2024). *EU Carbon Permits - Price - Chart - Historical Data - News*.

Trutnevyte, E., Hirt, L. F., Bauer, N., Cherp, A., Hawkes, A., Edelenbosch, O. Y., Pedde, S., & van Vuuren, D. P. (2019). Societal Transformations in Models for Energy and Climate Policy: The Ambitious Next Step. In *One Earth* (Vol. 1, Issue 4, pp. 423–433). Cell Press. https://doi.org/10.1016/j.oneear.2019.12.002

Tsopelas, I., Katiforis, Z., Van Den Berg, N. J., Stavrakas, V., Van Vuuren, D. P., & Flamos, A. (2023). *Development of decarbonization pathways based on social innovations of energy citizenship*. www.encludeproject.eu

Tsopelas, I., Stavrakas, V., & Flamos, A. (2022). *Model adjustments and modifications to match emerging energy citizenship trends and patterns WP5-The impact of energy citizen-ship in decarbonization pathways*. www.encludeproject.eu

Tzani, D., Stavrakas, V., Santini, M., Thomas, S., Rosenow, J., & Flamos, A. (2022). Pioneering a performance-based future for energy efficiency: Lessons learnt from a comparative review analysis of pay-for-performance programmes. *Renewable and Sustainable Energy Reviews*, *158*, 112162. https://doi.org/https://doi.org/10.1016/j.rser.2022.112162

UN DESA. (2023). *The Sustainable Development Goals Report 2023: Special Edition*.

Van Egmond, S., & Zeiss, R. (2010). Modeling for Policy. Science-based models as performative boundary objects for Dutch policy making. *Science Studies*, *23*(1), 58–78. https://doi.org/10.1093/oxfordhb/9780199548453.003.0038

van Sluisveld, M. A. E., Martínez, S. H., Daioglou, V., & van Vuuren, D. P. (2016). Exploring the implications of lifestyle change in 2°C mitigation scenarios using the IMAGE integrated assessment model. *Technological Forecasting and Social Change*, *102*, 309–319. https://doi.org/10.1016/j.techfore.2015.08.013

van Vuuren, D. P., Kok, M. T. J., Girod, B., Lucas, P. L., & de Vries, B. (2012). Scenarios in Global Environmental Assessments: Key characteristics and lessons for future use. *Global Environmental Change*, *22*(4), 884–895. https://doi.org/https://doi.org/10.1016/j.gloenvcha.2012.06.001

van Vuuren, D. P., Kriegler, E., O'Neill, B. C., Ebi, K. L., Riahi, K., Carter, T. R., Edmonds, J., Hallegatte, S., Kram, T., Mathur, R., & Winkler, H. (2014). A new scenario framework for Climate Change Research: Scenario matrix architecture. *Climatic Change*, *122*(3), 373–386. https://doi.org/10.1007/s10584-013-0906-1

Wang, X., Sun, X., Ahmad, M., & Chen, J. (2024). Energy transition, ecological governance, globalization, and environmental sustainability: Insights from the top ten emitting countries. *Energy*, *292*, 130551. https://doi.org/https://doi.org/10.1016/j.energy.2024.130551

Webster, M., Forest, C., Reilly, J., Babiker, M., Kicklighter, D., Mayer, M., Prinn, R., Sarofim, M., Sokolov, A., Stone, P., & Wang, C. (2003). Uncertainty Analysis of Climate Change and Policy Response. *Climatic Change*, *61*, 295–320. https://doi.org/10.1023/B:CLIM.0000004564.09961.9f

Wetter, M. (2011). Co-simulation of building energy and control systems with the building controls virtual test bed. *Journal of Building Performance Simulation*, *4*(3), 185–203. https://doi.org/10.1080/19401493.2010.518631

Wikberg, K. (2019). Renewable Energy Sources Promotion in Denmark. *RES Legal*. http://www.res-legal.eu/search-by-country/denmark/single/s/res-e/t/promotion/aid/premium-tariff-law-on-the-promotion-of-renewable-energy/lastp/96/

Wilcox, S., & Marion, W. (2008). *Innovation for Our Energy Future Users Manual for TMY3 Data Sets*. http://www.osti.gov/bridge

Williamson, K., Satre-Meloy, A., Velasco, K., & Green, K. (2018). *Climate Change Needs Behavior Change: Making the Case for Behavioral Solutions to Reduce Global Warming*.

Wind Europe. (2022). *Wind energy in Europe: 2022 Statistics and the outlook for 2023-2027*. https://windeurope.org/intelligence-platform/product/wind-energy-in-europe-2022-statistics-and-the-outlook-for-2023-2027/

Wolisz, H., Punkenburg, C., Streblow, R., & Müller, D. (2016). Feasibility and potential of thermal demand side management in residential buildings considering different developments in the German energy market. *Energy Conversion and Management*, *107*, 86–95. https://doi.org/10.1016/j.enconman.2015.06.059

Wurzel, R. K. W., Connelly, J., & Liefferink, D. (2016). *The European Union in International Climate Change Politics. Still Taking a Lead?* Routledge.

Yu, H. J. J. (2018). A prospective economic assessment of residential PV self-consumption with batteries and its systemic effects: The French case in 2030. *Energy Policy*, *113*, 673–687. https://doi.org/10.1016/J.ENPOL.2017.11.005

Zeraibi, A., Jahangir, A., Ramzan, M., & Adetayo, T. S. (2023). Investigating the effects of natural gas, nuclear energy, and democracy on environmental footprint and energy risk in France: Does financial inclusion matter? *Progress in Nuclear Energy*, *159*. https://doi.org/10.1016/j.pnucene.2023.104621

Zhang, L., & Marbach, P. (2012). *"Two Is a Crowd" - Optimal Trend Adoption in Social Networks.: Vol. vol 75*. Springer.

Ziras, C., Calearo, L., & Marinelli, M. (2021). The effect of net metering methods on prosumer energy settlements. *Sustainable Energy, Grids and Networks*, *27*. https://doi.org/10.1016/j.segan.2021.100519

Zuo, W., Wetter, M., Tian, W., Li, D., Jin, M., & Chen, Q. (2016). Coupling indoor airflow, HVAC, control and building envelope heat transfer in the Modelica Buildings library. *Journal of Building Performance Simulation*.

PARTICIPANTS

ENCLUDE project has received funding from the European Union's Horizon 2020 Research and Innovation programme under grant agreement No 101022791