Social Inclusion in the Governance of Regional Energy Transitions:
The Case of Coal-and-Carbon-Intensive Regions

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El hombre es tierra que anda.

Atahualpa Yupanqui

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SUMMARY

This PhD thesis examines how regional governance can address energy injustices while advancing low-carbon transitions, with a particular focus on coal and carbon-intensive regions (CCIRs). I begin from the observation that regions offer a meaningful governance scale for energy transitions: they are large enough to encompass key economic sectors, yet close enough to citizens to respond to social impacts. Building on this, the thesis asks: What governance arrangements can regions apply to address energy injustices and achieve social inclusion while pursuing a low-carbon transition?

To answer this question, I draw on sustainability transitions, regional and innovation studies, energy justice, and intersectionality theory. The research consists of one conceptual study and four empirical studies conducted in European and North American contexts, including my involvement in the EU H2020 Tipping Plus project.

The thesis first develops a clearer understanding of what energy regions are and how they transition. Through a systematic literature review, I propose a typology of energy regions based on the level of institutional formality and progress toward low-carbon transitions. This typology identifies five types of energy regions and positions CCIRs as peripheralized regions with strong path dependencies. It serves as a framework to compare transition pathways and assess how different governance arrangements shape social and justice outcomes.

I then examine how energy injustices manifest at the regional level. A case study of a wealthy Dutch energy region shows that energy vulnerability exists even in high-income contexts and is often overlooked in top-down regional transition strategies. I conceptualize energy vulnerability as an intersectional phenomenon that emerges from the interaction of socio-economic characteristics, access to knowledge, and institutional exclusion. Three main forms of vulnerability are identified: limited energy affordability, restricted access to clean energy, and lack of inclusion in decision-making processes.

To explore how transition pathways and justice outcomes interact across regions, I conduct a comparative analysis of fourteen CCIRs using fuzzy-set Qualitative Comparative Analysis (fs-QCA). Focusing on household energy affordability as a key distributional justice outcome, the findings show that justice outcomes are shaped not only by regional policies but also by national and international conditions. Regions with techno-economic capacity to transform their carbon-intensive sectors tend to experience better affordability outcomes than regions forced to phase out these sectors without viable economic alternatives.

Finally, I investigate how governance arrangements can motivate citizen participation, particularly among vulnerable and hard-to-reach groups. A case study in a US–Mexico cross-border energy region uses surveys and a discrete choice experiment to examine citizens' preferences for participation. The results show that vulnerable groups are willing to engage—and even take leadership roles—when governance arrangements combine local, regional, and national actors and are explicitly framed around justice. Trust and meaningful inclusion emerge as key conditions for participation.

Overall, this thesis demonstrates that addressing energy injustice requires regional-level action and inclusive governance. It contributes to theory by advancing the concepts of energy regions and intersectional energy justice, and it offers practical insights for policymakers seeking to design fair and socially inclusive regional energy transitions.

SAMENVATTING

Dit proefschrift onderzoekt hoe regionaal bestuur kan bijdragen aan het aanpakken van energie-onrechtvaardigheid terwijl tegelijkertijd een koolstofarme transitie wordt bevorderd, met een specifieke focus op kolen- en koolstofintensieve regio's (CCIR's). Dit proefschrift veronderstelt dat regio's een betekenisvolle rol kunnen hebben in energietransities: zij zijn groot genoeg om relevante economische sectoren te omvatten, maar staan tegelijkertijd dicht genoeg bij burgers om sociale effecten zichtbaar te maken en erop te reageren. De centrale onderzoeksvraag is: Welke bestuurlijke arrangementen kunnen regio's toepassen om energie-onrechtvaardigheden aan te pakken en sociale inclusie te realiseren, terwijl zij werken aan een koolstofarme transitie?

Om deze vraag te beantwoorden combineer ik inzichten uit de literatuur over duurzaamheidstransities, regionale en innovatiestudies, energierechtvaardigheid en intersectionaliteitstheorie. Het onderzoek bestaat uit één conceptuele studie en vier empirische studies, uitgevoerd in Europese en Noord-Amerikaanse contexten, onder andere in het kader van het EU H2020-project Tipping Plus.

Het proefschrift begint met het verduidelijken van het concept energieregio en de manieren waarop regio's hun energietransitie vormgeven. Op basis van een systematische literatuurstudie ontwikkel ik een typologie van energieregio's langs twee dimensies: de mate van institutionele formalisering en de voortgang richting een koolstofarme transitie. Deze typologie onderscheidt vijf typen energieregio's en positioneert CCIR's als perifere regio's met sterke padafhankelijkheden. Het raamwerk maakt het mogelijk transitiepaden te vergelijken en te analyseren hoe bestuurlijke arrangementen sociale en rechtvaardigheidsuitkomsten beïnvloeden.

Vervolgens onderzoek ik hoe energie-onrechtvaardigheden zich op regionaal niveau manifesteren. Een casestudy in een welvarende Nederlandse energieregio laat zien dat enertgiekwetsbaarheid ook in hoge-inkomenscontexten voorkomt en vaak over het hoofd wordt gezien in top-down regionale transitiestrategieën. Ik conceptualiseer energie-kwetsbaarheid als een intersectioneel fenomeen dat ontstaat door de combinatie van sociaaleconomische kenmerken, toegang tot kennis en institutionele uitsluiting. Er worden drie hoofdvormen van kwetsbaarheid geïdentificeerd: beperkte energiebetaalbaarheid, beperkte toegang tot schone energie en een gebrek aan inclusie in besluitvormingsprocessen.

Om de relatie tussen transitiepaden en rechtvaardigheidsuitkomsten in verschillende regio's te analyseren, voer ik een vergelijkende studie uit van veertien CCIR's met behulp van fuzzy-set Qualitative Comparative Analysis (fs-QCA). Met energie-betaalbaarheid

van huishoudens als centrale verdelingsdimensie laat de analyse zien dat rechtvaardigheidsuitkomsten niet alleen door regionale beleidskeuzes worden bepaald, maar ook door nationale en internationale contexten. Regio's met technologische en economische mogelijkheden om hun koolstofintensieve sectoren te transformeren kennen gunstigere betaalbaarheidsuitkomsten dan regio's die deze sectoren uitfaseren zonder economisch alternatief.

Tot slot onderzoek ik welke bestuurlijke arrangementen burgerparticipatie stimuleren, met in het bijzonder aandacht voor kwetsbare en moeilijk bereikbare groepen. In een grensoverschrijdende regio tussen de Verenigde Staten en Mexico analyseer ik aan de hand van enquêtes en een discreet keuze-experiment de voorkeuren van bur-gers voor deelname aan de energietransitie. De resultaten tonen aan dat kwetsbare groepen bereid zijn zich actief in te zetten—en zelfs leiderschapsrollen op zich te nemen—wanneer bestuurlijke arrangementen lokale, regionale en nationale actoren combineren en expliciet worden vormgegeven vanuit een rechtvaardigheidsperspectief. Een basis van vertrouwen en betekenisvolle participatie blijken daarbij cruciale voorwaarden.

Samenvattend laat dit proefschrift zien dat het aanpakken van energie-onrechtvaardigheid vraagt om actie op regionaal niveau en om inclusieve vormen van bestuur. Het onderzoek levert een theoretische bijdrage aan het denken over energieregio's en intersectionele energie-rechtvaardigheid en biedt praktische handvatten voor beleidsmakers die willen werken aan eerlijke en sociaal-inclusieve regionale energietransities.

1

INTRODUCTION

Coal-and-carbon-intensive regions (CCIRs) are among the most difficult places to embrace sustainable energy transitions. Socio-economic inequalities that already exist in these regions may increase or new ones may emerge due to the changes caused by the energy transition. Regions offer a suitable scale to address energy transitions, especially in regions with path dependencies like CCIRs. Energy justice literature studies such socio-economic inequalities and suggests measures to resolve them. Accordingly, research suggests including underrepresented groups in the regional energy transitions to prevent socio-economic inequalities from perpetuating because their involvement can help identify issues impacting diverse groups. However, it is not clear how to apply justice and inclusiveness in the governance of regional energy transitions, especially not in CCIRs. This thesis aims to answer the research question: What governance arrangements can be applied in regions to address energy injustices and achieve social inclusion, while advancing a low-carbon regional transition? By drawing insights from socio-technical and socio-ecologial systems theories I define what system's components to consider. To identify what groups are vulnerable in regions, I combine energy fairness-related frameworks, intersectionality theory, and regional innovation and governance frameworks. Four standalone studies are conducted to answer the research question.

1.1. BACKGROUND AND CONTEXT

THE energy system has for long been perceived as a technology-centered system where citizens are the mere receivers of energy services [1]. Although seemingly invisible, the human dimension determines key aspects of the energy system like the energy demand level through habits of consumption, the demand of sustainability standards of energy generation, and in some cases, the success or failure of energy projects. For this reason energy systems should not merely be perceived as technical systems but rather as sociotechnical ones, where social, technical and institutional elements interact, are co-dependent, co-evolve, and where citizens are not limited to just being end consumers [2].

Globally, today's energy transition is perceived as sectorial shifts from fossil-fuel-based to sustainable and renewable-based energy sources. However, energy transitions can be seen as sociotechnical processes where citizen participation is a right and duty of citizens and stakeholders. Transitioning the energy system is required, as this sector contributes with 75% of GHGs emissions worldwide [3]. Current and future climate change effects urge humans to undertake measures to limit global warming to 1.5 °C. Today's global energy transition requires decarbonization measures in synergy with a fair socioeconomic and environmental sustainable development [4]. Low-carbon transitions do not only require technological change, but also change in people's relationship with energy systems so that climate mitigation measures can be adopted. Citizens' attitudes toward the environment impact local and global sustainability. For example, citizens can choose using energy-efficient electric appliances at home, consuming renewable-based electricity, or adopting more environmental-friendly political choices. This shows that citizens do not only have a role of being passive energy consumers in energy systems. Citizens are also stakeholders in sociotechnical energy systems with interests, agendas and decision-making power influencing an energy transition.

Although stakeholders are essential for the realization of energy transitions, the different roles they can have in heat and electricity low-carbon energy transitions are not well understood in the literature [5, 6]. From a strategic management perspective [7], citizens should be included because of various reasons such as descriptive (to understand energy transitions), instrumental (to prevent social opposition), and normative aspects (to reduce social inequalities) [8]. From an energy democracy and gender perspective, citizens can have several roles in energy transitions; for example, as enablers through social innovation and entrepreneurship [9, 10], consumers, prosumers, social-movement mobilizers, or decision-makers [11]. Particularly, the understanding of the roles of vulnerable citizens is critically limited [12].

Regions dependent on coal or carbon-intensive economies are referred as coal-and-carbon-intensive regions (CCIRs) [13]. In CCIRs, the energy transition process is socioeconomically challenged as it can come with a negative social impact. Extractive industries in the energy sector such as coal and oil and gas are marked by socio-environmental impacts that disrupt the livelihoods of populations surrounding extractive zones [14]. In CCIRs, there is a clear imbalance of the distribution of risks and benefits. This issue is prevalent in the entire energy sector, including the upstream side (extraction) and downstream side (processing and consumption) [14]. An energy transition aims to decrease economic activities of the fossil-fuel industry, which cause substantial GHG emissions.

Therefore, people working in this economic sector will be impacted by green energy transition measures if no transition plan is available to compensate or support them in other ways [15]. In a similar vein, one should notice that growth in renewable energy industry's activities requires that negative impact on environmental and social domains are minimized [16]. Therefore, to pursue an energy transition in CCIRs, there is a need to better understand what injustices may occur.

Because of their spatial scale and interrelations with various economic sectors, CCIRs require a governance approach at a regional scale. One should acknowledge that fossil-fuel rich sectors - like the natural gas sector - are interconnected with other economic as well as public sectors. These interconnected sectors include transport, electricity, gas, heating, agriculture, water, and the residential sector [17]. This implies that energy transitions are of inter-sectoral nature, and therefore require governance approaches that can coordinate transitions whilst considering inter-sector complexity and dependencies. A national-scale or larger governance approach may cover all sectors; however, a national-level governance is not able to capture local needs, capacities, preferences, and locals' responses to socio-structural change [18]. An intermediate governance level that covers multi-sectoral transitions without losing its connection with the local reality is needed. In the Netherlands and other European countries, a regional-level governance approach to the energy transition has been developed to steer and coordinate transition strategies across several municipalities by distributing decision-making power. This approach is referred as the energy region governance approach [19].

1.2. JUSTICE IN ENERGY TRANSITIONS

Historically, there have been underrepresented stakeholders in decision-making in relation to the planning, implementation and operation of energy (supply) system. This particularly holds for the workforce of the energy sector [9, 20]. Decision power asymmetries permeate the governance of energy systems and tend to favor traditional or incumbent stakeholders [20–22]. Women are arguably the biggest underrepresented group in the energy sector, making up less than 8% of senior management positions in renewable energy technology sectors such as wind and solar [23]. Other underrepresented and vulnerable groups are impoverished communities [24–27], Indigenous communities [28, 29], immigrants [30, 31], among others. According to stakeholder management theory and energy justice studies, vulnerable groups should have the opportunity to participate in the transition because of normative reasons and their involvement can help push forward the transition [7, 9, 32].

Several research frameworks and justice principles help describe the vulnerabilities that underprivileged citizen groups experience. Among these frameworks there are just transition and energy justice [15, 33], energy democracy [20, 34], energy sovereignty [35], energy poverty [36], and community energy [37]. However, available fairness-related frameworks and concepts fail to distinguish between vulnerable citizen groups, which is necessary to effectively address injustices. To overcome this limitation, intersectionality theory can be applied, as it focuses on understanding inequalities between groups [38, 39].

1.2.1. ENERGY JUSTICE TRANSITION FRAMEWORKS

Just transition is a framework that combines three application fields of justice: energy justice, environmental justice, and climate justice [15]. This framework looks at justice issues in three dimensions of a transition, these dimensions are called the three tenets: 1) distributive justice, the allocation of costs and benefits among stakeholders; (2) recognition justice, the recognition of the marginalized groups in society and the respectful treatment of opposing voices, and; (3) procedural justice, e.g. inclusiveness and transparency of procedures" [33, 40]. These main concepts are briefly described and compared in Table 1.1. However, other dimensions of justice have also been proposed such as restorative justice, cosmopolitan justice, and others [15].

Among all dimensions of justice that belong to the just transition framework, recognition justice is the most related to the inclusion of underrepresented groups. Another related concept is energy democracy, which refers to the low-carbon emancipation or ownership of energy systems by local communities [34]. This concept has been defined and applied as an ideal goal mainly in the US and Europe. The concept energy democracy has been adopted by some political parties, unions, communities, and a few regions and nations [20]. The overarching goals of energy democracy have been described as phasing-out fossil fuels in the energy sector, public ownership and operation of the energy sector's production and consumption, and the restructuring of the energy model to prioritize social justice, inclusion, and sustainability instead of private profit. Community energy describes sustainable energy systems (with consumers and producers) run by and designed for local citizens [37, 41]. Another similar concept is community energy, which is typically framed at the intra-community (community groups) level. Often, authors link community energy projects with local democracy and opportunities for marginalized people, empowerment, and ownership are key concepts in community energy projects [37]. Energy sovereignty is another term that is framed at the household level. It refers to individuals and communities' rights to decide upon energy generation, distribution, and consumption [35]. Some authors point out that energy sovereignty has been adopted in Latin America whereas energy democracy in Europe and the United States, although both concepts overlap to some extent. However, one has to consider the local context when studying inclusiveness in CCIRs because social inclusion and CCIRs are strongly contextual dependent. This leads to the need to study social inclusiveness at the regional level.

1.3. ENERGY JUSTICE AT THE REGIONAL LEVEL

There is limited evidence and understanding on how to address inclusiveness of underrepresented groups in energy transitions at a regional level [47]. Interestingly, the energy justice framework has been applied to cover social inclusion at the national level, while at the local, community or household levels, other frameworks such as energy poverty and community energy, and research fields like gender and intersectional studies have been applied [9, 42, 48, 49]. However, there is limited evidence of the application of energy justice frameworks at a sub-national scale. Particularly, effective ways to engage and mobilize diverse citizen groups (with different attributes and roles) at the regional

level remain under-explored [50–52]. Burke and Stephens (2017) describe the few US energy regions as agglomerations of community energy cooperatives and as regions running their independent transmission system operators. They mention that the concept of energy democracy has been defined as a goal in these US energy regions; however, no guidelines to apply energy democracy were developed [20]. Other examples of energy regions are found in Austria, where guidelines have been developed to ensure participation in the design strategies for regional energy transitions [53].

Nonetheless, available justice-related transition frameworks lack granularity to describe injustices experienced by different vulnerable groups [49, 54]. Connecting energy justice with the regional context is necessary in CCIRs because of the regional challenges such as the influence of local, national, and international governance levels on the region [55], and the interconnection of socio-economic sectors like mining or construction with the fossil-fuel sector [17]. Regional governance and innovation frameworks can help account for the regional challenges like breaking path dependencies of coal mining industry with regional learning policies [56, 57], as they have been applied in non-justice-focused transition studies [58–61].

1.4. Research question, objectives, and methods

To address the knowledge gap on energy justice in regional energy transitions in CCIRs, I formulated a main research question and four research objectives for this dissertation, as presented in Figure 1.1. I selected four empirical studies to answer the research question because they represent regions with similar CCI sectors, but at different stages of their energy transition. The similarities and differences between these studies, presented from Chapter 2 to Chapter 5, helped make the analysis of energy justice more robust.

What governance arrangements can be applied in contextually different coal and carbon-intensive regions to address energy injustices, while advancing a regional low-carbon transition?

Objective A:
Understanding what governance arrangements entail and what characteristics energy regions have that influence regional energy transitions.

To meet objective A, a systematic literature review of energy regions was performed, which is presented in Chapter 2. This chapter offers an overview of theoretical frameworks that are applied to study regional energy transition governance from three research fields, being sustainability transitions, regional studies, and (social) innovation studies. The review identifies examples of energy regions in different contexts, revealing the contextual characteristics that influence the ways in which an energy transition takes place in regions. These characteristics are presented as three ways: geographical characteristics, the level of institutional formality, and the low-carbon transition progress. The analysis of the last two allows the formulation of a typology of energy regions.

Objective B:
Understanding what energy injustices occur in transitioning energy regions in different contexts and identifying what governance arrangements may help repair injustices and include diverse citizen groups.

To meet this objective a qualitative case study of an energy region was conducted: The case of the Rotterdam-The Hague energy region in the Netherlands. This highly-urbanized region is dependent on oil and gas imports, which is at an intermediate transition stage in a Global North country. Chapters (3) provides an overview of theoretical frameworks that help understand fairness issues in energy regions. Among these frameworks, energy justice, intersectionality, and sustainable development were proven relevant for the case studies when combined with the collaborative governance framework [60, 62]. A number of energy injustices and vulnerabilities are identified by using various methods such as stakeholder interviews, desk research, media analysis, stakeholder workshops, and a survey. The governance arrangements observed in the two regions are analyzed and discussed using the theoretical frameworks mentioned.

Objective C:
Understanding what possible contextual conditions influence a region's transition pathway and the creation or correction of energy injustices.

Objective C will be met by applying a fuzzy-set qualitative comparative analysis (fs-QCA) of fourteen CCIRs, described in Chapter 4. Contextual conditions at the regional and (inter)national level were selected to analyze their influence on regional just transitions. These conditions covered economic, technological, social, and governance aspects of a CCIR. Results show that contextual conditions for energy affordability, a type of energy injustice, differ between CCIRs that have technical feasibility to transition and those that can only phase out the CCIR sector without an apparent economic activity replacement. In both cases, a combination of regional and (inter)national conditions was always present in the set of influential conditions for energy affordability.

Objective D:
Understanding what governance arrangements and interventions can be proposed in energy regions to address energy injustices experienced by diverse citizen groups while advancing the low-carbon transition.

A discrete choice experiment of citizens' willingness to participate in a regional energy transition in the Baja California-California cross-border region between Mexico and the United States was conducted to meet objective D (see Chapter 5). Findings from the qualitative case studies in the Netherlands and Mexico-US helped define the questionnaire for this experiment. Justice-framing in energy policy was tested as intervention or bias in the study. The type of governance arrangements and justice framing that motivate citizens to have more active participation vary among citizen groups, especially between an online

representative sample and an in-person sample covering vulnerable groups.

1.5. ORGANIZATION OF THE THESIS

To answer the overarching research question, Chapter 2 identifies energy region concepts through a sustainability transitions and governance lens. These concepts help describe the selected energy regions in Chapter 3, which analyzes a region in-depth with qualitative and quantitative methods. This case study conceptualizes energy vulnerability as an intersectional phenomenon to identify vulnerable groups. Chapter 4 zooms out to evaluate the influence of contextual regional, national, and international-level conditions on just transitions, particularly on energy affordability. Chapter 5 analyzes the influence of perceiving justice on citizens' willingness to participate in a regional energy transition. This last study identified diverse groups' preferences for participation as responsible consumers and local leaders. Finally, in Chapter 6, the main research question is answered and the objectives are addressed; thus, stating the thesis's empirical and theoretical contributions and summarizing policy and future research recommendations.

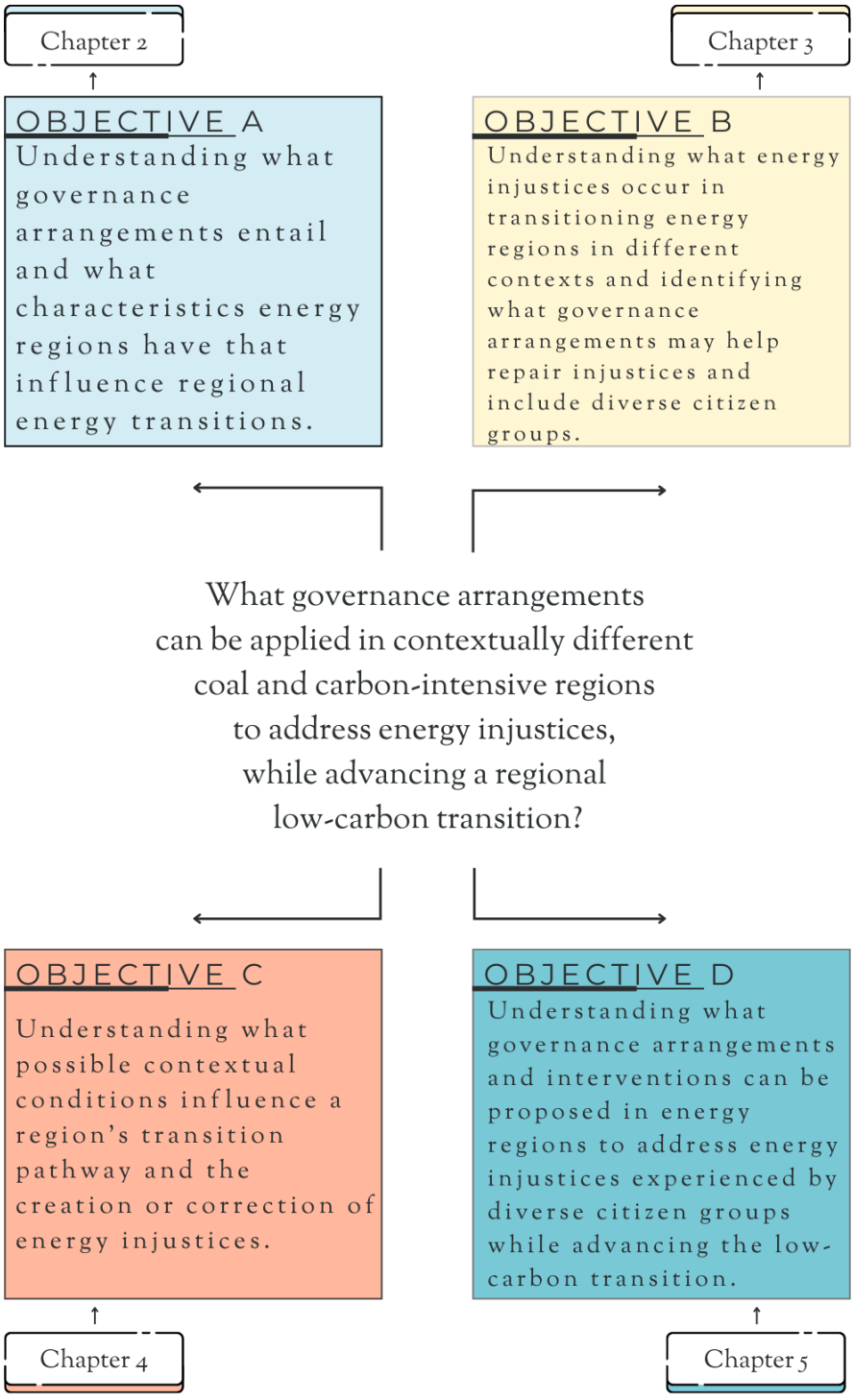

Figure 1.1: Research question and objectives

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Table 1.1: Main justice frameworks and concepts in the energy transition

Concept	General definition	Similarities & differences	References
Energy justice	A framework applied to address social inclusion and injustices in energy systems, often focusing on national-level analysis and recognizing the need to repair injustices and include vulnerable groups.	Similar to just transition in addressing justice issues; differs in scale (often national). Connected to other frameworks but lacks granularity to distinguish between vulnerable groups.	[15, 33, 42, 43]
Just transition	A framework combining energy justice, environmental justice, and climate justice, focusing on three tenets: distributive, recognition, and procedural justice.	Broader umbrella than energy justice; includes multiple justice dimensions. Shares goals of inclusion and fairness. Recognition justice closely linked to inclusion of marginalized groups.	[15, 33, 40]
Energy democracy	Refers to low-carbon emancipation and/or ownership of energy systems by local communities, aiming for fossil fuel phase-out, public ownership, and prioritization of social justice, inclusion, and sustainability over profit.	Similar to energy sovereignty in promoting control over energy; differs in geographic adoption (US/Europe) and scale (community/system level). Shares goals with community energy (local empowerment).	[20, 34]
Energy sovereignty	Refers to the rights of individuals and communities to decide on energy generation, distribution, and consumption.	Overlaps with energy democracy but is often framed at the household level and more associated with Latin America. Emphasizes rights and autonomy.	[35]
Energy community (community energy)	Sustainable energy systems run by and designed for local citizens, often linked to local democracy, empowerment, ownership, and inclusion of marginalized groups.	Similar to energy democracy in community ownership and empowerment; differs in being typically framed at the intra-community level. Focuses on local projects and participation.	[37, 41]
Intersectionality	A theory used to understand inequalities between groups by examining how intersecting identity attributes (e.g., gender, race) create marginalization and privilege.	Differs from other frameworks by focusing on distinguishing between vulnerable groups rather than general justice principles. Complements energy justice and just transition by adding granularity and improving inclusiveness analysis.	[38, 39, 44–46]

Table 1.2: Summary of energy justice-related concepts

2

A SYSTEMATIC LITERATURE REVIEW OF ENERGY REGIONS

This chapter aims to explore the fundamental aspects of regional energy transitions, providing a systematic literature review of regional concepts and proposing a typology of energy regions. It begins with a review of the energy region terms used in peer-reviewed empirical cases. The review draws from regional studies, innovation studies, and sustainability transitions frameworks to offer a comprehensive perspective. The chapter then delves into the governance arrangements and transition pathways regions have exhibited. A typology of energy regions is proposed based on two dimensions: The level of formality of institutions and the low-carbon transition progress. Through this analysis, it addresses objective A "understanding what institutional arrangements conform and what characteristics energy regions have that influence their transition". By the end of this chapter, readers will gain a deeper understanding of how energy regions in different contexts, including coal and carbon-intensive regions, can or cannot advance their low-carbon transition and get insights on what implications transition pathways can have on fairness. This conceptual chapter sets the stage for the analysis and discussions in the following chapters.

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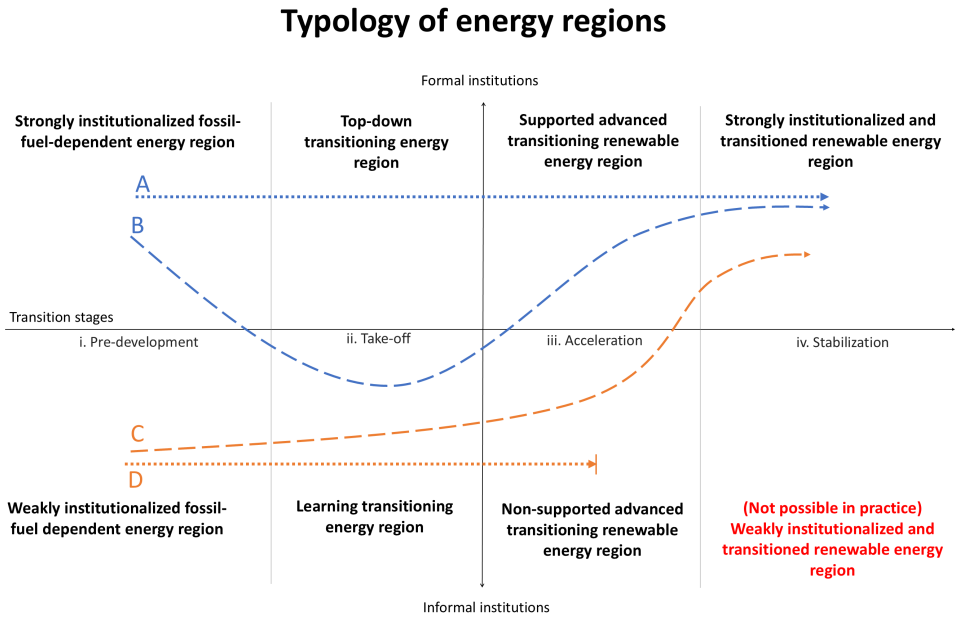
ABSTRACT

Low-carbon energy transitions are being increasingly developed at sub-national or regional levels, forming, thus, energy regions. More energy regions have been formed as energy systems become more decentralized, and national governments devolve decision-making power to local authorities. Energy regions have been studied in several countries, but no study has yet overviewed these regions' variety, transition process, and governance approach. It is important to draw lessons for other cases worldwide, like coal and carbon-intensive regions, to understand what type of regions and how they have stimulated their energy transition. Thus, this study investigated i) the concepts of energy regions that have been published and ii) the way energy regions have transitioned in terms of governance arrangements and innovation processes. A systematic literature review was conducted covering forty-seven academic publications and three grey literature reports of energy regions in ten countries. This review covered three academic (sub-)disciplines: i.e. sustainability transitions, regional studies, and innovation studies. Results (See Figure 2.1) show five concepts of energy regions: city-regions, peripheralized regions, coal and carbon-intensive regions, learning regions, and renewable energy regions. The formed typology shows the possible transition pathways that regions can follow. Interestingly, only those energy regions that adopted social innovations had the potential to empower their region, its organizations, and its citizens. Finally, recommendations for practitioners in similar regions worldwide are outlined to help overcome obstacles and advance their low-carbon transition.



Curve	Transition pathway	Geographical energy region concepts	Transitioning energy region concepts
A.	Top-down and stable	City regions	Top-down renewable energy region
B.	Learning and stable	Peripheralized, CCIRs and city regions	Learning region and renewable energy region
C.	Learning and stable	Peripheralized regions	Learning region and renewable energy region
D.	Learning and non-stable	Peripheralized regions	Learning region

Figure 2.1: Graphical Abstract. The pathways of the different region types are derived from the typology of energy regions according to the dimensions regarding the regions' level of institutional formality and transition stage. Four transition pathways are presented with the dotted and dashed curves for the geographical region concepts (city regions, peripheralized regions, and CCIRs). While pathways B, C, and D go through a learning region phase, pathway A does not and instead follows a top-down transition. The transition stages are adapted from [64]

2.1. INTRODUCTION

THE devolution to regions is a phenomenon of transferring or reclaiming power from the central or national government to regional or local authorities [65–67]. This phenomenon has been fueled by social movements supporting regionalism and growing global economic competition [67, 68]. Seeking more sub-national autonomy is a growing trend in regions with socio-cultural identity discrepancies, perceived low sovereignty, and high levels of income [69, 70]. Additionally, globalization has led to the specialization of industries within cities and regions, contributing to certain regions' desire for autonomy [67, 68]. In the EU, the regionalization process is based on the understanding that the management of natural "resources depends on the cooperation of appropriate international institutions on the one hand and national, regional, and local institutions on the other"[71] (pp.284). The European Union Congress of Local and Regional Authorities argues that regionalizing territories can make countries and intergovernmental cooperation work more effectively and efficiently. As a result, at least €200 billion was dedicated to helping EU regions become more efficient, competitive, inclusive, and sustainable between 2014 and 2020 [65, 72]. Therefore, municipal, provincial, and national governance levels can consider leveraging regionalization processes by moving towards an intermediate regional governance level when working on their sustainable development agenda.

When the regionalization process permeates energy systems, the concept of regional energy transition can be applied. In this paper, regional energy governance refers to the formal and informal governance approach that steers an energy transition strategy at the sub-national, inter-municipality, and sometimes cross-national levels [53, 55]. Additionally, the concept of energy region has been increasingly used when discussing sub-national territories whose energy systems undertake a regional energy transition strategy [53, 55, 73]. Although the term energy region has been used mainly by scholars in Western Europe and North America, energy regions can, in principle, be found worldwide. The Upper Nitra region in Slovakia, the South Kalimantan province of Indonesia, and the Coahuila region in Mexico are examples of coal regions undergoing energy transitions [74–77]. These regions can be considered energy regions because they are in the process of a low-carbon energy transition that involves the participation of regional (in)formal actor-networks [53].

The National government has created some examples of energy regions to implement a national Climate agenda. In the case of the Netherlands, thirty energy regions were formed to work towards the country's climate change mitigation goals by 2050 [78]. Each Dutch energy region has been tasked with drafting a regional energy transition strategy (RES) in negotiation and collaboration with formalized actor networks; however, RES has no formal constitution authority. Thus, energy regions are not legal entities in the country. Yet, by developing RES, Dutch energy regions have some degree of freedom to choose how to design their transition pathways and renewable energy projects that contribute to the national 35 TWh goal. In doing so, they are supported by a national program to share knowledge, build capacity, and use central government funding through subsidies and tax incentives. This includes examples such as the

renewable energy support scheme 'SDE++'. However, each RES is critically assessed and calculated based on its contribution to the national objective and is approved by the central government [55]. A reason behind the establishment of RESs is that some renewable energy projects cut across municipal jurisdictions and, therefore, require inter-municipal coordination to prevent the uneven distribution of risks and benefits between municipalities, cities, and rural areas [19]. In this way, a national energy transition agenda is implemented with strong involvement of regional actors so that decentralized governments (i.e., municipalities, water boards, and provincial government) can have more agency and 'regional ownership' [19, 79, 80].

Other examples of energy regions have started as a bottom-up approach, with local governments and citizens having some degree of autonomy in managing local energy projects that have received support from the central government at later stages [73, 81]. For example, in Austria and Germany, local governments, civil society organizations such as farmers' associations, and grassroots citizens' initiatives created energy regions to reclaim ownership of the energy sector. The creation of energy regions was fueled by demands for more social equity and sustainability, which resulted in more regional independency from fossil-fuel imports [73, 82–84]. Yet, local energy initiatives require government incentives or regulations to form, mature, professionalize, and sustain [85]. For example, direct geothermal use regulations are needed for an energy community to develop a geothermal district heat system. This includes government subsidies, like the €2.98 billion German scheme approved in 2022, which helped finance renewable energy and waste-fueled district heating networks [86].

Regional energy governance could be leveraged by many territories worldwide [87]. For example, Baja California, a border state of Mexico, has an electric grid not connected to the national grid and heavily relies on imported fossil fuels. Additionally, the state has abundant underused renewable energy sources such as geothermal, solar, and wind [88]. However, local governments lack the decision-making power or influence to define a regional-focused sustainable energy agenda. This is mainly due to natural resources such as energy and water being inefficiently managed by the national government and a lack of institutions that could readily enable regional governance in the border region [89, 90].

Nonetheless, a regional energy transition governance approach can positively impact environmental and climate co-benefits. A study showed that with a regional energy transition approach, Delhi, India, could reduce its primary energy demand by 40% and energy costs by 25% while reducing GHG emissions [87]. Other regions dependent on fossil fuels may benefit from an energy region approach. For example, regions economically-dependent on fossil-fuel extraction (e.g., coal mining) or carbon-intensive industries (e.g., steel and iron processing and manufacturing). These coal-and-carbon-intensive regions (CCIRs) could form energy regions to formulate transition strategies that address local problems like how to compensate for potential economic and job loss, for example, via the EU territorial just transition plans[13, 55, 91]. Other reasons for regions to adopt a regional transition approach are the benefits of cross-municipal

management. For example, coordinating the development of energy projects that cover more than one municipal jurisdiction (e.g., wind parks and geothermal energy projects) or promoting the sharing of resources between municipalities with different capacities available [92]. Also, countries with extensive territories like Mexico that struggle with the geographical differences in demand, supply, and availability of energy resources might benefit from decentralizing decision-making for the transition (NREL, 2022).

The energy region term has been gaining popularity in Western Europe, with examples in the Netherlands, Germany, and Austria. Energy regions in these countries have not initiated their transition the same way, nor have they pursued the same goals. There seems to be no consensus on what an energy region may entail nor what territories could benefit from it. Yet, policymakers are increasingly interested in applying 'energy region' concepts in the Global North, for example, to govern the low-carbon transition of coal and carbon-intensive regions in Europe [13]. To date, studies on regional energy governance primarily focus on regions within the same country [55, 60, 93, 94] or a few (two or three) similar countries (for example, see 20,21), impeding more general reflections around the energy region as a theoretical concept. Due to the lack of an overview of the variety of energy region concepts, a typology is needed. A typology that classifies the energy region concepts to a) describe their characteristics, b) inform decision-makers of the development of policies unique to the region's potential, and c) help benchmark and compare potential pathways developing across regions.

This study addresses the research gap in identifying energy region concepts applied in different contexts. Based on this research gap, research questions were formulated: i) What types of energy region concepts have been studied? And ii) how have regions transitioned regarding governance arrangements and innovation processes?

A novel systematic literature review of energy region studies through a sustainability transitions and institutional governance lens is conducted to answer the research questions. This conceptual review contributes to sustainability transitions and regional literature with a typology of regional energy transitions, accounting for different contexts in ten countries. The proposed typology distinguishes between a region's governance arrangement (formal/informal institutions) and transition stage [58, 95, 96]. Furthermore, the applied innovation (technological and social) policies of energy regions are discussed with empirical evidence. The typology provides an innovative and illustrative classification of energy regions that practitioners in other regions can use to learn from similar regional contexts.

Section 2.2 provides an overview of the theoretical frameworks used. Section 3 describes the systematic literature review process. Section 2.3 presents the results and introduces five concepts of energy regions. Section 2.5 discusses presents the typology of energy regions, by placing the energy region concepts in a 2D diagram. Contributions, limitations and policy recommendations are outlined in Section 2.5. Finally, Section 2.6 presents the conclusions of this study.

2.2. THEORETICAL FRAMEWORKS TO STUDY ENERGY REGIONS

This section draws from regional sustainability transitions and innovation studies to review theoretical frameworks describing governance arrangements and major innovation processes that drive regional energy transitions.

Regional energy transitions have been studied from the perspective of sociotechnical systems and sustainability transitions [19, 64, 97, 98]. Sociotechnical systems theory departs from complex systems understanding to explain how a technology system changes. It views the energy system as a sociotechnical system composed of the environment, society, technology, and economy. Sustainability transition frameworks help one understand why technological change happens and how economic, political, and societal agents influence it. Systemic change in sociotechnical systems is also called 'transition' because it implies a progressive shift from one regime to another (spread across economic and political structures, norms and values, institutions, and behavioral patterns) that determines the development of (new) technological sectors [97, 99]. Transition Management is a theoretical framework that addresses sociotechnical transition and adopts a governance approach. This framework has been widely used as a reasonably prescriptive approach towards sustainability transition governance that sets sustainable development as a long-term goal [64, 100, 101]. The transition management framework studies energy transitions as a change process of institutions and regime changes in a given subsystem. In this context, the regime pertains to energy systems in regions. It is assumed that regime change will take about 25-30 years [64, 100].

According to sustainability transitions, and more particularly transition management literature, there are four stages of an energy transition [64, 102–105]. The first stage, predevelopment, indicates the continuation of unsustainable-energy-based economies and the introduction of sustainable-energy-based economies [64, 102]. The second stage shows the take-off of sustainable-energy-based economies. The third stage describes the acceleration of sustainable-energy-based economies and the decline of non-sustainable-energy-based economies. The fourth stage covers the stabilization of sustainable-energy-based economies [64, 102].

2.2.1. INNOVATION FRAMEWORKS

Two innovation frameworks, regional innovation systems (RIS) and transformative social innovation (TSI), describe technological and social-driven innovation processes observed in regional energy transitions.

REGIONAL INNOVATION SYSTEMS

The RIS framework is one of the most applied theoretical approaches of the articles surveyed in this research because it describes how a region goes through a process of sociotechnological innovation. Additionally, it considers a region's resources and knowledge to spur innovation in the regional economic sector to become economically competitive [96, 106, 107]. RIS helps to understand how knowledge from various institutes, organizations, and the public influences industrial sectors in an (energy) region [53, 106]. For

example, the Ruhr Area in Germany was the country's major steel and coal producer. Still, the area experienced an industrial decline due to a lack of market competitiveness and declining policy support for the sector. The City of Bottrop decided to decarbonize this region's local energy-building sector. Together with over a hundred firms, the City administration set a 50% CO2 reduction goal in 2020 compared to the 2010 levels [58]. Defining this goal also set in motion a focus on innovation projects to help decarbonize other areas, such as urban planning, housing, and transport (Ibid). The RIS framework highlights the importance of coordinating economic sectors, sometimes referred to as knowledge elites, in driving innovation processes [58, 96]. This framework also considers factors indirectly encouraging regional innovation, such as inter-agent coordination, focusing on trust [108]. Cooke [96] argues that the likelihood of achieving RIS potential is higher when a region has centralized financial autonomy, can influence infrastructure development, has a culture of institutional cooperation (e.g., between the university and industry), supports the labor force, and aims to have inclusive organizations. Regional innovation experts argue that the RIS transformation process has not been thoroughly analyzed, and therefore, the framework has not evolved as a theory [109]. Furthermore, the approach of the RIS framework does not suffice in encompassing the richness and complexity of understanding energy regions, which can have a more bottom-up, informal, and socially-focused governance approach [107].

Transformative Social Innovation

The TSI framework departs from the sustainability transitions and social innovation literature to describe concept(s) and practices around social innovation, which also apply to energy regions. TSI describes a transformative innovation process that alters dominant institutions through social innovation practices [95]. Here, social innovation is understood as changes in social relations, the way society is organized, the way problems are framed or defined, and the knowledge created to contribute to low-carbon energy transitions, ultimately, citizens' empowerment and the wellbeing of communities [95, 110, 111]. Social innovation processes are characterized by having a social mission, the presence of social entrepreneurs, networks, institutions, systems, and cross-sectoral partnerships [111]. Energy systems rely on collective action to achieve a sustainability-related social mission since these societal challenges require a system transformation. An example of collective action is the Berlin-Brandenburg region in Germany, where municipalities successfully reclaimed critical energy infrastructure and formed regional energy utilities while joining the nation-wide energy transition strategy [73]. Collective action behind a social mission has been described as a model for institutional governance change based on the coercion of individuals in large groups like regional stakeholders pursuing a common goal [112]. According to social innovation studies, formal institutions (e.g., regulations and rules) and information and informal institutions are necessary for an energy transition. Informal institutions, often referring to values and norms, can be considered vital pieces to governance, enabling the emergence of new agents leading collective action [111].

2.2.2. GOVERNANCE ARRANGEMENTS FOR REGIONAL ENERGY TRANSITIONS

Energy transitions can be viewed and analyzed from a governance perspective. Governance comprises decision-makers (e.g., social networks, government, and formal or informal organizations) who can rule through laws, norms, power, or language [113]. Governance is carried out by a formal government and is seen as an arrangement conceived and agreed upon by multiple decision-makers active at various administrative levels [61, 114]. According to evolutionary governance theory, governance arrangements also found in regional energy transitions, can be distinguished in terms of centralization and formalization [19, 115]. Governing the energy transition can be done in different ways, either via centralized or decentralized decision-making or a combination. However, any extreme may adversely affect society's sustainable development, for example, when decision-making is centralized by elites (i.e., monocentric governance) or when decisions are made individually without considering society's needs at large [115]. A mode of governance stressing the existence of multiple centers of decision-making is polycentric governance, which can consist of multi-level governance (between local, regional, national, and international levels), collaborative governance, network governance, including public and private sector actors, and citizen participation [19, 116]. For example, the Netherlands' thirty energy regions (RES) are considered polycentric because of their decentralized decision-making centers. These centers include multiple municipalities, which, together with other decentralized government organizations (e.g., the provincial government and water boards), are involved in the structuring and formulation of regional strategies (RES) [19, 55, 117].

Moreover, the RES approach is ultimately aligned with the national Climate Agreement (i.e., energy transition agenda), following a lengthy negotiation process between central government, decentral governments, and other societal actors [19]. Another interesting aspect is whether formal or informal institutions or incumbent or emerging agents constitute governance arrangements. Formal institutions are associated with written rules, laws, policies, and plans, whereas informal institutions pertain to social values, norms, and cultural guidelines [118]. Informal and formal institutions co-evolve and influence each other and regional energy transition processes (ibid).

2.2.3. APPLYING ENERGY REGION CONCEPTS IN DIFFERENT CONTEXTS

Different concepts of energy regions have proven helpful for sub-national territories seeking low-carbon pathways, as showcased with the Dutch energy regions [19, 55]. More generally, it is crucial to understand how to govern energy regions directly or indirectly dependent on fossil fuels. For example, CCIRs in Europe find it particularly challenging to adopt strategies that comply with EU climate change goals toward decarbonization [119]. If only strict top-down national energy transition approaches are followed, CCIRs risk facing social energy injustices such as economic loss, loss of jobs, and population shrinkage if they do not consider necessary regional contextual conditions [120]. Additionally, strong ties between the fossil fuel industry and people's livelihoods and identities are common challenges for low-carbon transitions in CCIRs.

These strong ties permeate the culture and impact readiness for sectoral transitions differently than in non-fossil-fuel-dependent regions [121]. For example, the Ruhr region reinvented its regional identity from a traditional coal and steel region to a postindustrial energy region [121]. Similar challenges are found in carbon-intensive regions, where the industrial sector's energy consumption heavily relies on fossil fuels [13]. Carbon-intensive sectors such as steel and cement production may negatively or positively influence people's livelihoods in certain regions because of employment, economic influx, health, or environmental impact. For these reasons, gaining a further understanding of regional governance arrangements for the energy transition, as a pillar of a multi-level governance approach, might be helpful for sub-national territories that struggle to meet Climate goals.

Differences between regions make it infeasible to have one single governance approach to bring transformative change to energy sectors. There is no one-fits-all blueprint of regional energy governance that decision-makers and planners could readily apply. Regions generally differ regarding geographical characteristics, the socio-economic and political setting, and development agendas. These contextual differences may determine the type of governance arrangement required for their transition. Therefore, there is a critical knowledge gap in understanding energy regions' concepts, practices, and examples and their adopted innovations, governance arrangements, and transition processes. A systematic literature review is conducted to address this gap. This review allows for further understanding, conceptualizing, and classifying energy region types regarding governance arrangement(s) and the transition processes they undergo.

2.3. SYSTEMATIC LITERATURE REVIEW

A systematic literature review was conducted to identify concepts of the energy region of fifty crucial studies from ten countries over the last two decades. The studies were analyzed to answer the research questions on identifying the energy region concepts and understanding their governance arrangements, adopted innovation, and transition process. The systematic literature study approach by Van Wee and Banister was adopted because it provides an overview of the literature and adds value by analyzing and categorizing the studies reviewed. [122]. In this study, the added value lies in formulating a typology of energy regions and their evolution along the energy transition stages. Also, the regions' governance arrangements and innovations that helped drive energy transitions are discussed.

2.3.1. DATA COLLECTION

The keywords and their combinations (see Table 2.1) provide evidence of how studies on energy transitions apply the regional governance concept and come from three research fields: i.e. regional energy studies, sustainability transitions, and innovation studies. The keywords in Table 1 were chosen because they cover energy regions in these research fields. Emphasis was given to CCIRs for their potential to be studied from an energy region perspective.

The first two combinations of keywords from regional energy studies covered 1) "regional energy governance" and 2) "regional energy transition" since they represent the main topic of the study's literature review—the third combination, 3) "regional energy industry", covered papers on different industrial sectors. The second set of keywords reveals how regional governance is applied in low-carbon and coal-and-carbon-intensive territories that aim to achieve sustainability transition goals. The keywords covered regions seeking: 1) "low-carbon pathways" in general, or territories in 2) "coal-intensive regions", or 3) "carbon-intensive regions". The keyword "low-carbon pathways" refers mainly to territories with renewable energy source availability. The third set of literature explored regional energy governance in the policy innovation process, either as a technological innovation process with 1) regional innovation system studies or as a 2) social innovation process. The keyword 3) "regional innovation" was included to look for other frameworks describing the innovation process in regional energy governance.

Table 2.1: List of keywords used and their relation to three disciplinary research domains

Number	Regional energy studies	Sustainability transitions	Innovation studies
1	"Regional energy governance"	"Low-carbon pathways"	"Regional innovation systems"
2	"Regional energy transition"	"Coal-intensive region"	"Social innovation"
3	"Regional energy industry"	"Carbon-intensive region"	"Regional innovation"

The Scopus database was used instead of the Web of Science because Scopus contained more English-written peer-reviewed articles from the social sciences than the Web of Science, which has more articles from the natural sciences. The review covered articles on energy regions published in the last sixteen years, from 2007 to 2023, although the search started in 2000 (available time range on Scopus). There were two peaks of six publications in 2015 and 2022, as shown in Figure 2.3. This histogram shows regional energy governance articles published in peer-reviewed journals and three reports. However, Germany started experimenting with learning region policies in the 1980s to reflect on the social innovation dynamics for spatial planning in regions in North Rhine-Westphalia and Saxony [56]. The German learning region policies, feed-in tariffs for renewable energy generation, and the EU power market liberalization influenced initiatives toward regional energy transition governance in Germany and other European countries. This was because these changes allowed local stakeholders such as farmers, municipalities, financial institutes, and regional governments to participate as energy generators or investors [81–83]. This indicates the socio-political relevance of the regional energy governance concepts and their mainstreaming [82, 123]. These articles cover mainly energy regions in the European continent, as presented in Table 2.2.

The first survey included all keyword combinations and the Boolean operator OR (see the Identification step in Figure 2.2), producing over one million papers. Papers were screened by selecting those mentioning "region" AND "energy transition" because many papers did not emphasize nor address regional energy transition. This screening

Table 2.2: List of countries where energy regions have been studied

Country	Regional energy studiesReference
Germany	[56, 81–84, 124, 125]
Austria	[53, 60, 81, 82, 124, 126, 127]
Netherlands	[19, 55, 79, 80, 93, 94, 128]
United Kingdom	[129, 130]
Italy	[124]
Switzerland	[81]
Denmark	[82]
Sweden	[131]
United States	[132]
Indonesia	[77]

process narrowed the list own to four hundred and forty-five articles. Then, the ten to twenty most cited papers for each keyword were selected. This step narrowed the pool to one hundred and twenty-six articles.

In the classification step, these papers were skimmed from the title to conclusions and categorized into seminal (n = 19), relevant (n = 41), and non-relevant (n = 66) papers. The seminal papers directly discussed the concept of energy regions and described the characteristics of energy regions. After adding the relevant and non-relevant papers and eliminating repeated papers, the selected list of publications added up to fifty-three papers. After a review of the references for the selected fifty-three papers, it was noticed that the keyword search or screening steps did not capture some relevant energy region papers. This was because these papers were only published recently. Therefore, a snowball approach was performed by looking at the references of the seminal papers that mentioned "energy region" or "regional energy governance." This snowballing step added twenty-seven papers to the final list, with eighty-two peer-reviewed articles in English and three reports in German and Dutch (some of these papers were not part of the Scopus database). In the second screening (see Figure 2.2), these eighty-five articles were coded with a qualitative thematic analysis. With this analysis, the articles were selected based on their proximity to the regional energy governance topic; specifically, they discussed energy region types and their governance approach according to the research questions. After this first coding, thirty-five papers were excluded from the review because they lacked relevance to our research questions. Five additional publications were added during the manuscript revision process. This selection resulted in forty-seven academic publications and three grey literature reports. The list of the analyzed publications can be found in the Zenodo database [133].

2.3.2. Data analysis

A qualitative thematic analysis was conducted using the database of 50 articles and reports and the NVivo 12 Plus software, which is suitable for categorizing and analyzing text from multiple sources [135]. To build a typology of energy regions, the insights

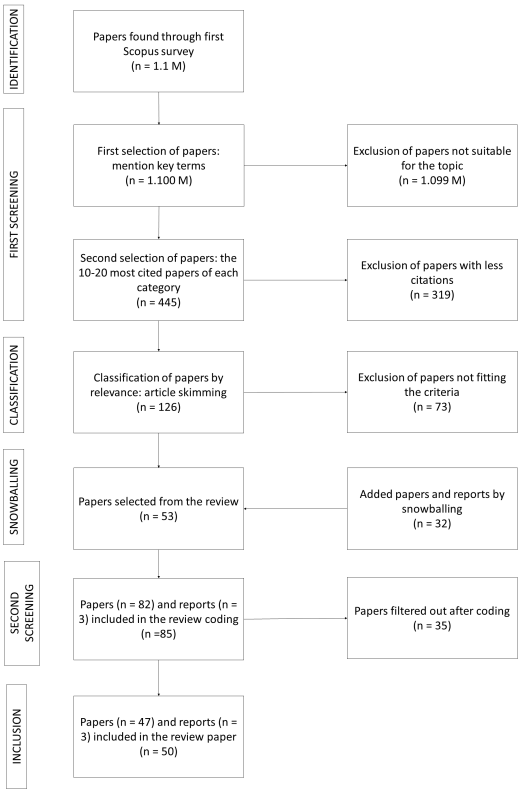


Figure 2.2: Flow chart diagram showing how publications were selected. Adapted from [134]

from these papers were categorized in a thematic analysis using five frameworks: RIS [109], the polycentric regions framework [19] as a framework rooted in RIS and STS [103], evolutionary governance theory [115], and TSI [95]. These frameworks were selected because they helped describe different cases of regional energy governance in terms of their transition agendas, governance arrangements, and transition processes.

The analysis began with defined themes highlighted by the polycentric regions framework because it was the most recent (2020) and comprehensive framework that described energy regions with various concepts from previous studies [19]. These initial themes covered 1) energy region definitions and characteristics such as 2) geography, 3) stakeholders, 4) industrial sectors, 5) energy technology, and 6) governance arrangements. After considering the governance and innovation frameworks, the final five themes were selected: 1) energy region types, 2) governance agenda, 3) governance arrangement, 4) region scope, and 5) transition process. The final fifty articles were coded

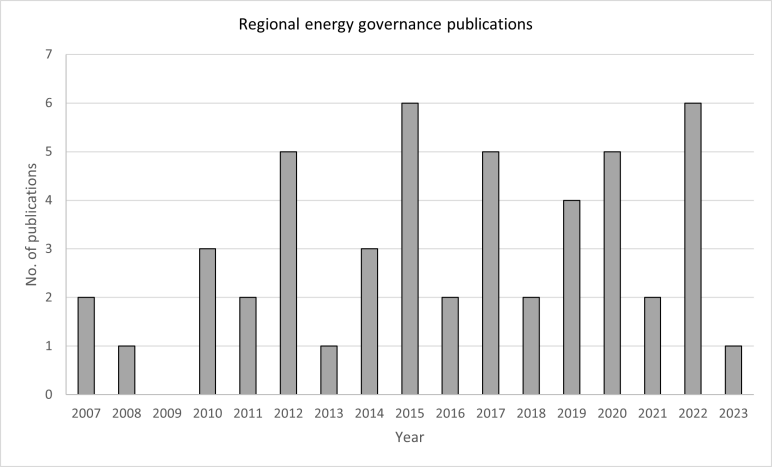


Figure 2.3: Histogram of publications on regional energy governance from 2007 through 2023.

with these themes three times, allowing the creation of new sub-codes under each of the five themes. The coding process for qualitative thematic analysis covered a selective coding step with predefined themes drawn from relevant frameworks, followed by the creation of new sub-codes [136].

2.4. INTRODUCING THE ENERGY REGION CONCEPTS

Five energy region concepts were identified with the thematic analysis: Three geographical concepts and two transitioning concepts. The geographical concepts are city-regions, peripheralized regions, and CCIRs. City-regions and some CCIRs can be rich in economic resources, strong in formal institutions, and dependent on fossil-fuels. Peripheralized regions, including CCIRS and rural regions, are energy regions with limited financial resources, fossil-fuel dependency, and whose formal institutions cannot support an energy transition. These three geographical concepts are referred to as learning or renewable energy regions when transitioning. The articles corresponding to each energy region type are enlisted in Table 2.3 and described in Sections 4.1-4.5.

The five energy region concepts differ in their definition of governance arrangements and innovation processes. In terms of the governance arrangements, the energy regions' centralization and formalization levels were analyzed through the theoretical lenses of evolutionary governance theory, RIS, and TSI frameworks [19, 96, 111, 118]. The centralization level goes from monocentric (centralized) to highly polycentric (decentralized) [19, 137]. The formalization level refers to whether a governance arrangement is constituted by formal or informal institutions [115].

2.4.1. CITY ENERGY REGIONS

City-regionalization is a phenomenon that is commonly found, among others, in European countries and the United States. The city-region concept has been widely employed in regional studies since the 1980s, mainly in the Global North and megacities [87, 142], with recent attention in the Global South [77]. Rodríguez-Pose has defined city-regions (2008) as a city hub connected with 'spokes' (i.e., smaller populated areas) connected with functions and multiple 'hubs and spokes' with [**bidirectional??**] interdependencies in the economy, environment, and society [67]. These regions host network configurations within or across states (e.g., the Øresund region across the Swedish-Danish border) and are driven by regional identity, policies, and macroeconomic dynamics such as globalization [67, 68, 132, 142]. In sustainability transitions, city-regions represent energy-intensive urban and industrial areas (e.g., city districts, industrial parks) that seek to transition into fossil-free energy systems [159]. Some examples of transitioning city-regions are Rotterdam-Den Haag and Drechtsteden (Netherlands), Dublin (UK), Göteborg (Sweden), Catalonia (Spain), and Denver (US) [55, 131, 132, 141, 160, 161].

Economically driven city regions can experience rapid urbanization, thus forming a 'metropolis' [68, 132, 142]. A major critique of city-regions' rapid urbanization is their limited capacity to meet their citizens' essential needs, such as water and food [68]. Only a few cases of economically-driven city-regions (e.g., Mexico City, Cairo, and Jakarta) have been reported as meeting the conditions for continuous development, that is, being able to compete in the global market while benefiting from trade [67]. Without these conditions and targeted policies that ensure regional empowerment, city-regions may risk greater inequality and stronger top-down influence [67].

The governance arrangements leading the energy transition in city-regions can be either monocentric or have some degree of polycentrism (e.g., hubs and spokes). However, urban cores are typically favored economically over rural areas. In city regions, decision-makers typically see rural areas as resource suppliers for urban institutions. The governance structure of city-regions is both horizontal (i.e., coordination between the civil society, public, and private sector actors within a region) and vertical (i.e., coordination between multiple –levels of government) [67, 142]. The horizontal dimension is reflected in the partnership networks or actor constellations that form city-regions [83, 142]. Regarding its institutions, city regions often have public, local, and formal institutions (e.g., regulatory and legal frameworks and rules) and strategies implemented by local government in collaboration with private sector actors and voluntary organizations [67]. Although sometimes unrecognized, grassroots initiatives can have an essential role in the transition vision framing of urban energy systems, also referred to as decentralized local governance, such as in Berlin (discussed in section 2.1.2)[162].

Depending on the city-region's energy transition agenda, the innovation process may follow a techno-economic or social innovation process [132]. City-regions following social innovation dynamics can benefit from the devolution process, returning decision-making power from the nation to city-regions [132]. This potential benefit may occur

because when city-regions, their local organizations, and society are empowered with knowledge, skills, and opportunities, they can better navigate the competitive globalized economy [67]. However, with a pure techno-economic innovation process, city-regions may not achieve sustainable development goals [67]. For example, in the Amazonas state in Brazil, city-region initiatives have been rooted in the unsustainable extraction, exploitation, and manufacturing of natural resources, creating socio-economic inequalities [68]. Most available city-region examples tend to have poor sustainable conditions (e.g., Mexico City and Jakarta) [132], although some have sustainable development plans (e.g., Drechtsteden, Jakarta, and Montreal) [68, 163].

2.4.2. Peripheralized and fossil-fuel-dependent energy regions

The third energy region concept is referred to as a peripheralized, marginalized, or locked-in region due to having limited endogenous resources to pursue energy transitions [56, 143]. These regions face lock-ins, which can be understood as a combination of social, economic, cultural, and political structures that block regional development and hinder sustainable transitions [56]. Some transition agendas in peripheralized regions focus on pursuing energy autarky [81, 156]. In terms of governance arrangements, peripheralized regions tend to rely on informal institutions and informal actor networks because of issues with formal institutions. For example, a lack of trust between regional agents was present at the beginning of the Ruhr region's transition due to the contested discussion around coal mining and climate change [164]. Some Innovation Studies scholars hold that when formal institutions and actor networks fail to lead, new agents have to participate and co-create knowledge under existing (informal) institutions and later establish new "rules of the game", or new formal institutions [164, 165]. Therefore, a peripheralized energy region may not be supported or led by formal institutions and incumbent actors at the start of the transition.

2.4.3. Coal-and-carbon-intensive regions (CCIRs)

CCIRs (introduced in Section 2.3) are a sub-group of peripheralized regions with carbon lock-ins and locked or limited formal institutions supporting the energy transition. CCIRs depend on fossil-fuel extraction industries such as coal, oil, and gas, as is witnessed in some regions of the United States, Slovakia, Australia, and other countries across the world [75, 145, 146]. CCIRs may depend on carbon-intensive industries such as steel or cement production [166]. The European Commission has identified CCIRs in twelve EU countries, such as Germany, Poland, the Czech Republic, and Greece [13]. CCIRs typically face particular challenges, such as a shared cultural identity permeated by the CCI industries, carbon-locked formal institutions that do not promote sectoral transitions, path dependency on the fossil-fuel infrastructure networks, and a working force only specialized in the fossil-fuel industry, among others [58, 121, 140]. Because of these challenges, CCIRs are sometimes called locked-in or peripheral regions. One of the first studies on locked-in regions was in the Ruhr area in Germany, whose industrial development was in a structural crisis [56]. Coenen, Campbell, and Wiseman [164] explain that a major barrier in coal regions to sustainable energy transition in the Ruhr region was the coal-regime dependency [164]. This dependency permeated social struc-

tures, institutions, and politics, as often occurs in industrial fossil-fuel regimes. Other barriers include limited infrastructure and institutions to move away from coal-industry dependency [121, 164]. Although many CCIRs are referred to as peripheralized regions, there are also CCIRs with available financial resources but locked or insufficient formal institutions to carry out the transition, such as the iron and steel sector's transition in Upper Austria [166].

According to RIS studies, locked-in coal regions reflect a limited innovation capability in the industry's value chain, the enterprise's development of new ideas, and the public-private sector relationship [164]. This framework suggests that policy support for technological innovation is needed for coal regions to resolve their locked-in situation [164]. In the Ruhr region's low-carbon transition, the state government, coordinating with municipalities, universities, and the private sector, took on a leadership role in reshaping the regional development strategy. However, the energy transition process developed slowly because the region's system was not based on a skilled labor force, lacked a fair degree of knowledge exchange between regional agents, and did not sufficiently support local entrepreneurship [164].

2.4.4. TRANSITIONING LEARNING ENERGY REGIONS

Learning regions pertain to regions adopting innovations that enable learning in regional governance systems that support the creation of alternative development pathways [57]. Alternative pathways - such as pursuing a knowledge-based economy - result from the abilities of regional agents and developing learning policy programs [56, 57]. A comprehensive overview of this concept beyond the sustainability transitions field is presented by Hassink (2005), who describes that most lock-ins are framed as political structures that keep old industries and hinder endogenous innovation [57]. In terms of the transition progress, learning regions represent the evolution from the first transition stage (predevelopment) to the third stage (acceleration) through the second stage (take-off).

Particularly, learning regions are presented in selected studies as a development pathway alternative to regions having limited resources and institutions (i.e., for peripheralized regions) [143]. However, city-regions can also become learning regions once they start adopting innovations. Learning regions represent a subsequent energy region type where the governance arrangement changes despite the geographical unit remaining the same. The essential difference is that when a city-region or peripheralized region becomes a learning region, its governance structure can be transformed into a more polycentric structure, like with the formation of RES in the Netherlands [19], or rely more on informal institutions and actor networks and later reach formalization like the Ruhr region [164].

Several governance mechanisms have been reported to enable deconstructing lock-ins or path dependencies in regions. A commonly reported mechanism is shifting from a government to a governance approach. This shift suggests distributing the central government's power and responsibilities among the public and private sectors.

Governments can promote such power decentralization by initiating cooperation and knowledge exchange between the public and private sectors and between individuals and organizations, for example, by pursuing cooperation between municipalities [56, 57]. In some cases, learning regions are enabled by creating a new governance level that merges several administrative boundaries, such as municipalities, and by creating intermediaries that coordinate the work between public organizations, private enterprises, and civil society [56]. Mechanisms that can trigger the development of learning regions are innovation-oriented policies that create long-term visions, integrate sectors and disciplines, and open funding calls that incentivize sustainable projects [56].

The Austrian regions of Güssing, Hermagor, and Murau are examples where agents could find synergies to shape a regional transition despite limited resources and a lack of formal institutions supporting a transition [143]. In 1990, the municipality of Güssing saw the opportunity to address economic and population decline by shaping a new development pathway based on a regional low-carbon energy strategy. Municipality representatives formed a coalition of citizens and investors to reduce energy costs by promoting energy self-sufficiency. Regional agents created synergies by sharing local knowledge and financial and technological resources. After piloting energy-efficient housing, the municipal leaders gained regional support and launched a district heating system and a biomass power plant. The success of this project eventually led to a regional-scale energy transition in 2005. The key to this bottom-up success was the presence of a social network and trust between municipal leaders, which helped reach and convince citizens, organizations, and regional decision-makers [143]. This example highlights the importance of informal institutions and social innovation practices that trigger collective action because they are essential to the first steps in the transition stages of locked-in and peripheral regions [56, 111]. However, one should notice that Güssing's regional energy transition in 2010 was also made possible by securing federal funding.

Other examples of policy promoting regional competition and eventual formalization, hence institutionalizing regional development strategies, are found in Germany. They are concerned with the 'Competition Impulse Regions program' in the 1990s and the 2016 'Regionale program' in 2016 [56]. These exemplary cases in Germany and Austria show that a social network can develop social innovation through exchanging knowledge, civil society mobilization, and cooperation between sectors. These regions could temporally substitute lacking institutions and resources with informal institutions and social innovation practices to open development pathways away from locked-in industrial structures and practices.

However, the learning region concept should be applied with care due to its ambiguous definition of breaking path dependencies with agents' abilities, which is present in different types of energy regions [57]. Therefore, this study distinguishes between learning regions that were peripheralized or city regions before adopting innovation policies. The first type of learning region is those that struggle due to a lack of resources or formal institutions to support energy transition. This definition is covered by the bricolage concept developed in Austrian energy regions, which refers to "an actor's behavior of problem-solving with available resources instead of acquiring specific resources for a certain problem". Some examples of these learning regions are mentioned above

(e.g., Güssing, Hermagor, and Murau) [143]. The second type of learning region has a city-region structure. Drechtsteden, covering the southern path of the mega city-region Randstad in The Netherlands, is an example of a learning region with a city-region structure. This Dutch region participated in the RES pilots program, which guided seven pilot regions to formulate a transition strategy by 2016-2017 [167]. This RES pilot program promoted cooperation and cross-learning between public, private, and civil organizations, in seven pilot regions, later expanded to 30 regions, to formulate a short and long-terms strategy to become carbon neutral by 2050 [55, 80]. Drechtsteden's RES seeks to reduce 20% of energy consumption in buildings and achieve 0.60 TWh of local clean energy generation by 2030 [161, 168]. Another general critique lies in the normative nature of the learning region concept because no ideal principles can always underlie learning-based economies [57]. In this study, normative principles like just transitions, energy democracy, and equity are implied that underpin the direction of energy transitions [15, 20, 43].

2.4.5. TRANSITIONING TO RENEWABLE ENERGY REGIONS

Renewable energy regions were the largest energy region type identified in the systematic literature review. This type can be defined as regions with plans to develop renewable energy technologies at the regional level. Renewable energy regions usually have polycentric governance structures. They can have multiple levels of governance (e.g., local, provincial, and national) and are formed by a network of experts and stakeholders [55, 137]. Cases of renewable energy regions are found in the Alpine regions in Austria [53, 81, 82, 124, 126, 169] and Switzerland [81], Denmark, Italy [82], the Netherlands [19, 55, 79, 80], and Germany [56, 81–84, 124, 125]. We further distinguished two renewable energy subgroups: The ones that originated in the Netherlands, 'Regionale Energiestrategieën' (RES; renewable energy strategies in English; translation by the authors) driven by a combined top-down and bottom-up approach, and the renewable energy regions in Germany-Austria 'Erneuerbare-Energie-Regionen' (renewable energy regions in English; translation by the authors), with a distinctive bottom-up approach.

Since 2018, thirty renewable energy regions have defined the Dutch regions' energy transition strategies and implementation plans (RES). RES are conceived as either clusters of neighboring municipalities or, in some cases, entire provinces, among which the national funding for energy transitions is distributed [19, 55]. Renewable energy regions in the Netherlands aim to contribute to the national climate agenda, which aims for a 50% CO2 emission reduction by 2030 through renewable-energy-based electricity and heating generation [55, 78]. This top-down approach to agenda-setting may cause difficulties in the engagement of regional agents because they might not be familiar with the reasoning behind the agenda [79]. Hoppe [55] explains that the country has inter-municipal regional governance bodies that manage environmental and mobility issues that require coordination between the municipalities but also concerning other levels of government like provinces, national, and supranational government. Since RESs are not considered a formal governance arrangement, they lack decision-making authority, making them vulnerable because regional transition strategies are not binding. A RES depends on decision-making and approval by formal decentralized government bodies

(i.e., municipalities, provinces, and water boards) with the authority to decide. Also, the governance of RES is highly dependent on social and economic networks in the regions [79]. However, it is not only public bodies that participate in RESs. There is also the participation of citizens, NGOs, and renewable energy communities who contribute to formulating regional visions and the planning of RESs [55]. Since the RESs focus on networks of organizations developing clean energy technology, their innovation process can be studied from a RIS and STS perspective [19, 58].

In Austria, renewable energy regions ('Energieregionen') have been studied and developed since the 1990s, and later in Germany, Switzerland, and other EU countries [53, 126, 127, 144]. In Germany, the renewable energy region concept ("100% Erneuerbare-Energie-Regionen"', 100% renewable energy regions, translation by the authors) refers to the governance of inter-municipal or inter-communal energy transitions to define energy regional visions and strategies and implement them [144]. In Austria, energy regions have been framed as agent networks and regional initiatives supporting regional development using renewable energy [53]. The visions of these renewable energy regions focus on achieving 100% supply from regional renewable energy, energy self-sufficiency, or becoming independent from fossil-fuel imports while pushing a regional economic development agenda [53, 82, 126, 144]. These regional visions began as initiatives, as seen in Güssing, Austria, where the local government phased out fossil-fuel imports and developed a biomass-based district heating with EU funding [126]. This initiative has supported the energy sector's decarbonization plans (ibid). Another example is the Murau region in Austria, which defined energy autarky or energy self-sufficiency as its goal for the region's development pathway [127].

From 1983 until 2014, at least one hundred and forty energy regions were formed across Germany by adopting bottom-up approaches. These regional initiatives could receive funding from the local or national government [144]. The governance of these energy regions functioned as a bridge between the niche (i.e., initially informal and grassroots innovations) and regime levels (i.e., well-established, incumbent, and institutionalized technological sectors) [53, 97]. Although these regions have been referred to as exemplary because of their quick response to global trends [162], the availability of renewable energy sources and access to competitive technologies have been insufficient to formalize energy region visions for a regime shift [53]. Studies of German and Austrian energy regions have used theoretical frameworks like multi-level governance, transition management, and institutional governance, which have revealed several important drivers. Necessary factors for regional energy transitions cover macro socio-political pressure for decarbonization, a cooperative regional social network, and having the ability to act as a constant learning region (i.e., social innovation factors) [53, 83, 124].

Regarding governance arrangements, strategies were created by formal (national) institutions, although they lacked formality in their regional organization. In the Netherlands, the six pilot RES followed a top-down and bottom-up governance approach, while the other twenty-four regions started with a top-down approach. In RESs, formal agent networks like incumbent stakeholders (system operators, municipalities,

and the Ministry of Economic Affairs), although with limited autonomy and authority, have been designing transition strategies [19]. In contrast, 'Energieregionen' in Austria and Germany began as bottom-up initiatives where informal agent networks were vital for their emergence and formalization [53, 58, 144].

2.5. Discussion: Towards a typology of energy regions

A typology of energy regions was developed to visualize the meaning of each energy region concept from a sustainability transition perspective. This typology answers the research question ii by describing the relationship between governance arrangements and innovation processes of energy transitions.

The diagram in Figure 3 shows the energy region concepts according to their transition stages and whether the region's transition relies mainly on informal or formal institutions. The city-region concept describes highly urbanized territories driven by (non-sustainable) economic growth; thus, they were located at transition stage I (predevelopment). These city-regions are typically governed by formal institutions that seek development significantly based on economic growth. The next concept, the peripheralized region, is generally well governed by formal institutions that reinforce lock-in development pathways and may hinder regional energy transition processes. Peripheralized regions begin destabilizing current regimes by cooperating to work towards a social mission or sociotechnical vision, such as reinventing development pathways. When destabilization occurs, regions deviate from carbon lock-ins and become learning regions (stage ii. take-off). Learning regions can further transition to stage iii. (acceleration) through institutionalization or (inter)national support. Social innovation practices inside learning regions are enabled by informal institutions such as collaborative values and habits that can empower regions. The last concept is the transitioning renewable energy region, which either informal or formal institutions can govern, and it generally relates to the transition from stage ii (take-off) to stage iii (acceleration). At stage iv (stabilization), the region is considered fully transitioned and supported by formal institutions. Empirically, it has not been demonstrated that a region can be fully transitioned without the support of formal institutions.

An interesting finding is the role of informal institutions and social innovation practices in transforming peripheralized or locked-in regions into learning regions [56]. Studies show that regions worldwide may have lock-ins due to the region's fossil-fuel-dependent history [57]. These locked-in or peripheralized regions face considerable challenges to transition. Yet, the bricolage concept developed in Austria showed how peripheralized regions could overcome their limited availability of resources to achieve a low-carbon regional transition [143]. This empirical-based framework shows that the transition from stage I (predevelopment) to II (take-off) is possible when social networks and leaders support a transition, and there is a shared collective mission (ibid). For instance, social innovation practices and informal institutions enabled collective action

and transformed the Austrian locked-in regions into learning regions [56]. Additionally, the Güssing region formed low-carbon pathways and a new regional innovation identity that changed the region's self-perception to become green energy pioneers [143].

For peripheralized regions to achieve acceleration (stage III) and for renewable energy regions to reach stabilization (stage IV), political support from formal institutions and actors networks is needed [56, 143]. On the contrary, without informal institutions, there is a higher threshold for breaking path dependencies. Some city regions reported limited informal institutions, such as values and habits, and social innovation practices, such as a social mission, learning, and cooperation. These regions faced risks such as reduced agency and increased dependency on international market trades that did not improve the regional economy [67]. Curve A describes a region with support from formal institutions to initiate an energy transition, with a top-down transition strategy, and without a learning phase. Examples of this transition pathway are city regions like the Rotterdam-The Hague RES in the Netherlands, where policymakers designed a regional transition strategy without promoting learning dynamics in the region nor learning from existing practices elsewhere [170]. Although no clear example was identified, regional studies state that when peripheralized or transitioning renewable energy regions do not get support from formal institutions or do not find a feasible transition strategy, their transition does not move forward [127, 143], which is represented by curve D. Other possible pathways are not shown in the diagram. For example, CCIRs whose transition ends at earlier stages or does not start a transition at all, such as Jiu Valley, Romania, after the closure of coal mines in the 1990s [171].

Peripheralized and city regions may become learning regions through innovation policy programs. Two transition pathways are shown for city regions (curves A and B) and peripheralized regions (curves C and D) in Figure 3. When innovation policy programs are combined with social innovation practices and informal institutions, they may trigger learning and experimentation practices [100]. This combination may ultimately enable renewable energy regions with more formalized institutions that bring them stability. The Drechtsteden region and the Ruhr area are examples of a city region and a CCIR, respectively, that were transformed into learning regions by innovation policy programs (curve B) [140, 164, 167, 168]. Regional stakeholders established the transition strategy of Drechtsteden as a result of the RES pilot program that promoted cooperation and cross-learning. Similarly, the Güssing region exemplifies a peripheralized region that became learning region through innovation (curve C) [143]. In comparison, the innovative coalition of citizens and investors enabled the beginning of Güssing's energy transition to promote energy self-sufficiency. Although these regions have not yet completed their transition, they seem to follow the described transition pathways [143, 168]. Other transition pathways for different regional contexts may not require informal institutions or learning policies. However, more studies are needed to define the region-type boundaries and their transition pathways clearly.

Concepts from evolutionary governance theory were applied to understand governance arrangements for energy regions, such as the level of governance centralization

and institutional formality [115]. This theory suggests that the type of governance arrangement of the energy region changes along the innovation transition curve across four stages [64, 102]. Results show that in stage I (predevelopment), energy regions are described as monocentric and formal due to the dominance of well-established institutions and incumbent stakeholders, such as city regions and CCIRs [56]. From stage I to stage II, the governance arrangement can become less formal and centralized with the emergence of new players, such as renewable energy cooperatives. Some examples are the peripheralized regions and the energy autarky regions in Germany and Austria, which were initiated mainly by informal institutions that enabled cooperation and collective action [73, 81, 156]. Contrary to what RIS argues, an informal and polycentric regional governance arrangement can lead to innovation in regional energy transitions like in the 'Energieregionen' and RESs [96].

The RIS framework could describe market competition and technological-innovation-driven regions, while the TIS framework could describe regional-empowerment-driven regions. A prosperous region (e.g., Silicon Valley in the United States), according to RIS, is formed when the private sector has an active role in technological innovation, ultimately leading the region to rapid economic growth [96, 108]. If such development pathways do not enable the entrance of emergent agents, then the benefits of innovation will remain with incumbent stakeholders. In that sense, energy regions can experience regional technological innovation while not improving the distribution of benefits or justice beyond the incumbent stakeholders [33]. For this reason, the RIS framework must be complemented with social innovation that describes different power dynamics between emergent agents and incumbent stakeholders when studying just transitions.

2.5.1. Contribution to sustainability transitions research

This study makes three contributions to the field of sustainability transitions, in particular to the understanding of regional energy transitions. The first contribution is the identification of five concepts of energy regions, three geographical and two transitioning concepts. These concepts were identified following a systematic literature review of peer-reviewed academic publications, as well as gray literature publications. The geographical concepts cover 1) city regions as highly urbanized places, 2) peripheralized regions as territories with limited resources or carbon lock-ins that limit their transition, and 3) CCIRs with fossil-fuel sector dependency and locked or limited support from formal institutions to transition. The transitioning concepts are 4) learning regions, which can be regions 1, 2, or 3 that have implemented learning policies or innovation, and 5) transitioning renewable energy regions, as regions 1, 2, 3, or 4 that have an advanced renewable energy development.

The second contribution is the formation of a typology of energy regions, shown in Figure 3. The five energy region concepts were distinguished by three aspects: Governance arrangement, innovations they pursue, and stage of the transition. In terms of governance, regional governance can create and pursue energy transition strategies with different degrees of institutionalization. This is relevant for peripheralized

regions where informal institutions are crucial to initiating an energy transition. In contrast, formal institutions have been leading in city regions since the beginning of the transition. Another finding is that different types of innovation (e.g., social and technological) can help initiate low-carbon transitions in different energy regions. In the case of city-regions, technological and policy innovations are essential to advance low-carbon transitions. Whereas in peripheralized regions, social innovation is of even greater importance.

The third research contribution is a further understanding of transition pathways in energy regions, particularly those starting in city regions and peripheralized regions. Section 4.4 presented examples of city regions and peripheralized regions becoming learning regions, which assisted the transition into renewable energy regions. Yet, the learning region phase has been bypassed in some cases, indicating a different transition pathway (see curve A in Figure **??**). For example, twenty-four Dutch energy regions (some peripheralized and others city-regions) did not undergo an experimentation phase [167]. Instead, the central government applied the lessons learned from six regional pilots to serve as teaching examples to develop a regional energy transition program, which was then top-down implemented in the other energy regions, thus skipping the learning phase for these twenty-four regions.

2.5.2. POLICY IMPLICATIONS

Additionally, this study formulates policy implications for stakeholders in regions that can be identified as city-regions or peripheralized regions. Policymakers may refer to the examples described in regional energy transitions in similar contexts and learn from the innovations in the interactions between organizations, the particular governance arrangements, and policy mixes that can advance the transition. The typology can be illustrative for practitioners as a means to reflect on the followed or preferred transition pathways as well as to formulate more contextual and transition stage detailed policy advice. Yet, regional innovation platforms to share learnings, opportunities, and resources are needed to promote cross-regional learning [172, 173]. Policy makers in CCIRs are recommended to learn from other peripheralized regions with carbon lock-ins that have become learning regions, like in Germany and Austria, by leveraging available informal institutions and social innovation practices [56, 143]. Even when informal institutions and emerging agents are key for the energy transition, political support from formal and overarching institutions (e.g., national government) is eventually needed. Policy makers in city-regions like metropoles or highly-urbanized regions can rely on formal institutions to initiate a transition strategy because they tend to have more capacity and more specialists while having more protocols in place to implement policies, which allows them to tackle the different areas of an energy transition (electricity, transport, water). Yet, city-regions face challenges when implementing policies and reaching goals, given the complexity of the socioeconomic system in big cities. A potential limitation of this type of energy region is that they resist introducing new agents because they are highly regulated. Policy and decision-makers should be aware that multiple transition agendas (e.g., from the national government and local communities) are usually present in a region. Since such agendas can sometimes be conflicting, an early interaction be-

tween different governance levels is needed to address various goals while meeting wider climate change objectives. The developed policy mixes should consider the distinctive characteristics of city-regions and peripheralized regions. For example, the presence of energy-intensive industrial activity (e.g., ports or large-scale industrial parks), and dense populations in city-regions, and natural resource-related economic activities in peripheralized regions.

2.5.3. Limitations and suggestions for future research

The studies on energy regions covered by this systematic literature study are mainly found in Western European countries. Studying energy regions in the Global South is recommended to move beyond a Global North or Eurocentric bias, which may provide new insights into how energy transitions can be started and advanced [174]. However, some of these regions might be well represented by the peripheralized region concept. Other areas may be described by a combination of the peripheralized and city-region concepts since big cities can also lack resources, capacities, and formal institutions to aid a transition. Therefore, it is suggested that the energy region typology be improved once more empirical cases are available.

Although CCIRs generally express characteristics similar to those of the reviewed energy regions, only a few studies were found that applied a regional energy governance approach in CCIRs. Thus, further research can provide more recent empirical evidence on how peripheralized CCIRs can transition into learning and renewable energy regions.

Another open question is to what extent energy regions can maneuver between local and national agendas and attain both. This requires strategic agency through collaborative governance and multi-level governance [62]. Additionally, only one case with cross-border regional energy governance (the Øresund region between Sweden and Denmark) was found [132]. Yet, other places worldwide with a history of cross-border governance of water resources could provide insights.

Lastly, since this study had a governance focus, a psychological approach may deepen the understanding of the role of human behavior in the progress of regional energy transitions. For example, social psychology can help explain to what extent social innovation and informal institutions such as values, norms, and collective habits influence the lifting of lock-ins in peripheralized regions. Environmental psychology surveys can reveal the drivers for decision-makers behavior, causal drivers, and ways to overcome barriers to citizens' engagement in the decision-making of regional energy transitions [175, 176].

In the review process, some relevant papers may have been lost on the way because they were not among the most cited papers. Although this step was partially compensated with a snowballing search with references, it is recommended to complement or replace the most cited publications with the relevance filter option on Scopus for future reviews. Also, future reviews should consider covering non-English publications and other energy region-related terms such as district energy.

2.6. CONCLUSIONS

This study answered the first research question: i) What types of regional energy governance concepts have been studied? In doing so, a typology of energy regions was developed based on the concepts applied in ten countries and published over the last seventeen years. It includes four major energy region types: 1) city regions, the most applied concept in sustainability transitions; 2) renewable energy regions, including RES and 'Energieregionen', mainly developed in Germany, Austria, and the Netherlands; 3) peripheralized regions that have limited resources, with CCIRs as a subgroup with a carbon lock-in; and 4) learning regions (e.g., city-regions or peripheralized regions) that implement knowledge-based and learning innovation policies. Energy regions, starting as city or peripheralized regions, can transition into learning regions, especially to overcome challenges (like limited resources, institutions, and capacities), and then become renewable energy regions in a more advanced transition stage.

The RIS and TSI frameworks were used to answer the second research question: ii) How have regions transitioned in terms of governance arrangements and innovation processes? [111, 164]. Two primary motivations underlying energy regions were discerned, being the effective operationalization of a national agenda (e.g., the Dutch RES program 'NP RES'), and reclaiming decision-making power for the region (e.g., the Austrian energy autarky regions) [55, 156]. The energy region's agenda determines the type of innovation process the region follows: technological, social, or both. For instance, the RIS framework cannot describe the transition process of renewable energy regions in Austria and Germany that aim for a shared regional autarky. Instead, these regions are better described with the TSI framework because of citizens' active role in defining visions and owning energy projects [64, 73, 111]. The combination of social innovation practices and (in)formal institutions may enable the empowerment of collective actions like community energy initiatives (e.g., in Austrian and German 'Energieregionen') [53, 110, 111]. In the case of the Dutch RES approach, regions do not necessarily aim to empower citizens but rather pursue the goal of shifting towards low-carbon economies. Interestingly, emergent agents of energy regions had to rely on informal institutions to break path dependencies like in past coal regions. Eventually, support from formal institutions and incumbent stakeholders was necessary for energy regions to move towards stabilization and institutionalization [56, 143].

The empirical gap from the findings on peripheralized regions revealed a subgroup of CCIRs. These regions (e.g., the Ruhr region) developed pathways that diverged from coal mining and steel by reinventing their regional identities [164]. This finding shows that the energy region framing goes beyond a particular (coal) sector and focuses on the regions' capacities and abilities to transition. This process could be triggered, like in some German regions, by the coordination between municipalities, universities, and the private sector. CCIRs that face path dependencies could benefit from learning regions that have overcome limited resources and unsupportive formal institutions. This study shows that city regions and peripheralized regions face different challenges to transition because of their unique characteristics. These barriers can be overcome depending on the innovations and governance approach adopted.

Table 2.3: Overview of the identified energy region concepts

Energy region concept	Concept type	Concept description	Reference
City energy regions	Geographical concept	City energy regions are hubs connected with smaller population areas with formal institutions that can implement an energy transition strategy.	[67, 68, 125, 131, 132, 138–142]
Peripheralized energy regions	Geographical concept	Peripheralized energy regions have limited endogenous resources, informal institutions, and carbon lock-ins that impede their energy transition.	[56, 58, 81, 121, 140, 143]
Coal-and-carbon-intensive regions	Geographical concept	CCIRs are regions with socio-economic dependency on an upstream (extraction) or downstream (consumption fossil fuel sector.	[13, 56, 58, 75, 140, 144–146]
Learning energy regions	Transitioning concept	Learning energy regions implement innovation policies and pilot demonstrations. This experimentation phase helps regions develop learning-based pathways to achieve sustainable energy transition goals.	[56, 57]
Renewable energy regions	Transitioning concept	Renewable energy regions follow a strategy to develop renewable energy technologies at the regional or sub-national levels.	[19, 53, 55, 56, 58, 61, 79–84, 124–126, 129, 130, 140, 147–158]

3

WHO IS VULNERABLE IN REGIONAL ENERGY TRANSITIONS? AN INTERSECTIONAL ENERGY JUSTICE ANALYSIS OF THE ROTTERDAM-THE HAGUE REGION

This chapter aims to acquire empirical knowledge about energy injustice in an energy region. It begins with an overview of relevant research frameworks, including intersectional energy justice and regional energy governance. The chapter conceptualizes energy vulnerability through an intersectional lens and identifies three vulnerability types, being lack of: energy affordability, clean-energy accessibility, and decision-making inclusivity. Through this analysis, it seeks to address objective B "Understanding what energy injustices occur in transitioning energy regions in different contexts and identify what institutional arrangements (un)favour the correction of injustices and the inclusion of diverse citizen groups". This study provides only one example of energy regions in the Netherlands, which is a carbon-intensive region with the possibility to transition, with a top-down approach that did not consider justice issues as part of its goals, and with a high level of institutionalization. By the end of this chapter, readers will gain a deeper understanding of energy vulnerability in regions and what governance institutions and policy mixes (un)favour the creation or correction of them.

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ABSTRACT

A just energy transition requires not only the achievement of low-carbon goals but also the creation of fairer energy systems where special attention is given to identifying vulnerable groups and addressing the inequalities they experience. Governing energy transitions at the regional level may help formulate and implement tailored policies addressing vulnerabilities at the local level. However, there is limited understanding of the vulnerabilities that citizen groups experience in energy regions. We formulated three objectives to address this gap: I) identifying energy vulnerabilities in a regional transition context; II) understanding what citizen groups experience them and why; and III) identifying barriers that prevent policies from engaging with these groups. We applied a case-study research design to the Rotterdam-The Hague energy region in the Netherlands. Data collection involved semi-structured expert and stakeholder interviews and a review of newspaper articles and policy reports. We processed data with a thematic analysis drawing from energy justice literature and intersectionality theory. Three main energy vulnerabilities were identified: unaffordability of energy consumption, the lack of opportunity to own self-generation technology, and little to no inclusion in decision-making processes. The findings reveal five groups prone to vulnerability and the conditions that put them in a vulnerable situation, such as living in an energy-inefficient house. We conclude that regional energy transition policies should consider intersections of society while offering more support to municipalities to enable them to engage citizen groups at higher risk of energy vulnerability.

3.1. INTRODUCTION: JUST TRANSITIONS AND VULNERABLE CITIZENS

THE transition towards low-carbon energy is embedded in an unequal socio-economic system [177]. The disproportionate accumulation of wealth and the barriers to a better quality of life that some groups face are common inequalities that also play a role in low-carbon transitions. If ignored, those inequalities could be reproduced and strengthened during and after a low-carbon transition. Therefore, energy transition agendas often seek to achieve low-carbon goals and fairer energy systems [178, 179]. These types of transitions are referred to as just transitions [15].

Just transitions follow the principle of "leaving no one behind" [178]. This principle states that all society groups should be part of energy transitions and that special attention should be given to disadvantaged or impacted groups. Citizen participation can be considered as a means to pursue this principle and a legal right in the EU [180]. Citizens can participate in the energy transition in different ways, for example, by consuming low-carbon energy, adopting low-carbon technologies, or partaking in decision-making. However, citizen participation has primarily been limited to a few sections of society, further reinforcing underrepresentation [181]. This calls for a need to achieve more equitable citizen participation, in which disadvantaged groups also have the right to gain access to participate actively and reap the benefits of participatory action. A distinction between citizen groups is necessary for equitable participation. However, just transition studies and policies tend to generalize citizens as one big homogenous group, overlooking the characteristics of different vulnerable groups.

One reason for such generalization is the scope of just transition frameworks. The widely applied energy justice tenet framework focuses on the fairness of energy transitions' process, outcomes, social involvement, and past impacts [15, 33, 43]. Although this framework recognizes the need to discern between citizen groups, it does not help identify, describe, or understand them. To cope with this, energy justice researchers have started engaging with intersectionality theory [38, 182]. This theory explains that social marginalization mainly exists when combinations of group characteristics related to marginalization are at play, such as ethnicity, class, geography, age, and gender [39, 44].

Despite policies implemented to mitigate vulnerabilities, certain groups are often overlooked and, therefore, cannot sufficiently benefit from just energy transition programs or approaches. One of the reasons why just transition policies overlook vulnerable citizen groups is that they are typically defined at the national level. Policies aiming for just transitions have a high potential to be efficient in local or subnational settings [43], like in coal regions [183] or other industrial sector transitions, and therefore require tailoring to regional/local conditions [184]. For this reason, from a governance perspective - energy transition agendas can benefit from being formulated at the regional level [147, 185]. Regional energy transitions refer to a sub-national energy transition strategy that typically includes more than one municipality but has a smaller scope than a province

or country [55]. Since a region is situated between the national (or even provincial) and local level, it can potentially help implement national government policies while considering regional contexts, which is particularly important when discussing inter and intra-group citizen differences.

No studies have been yet conducted on regional energy transitions combining intersectional and energy justice perspectives. Therefore, this study aims to: I) identify energy vulnerabilities in a regional transition context; II) understand what citizen groups experience them and why, and; III) identify barriers that prevent policies from engaging with these groups in regional transitions.

This paper contains six sections. Section 2 presents three key theoretical concepts to this study: Energy regions, energy justice, and intersectionality. Section 3 outlines the research approach and methods, addressing how we conducted a case study in the Dutch Rotterdam - The Hague energy region (RDH-RES). Section 4 presents the results, which cover six vulnerable citizen groups, the conditions that put them at higher risk, and a reflection of how stakeholders perceive policies promoting mitigation of vulnerabilities related to energy transitions, including citizen participation. Section 5 discusses the study's results and compares them against ongoing academic debates regarding regional energy transition literature. It also provides recommendations for practitioners and policymakers in energy regions seeking to operationalize just transitions. The paper ends with conclusions and recommendations for future research in Section 6.

3.2. Research framework: Intersectional energy justice in regional energy governance

In this study, we use and combine theoretical concepts and frameworks to understand the phenomenon of vulnerability in regional energy transitions. They cover: I) Energy regions as a governance concept [19, 53, 55, 100, 126]; II) the energy justice tenet framework [27, 33, 49], which can help identify types of vulnerabilities; and III) intersectionality applied to energy transitions to disentangle intergroup characteristics [38, 186–189].

3.2.1. Energy regions

An energy region refers to a subnational territory with institutions, structures, and policies that steer or govern a transition [53]. Energy regions provide a platform to innovate modes of governance because part of their core strategy is to pursue research and development with partners in the public and private sectors. Furthermore, these regions can also be seen as promising decentralized governance approaches to coordinate energy transition efforts between the local and national levels [53, 55]. The regional level is particularly relevant regarding just transitions, as regional low-carbon transition policies have been widely implemented in Europe and other Global North contexts [184]. In the EU, regional policy programs like the Just Transition Mechanism have been enacted for coal mining and other carbon-intensive regions [190]. These regional policies are meant to help these regions overcome the challenges of transitioning away from pollut-

ing industries, for example, by providing €11.5 billion in loans to mitigate the negative socio-economic impacts [191]. In these regions, a governance approach can be used to minimize negative impacts and decide on regional development plans [84, 100].

3.2.2. ENERGY JUSTICE AND VULNERABILITY

Just transitions have been widely studied using energy justice conceptual frameworks. The most applied framework is based on three key tenets: recognition, distribution, and procedure justice [33, 43]. Recognition justice focuses on identifying groups in society that are affected by energy transitions and are underrepresented in energy transition decision-making spaces. This tenet aims to find ways to avoid or correct negative impacts (e.g., energy poverty or households struggling to afford their energy bill) and the lack of representation (e.g., of minority groups). Distribution justice refers to an equitable allocation of benefits and costs of the transition. Procedure justice aims for a decision-making process that includes diverse voices of society [33]. Other energy justice tenets like epistemic, restorative, and cosmopolitan justice have been further developed and applied [42, 192, 193].

Vulnerability is a concept used in social policy to study the drivers and experiences of disadvantage and marginalization [194]. In the context of energy transitions, energy vulnerability can be understood as the quality of the state of citizens being prone to experience energy injustices during a low-carbon transition. This concept enables the understanding of what conditions of the sociotechnical energy system [195, 196] put citizens and households at higher risk of experiencing energy injustices. Energy vulnerability originates from fuel poverty studies [194, 197], where vulnerable households have been identified as householders at an older age, with children, and disabled [194, 198]. Other vulnerable groups described by energy justice studies include rural populations, women [181, 199], Indigenous communities [200], communities close to project sites, ethnic minorities, foreign-born residents, and poor communities [201]. Several studies report a lack of tools to identify vulnerable groups and understand their differences as barriers to addressing vulnerability [181, 182, 194]

Drives for energy vulnerability have been discussed. Energy vulnerability has expanded to identify drivers of energy injustices like energy poverty and lacking access to low-carbon technologies like solar panels, electric vehicles, and low-carbon heating [202–204], as well as to understand the acceptance of energy systems flexibility [205]. In the case of the Netherlands, energy vulnerability has been applied to understand households' (un)affordability of energy services and limited access to low-carbon measures [203]. Vulnerability can be driven by income level, energy prices [181], and household efficiency [194].

3.2.3. INTERSECTIONALITY

Intersectionality theory helps understand what traits make some groups marginalized or privileged [44, 45]. Al-Faham, Davis, and Ernst [44] have stated that oppression is created by the combination of intersectional and interlocking (macro) processes

[44]. The intersectionality lens helps differentiate between and within groups and can indicate a course of action for more inclusive policies. "Black feminists" in the US used intersectionality to address how intersections in combination with identity attributes like gender and race reinforce marginalization [39, 46]. Such identity attributes can be categorized, but not for quantifying groups like in surveys, but rather to identify what intersections create marginalization. This is also mentioned by Crenshaw, who argued, "Because the intersectional experience is greater than the sum of racism and sexism, any analysis that does not take intersectionality into account cannot sufficiently address the particular manner in which Black women are subordinated" [12, p. 140]. She then argued that white feminism does not cover the concerns "Black feminist" feminists have, which can be perceived as struggles faced by, for example, Global South working women.

Similarly, just energy transition policies and strategies tend to overlook vulnerabilities that some citizen groups experience. Generally, studies on just transitions [206], energy justice [15, 43], and energy poverty [207, 208] refer to vulnerable and underrepresented groups and describe them in terms of their interactions with energy needs and services (e.g., low energy affordability). However, these studies fail to provide tools to identify diverse, vulnerable groups, as they have overlooked the connection between energy vulnerabilities and citizen identity attributes. A few energy justice studies have recently considered intersectionality to identify and better understand vulnerable groups' experiences [38, 182, 194, 201, 209]. A review of intersectionality and energy transitions shows how gender and equity are studied empirically in energy transitions' contexts, revealing that an intersectional lens is needed to understand how socio-cultural and economic energy systems allow the reinforcement of marginalization of certain societal groups [38]. Another review study focused on the connection between energy affordability and gender equality, revealing that contextual factors are crucial in shaping the energy-gender relationship [210].

3.3. Methods

We adopted a case-study research design to meet the research objective. The selected case study is the Dutch Rotterdam-The Hague energy region (RES-RDH). The research followed five steps: 1) Understanding the governance structure of the selected energy region; 2) identifying energy vulnerabilities that limit the engagement of citizen groups in the context of energy transitions; 3) identifying citizen groups that experience such vulnerabilities; 4) identifying barriers that prevent energy transition policies from achieving equitable citizen participation in the energy transition; and 5) proposing policy interventions for stakeholders to tackle vulnerabilities more effectively.

3.3.1. Case selection and background: The Rotterdam-The Hague energy region

The Netherlands is a pioneer in regionalizing energy transitions since the national government divided decision-making into thirty energy regions [55]. This study focuses on one of those regions, the RDH-RES, due to its relevance in the country's goal to achieve a 35 TWh generation of wind and large-scale solar parks by 2030 [55, 79, 211].

This region hosts twenty-one municipalities, four water boards, and the province of South Holland. It hosts a global port, two large cities, extensive greenhouse horticulture, and a densely populated residential area. In 2021, RES-RDH adopted a regional energy transition strategy, RES 1.0. In doing so, the regional network of stakeholders committed themselves to generating 2.3 TWh of renewable electricity by 2030, of which the majority will be generated from solar panels installed on home rooftops.

The RES-RDH case was selected for several reasons. First, the case presents a dedicated energy region with a governance structure and regional energy transition strategy. Second, the region encapsulates a broad spectrum of urban, industrialized, suburban, and rural areas, a dense population, and is of socio-economic and political importance to the country. Third, it is the most energy-intensive region in the Netherlands. Finally, the existing literature on citizen engagement in regional energy transitions appears to overlook regions demonstrating high socio-economic and demographic diversity, such as those within RES-RDH-RES. For example, Bouma *et al.* [212] and Lelieveldt and Schram [94] analyzed smaller, sparsely populated energy regions, mainly in predominantly rural parts of the country [94, 212].

In 2021, more than 600,000 people in the Netherlands were experiencing energy poverty [213]. These low-income households have difficulty covering energy expenses, which leads to inadequate housing quality and limits their ability to invest in sustainable home improvements [213]. This group is highly prevalent in the RES-RDH region compared to other country areas.

3.3.2. Data collection: Interviews, newspaper articles, and grey literature

Twenty semi-structured expert interviews were conducted from April to June 2023. These interviews covered a total of sixteen stakeholders from the public and semi-public sectors and four with stakeholders from civil society. In addition, three civil servants provided information via e-mail in the form of a questionnaire, which served as input to develop the interview protocols. This set of interviews provided a wide variety of stakeholders representing eleven organizations. Each interview lasted over an hour and was recorded using a phone for in-person interviews or MS Teams for online interviews. The participants used and approved a consent form, and their personal data were anonymized.

Stakeholders were initially identified using a purposive sampling method and later complemented with a snowball approach. Various stakeholder groups represented decision-makers in the RES-RDH, including municipalities, the province, and others. Another set of stakeholders represented citizens struggling with energy injustices. These stakeholders work in several different district councils of the cities of Rotterdam and The Hague, as well as in social welfare organizations ('welzijnsorganisatie' in Dutch; translation by the authors) like 'Dock' and 'Schuldhulp maatjes' where expert volunteers help citizens find solutions to financial-related or other problems [214, 215]. We employed social media platforms like LinkedIn to reach the participants. A list of the stakeholder

roles covered by the study is presented in Table 3.1. We prepared an interview protocol for decision-makers and another for citizen representatives, both in Dutch (see Appendix B).

Table 3.1: List of stakeholders' roles that were interviewed

Stakeholder	No. of participants
Alderman Middle-large municipality	1
Consultant Province of South-Holland	1
Civil Servant Middle-large municipality	1
Civil Servant Province of South-Holland	1
Civil Servant Middle-large municipality	2
Consultant NP RES	2
Civil Servant Large Municipality	1
Civil Servant Waterboard	1
Director Energy Cooperation	1
Alderman Middle-large municipality	1
Civil Servant Middle-large municipality	1
Alderman Middle-large municipality	1
Alderman Large Municipality	1
Civil Servant Middle-large municipality	1
Alderman Middle-large municipality	1
Employee Welfare organization	1
Alderman Middle-large municipality	1
Director Energy Cooperation	1
Total number of interviewees	20

The second source of data concerned newspaper articles that covered topics related to social injustices in energy transitions. Articles showing a (negative) public opinion on the energy transition were used as a proxy to identify social injustices. It should be noted that newspapers often act as an intermediary for the opinions of politicians, organizations, and citizens on climate topics [216]. A total of 36 newspaper articles published from January 2017 to May 2023 were selected for the media analysis. The newspapers comprised: "Algemeen Dagblad" and "Google News", a local and a pool of Dutch national newspapers, respectively, because of their high reach among the population. The keywords combined and used for the newspaper article selection were (translated from Dutch) "Energy transition", "energy poverty", "citizen participation", "participation", "energy inequality", "protest", "The Hague", "wind energy", "wind turbines", and "conflict". Other newspaper articles were added to the list following a snowball approach. Only articles that were written in the RES-RDH region or neighboring regions like 'Drechtsteden' were selected based on their relevance to this study. Additionally, grey literature, such as policy briefs and reports (e.g., RES strategy reports), was reviewed to formulate the interview protocol and connect with ongoing policy debates in the Netherlands.

3.3.3. Data analysis: qualitative thematic analysis of interviews and newspaper articles

A thematic analysis of the twenty interview transcripts and thirty-six newspaper articles was conducted using a licensed version of Atlas.ti, a qualitative data analysis software [217]. Two researchers (i.e., the second and third authors of this paper) conducted two qualitative thematic analyses in parallel for the sake of robustness. One analyst started with closed themes defined by the energy justice framework, and the other with open themes defined by the data. The energy justice framework was operationalized based on the three main tenets (i.e., distribution, procedure, and recognition justice) which are introduced in Section 2.2 [33] to identify energy vulnerabilities. Each tenet was used as a theme, helping to focus the search for energy vulnerabilities: Distribution justice helped identify access to clean energy and energy affordability, procedure justice led to identifying access to decision-making spaces, and recognitional justice was later linked with intersectionality to identify and distinguish diverse, vulnerable groups. The researchers converged in their coding trees to identify energy vulnerability types. We performed a second thematic analysis of the converged coding tree by focusing on intersectionality. The coding trees are presented in Appendix A.

3.4. Results

A qualitative thematic analysis focused on the justice tenet framework (i.e., procedural, distributional, and recognitional justice) was applied to the stakeholder interviews and newspaper articles. This analysis helped to identify three main energy vulnerabilities. These are lack of: 1) Affordability of energy consumption, 2) the opportunity to (co-)own self-generation technologies, and 3) inclusion in decision-making processes.

Although the first and second vulnerability types are related to energy accessibility, a fundamental Millennium Goal [218], these are presented separately in this analysis because they cover different types of citizen participation. Affordability of energy consumption represents a consumer role, ownership of self-generation technologies relates to a prosumer role, and inclusion in decision-making to a more deliberative form of participation [2]. We combined the tenet-based energy justice framework [33] with intersectionality theory [38, 44] to understand better the groups that experience injustices. The justice framework allowed for the identification of the mentioned vulnerabilities, which are related to the distribution (affordability of energy consumption, opportunity to own self-generation technology), procedure (inclusion in decision-making processes), and recognition (three of them) tenets.

However, the justice tenets cannot fully describe these energy vulnerabilities because the justice framework does not distinguish between citizen groups. Therefore, this framework was combined with intersectionality to identify different citizen groups and understand what conditions put them at higher risk of energy vulnerability.

3.4.1. UNDERSTANDING CITIZEN ENERGY VULNERABILITY

By applying intersectionality to recognition justice, we identified several energy-vulnerable groups. We considered the intersections of the RDH region's society to identify the citizen groups prone to experiencing energy vulnerability. Based on the analysis of the newspaper articles and stakeholder interviews, we discerned five groups prone to being vulnerable: Single parents, unemployed people, elderly people, students, and immigrants. Yet, not all of these socio-demographic groups experience energy vulnerability. When these groups present one or more vulnerability conditions, they become vulnerable to experiencing energy injustices. Such conditions for energy vulnerability include: Socio-economic aspects like income level, a household's insulation quality, (not) having property rights; social aspects like language, time spent at home, and; others like level of interest in, knowledge of, and awareness about energy policies, and time availability. Figure 3.1 shows that those citizen groups prone to vulnerability with one or more vulnerability conditions are likely to experience energy vulnerability.

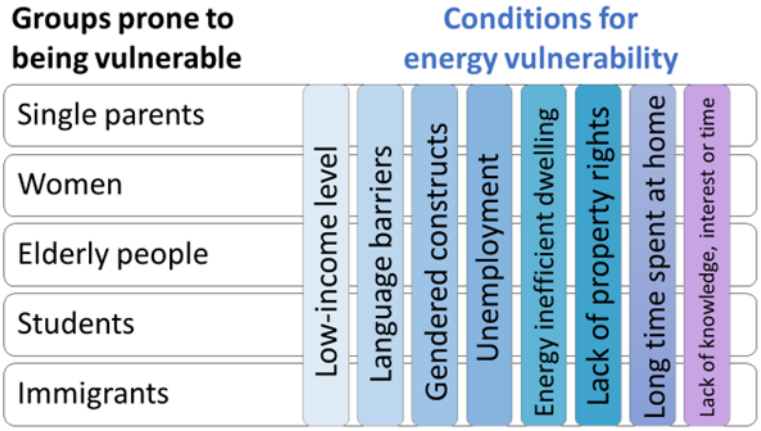

Figure 3.1: Overview of intersectional energy vulnerability in the RDH-RES region. The combination of groups prone to being vulnerable (horizontal) and conditions for energy vulnerability (vertical) puts these groups at higher risk of experiencing energy vulnerability

LACKING AFFORDABILITY OF ENERGY CONSUMPTION

Energy affordability, as a type of distributional justice, emerged as the most frequently mentioned topic in the analyzed newspaper articles and stakeholder interviews. It refers to a household's ability to pay electricity and heating energy bills, perceiving households as energy consumers. Traditionally, this phenomenon has been measured in Europe as the percentage of households spending equally or more than 10% of their income. In the RES-RDH region, an energy poverty study conducted in 2021 revealed that 9% of households spend more than 8% of their income on energy bills [213, 219]. Big cities like Rotterdam and The Hague feature high levels of energy unaffordability among households. It was widely discussed during the interviews that low

household income levels can lead to a higher risk of experiencing energy unaffordability.

As presented in Figure 3.2, the lack of affordability of energy consumption was found to be related to six vulnerability conditions, such as low household energy efficiency performance. In Dutch studies, the income level and the dwelling's energy label are considered to measure energy poverty. These labels, ranking from A++++ (most energy efficient) to G (least energy efficient), consider the house's thermal insulation, type of heating, type of water supply, ventilation system, and whether renewable energy technologies are installed [220]. Six percent of Dutch households are low-income and reside in low-degree energy-efficient dwellings labeled E, F, and G [221–223]. In the South Holland province, where the RES-RDH region is located, this figure is even higher, namely eight percent, which accounts for 133,054 households. Interviewees provided insights into what groups in society experience energy unaffordability.

"Yes, social housing is quite old, and people who receive governmental support are often at home, or elderly people are retired. Yes, people who are not working, often also large families with many children in small homes [...] so all of that together does cause many people to have problems paying the energy consumption bills." (Coach and family support worker at a welfare organization, 2023).

"They [people experiencing energy unaffordability] are most often not sufficiently educated or do not have the time to educate themselves in making [well-informed] energy decisions." (RES-RDH decision maker, 2023).

Poor household energy efficiency performance is related to high energy consumption and hinders the fulfillment of the household's energy services. These households can face challenges in meeting their daily expenses due to high energy costs [222, 224, 225].To alleviate the financial burden, energy-inefficient dwellings can make people adopt energy-saving behaviors like switching off central heating, reducing warm showers, and limiting cooking [221, 222, 226–228]. Furthermore, those living in housing with poor energy efficiency performance have a high likelihood of experiencing a moist living environment, which causes fungal growth and, ultimately, health issues [226]. A quote from an interview illustrates this. According to Voermans [228], cold and damp living conditions lead to hospital admissions, particularly for individuals under the age of eighteen with asthma-like symptoms, and in combination with financial concerns, this can cause mental health problems [228, 229].

"In Winter, people do not ventilate, even less now because they are all afraid of, yes, that's even more energy. [...] if people do not ventilate at all, it becomes very damp, and then you cannot apparently heat as good because then the air is too humid, and these are all things that people really don't know. People think, yes, but I'm going to open, I'm just going to get cold in the house, when sometimes it's actually good to air, especially If you have an old house without mechanical ventilation. So, I think a combo of lower prices and more economical homes and also a piece of education." (Coach and family support worker at a welfare organization, 2023).

Spending a long time at home and living in a household with a low level of energy efficiency is a combination that can lead to energy unaffordability. Citizens who tend to spend a longer time at home are women because of the gendered construct of women being the house and family caregivers [230, 231] and older adults and full-time parents. If these groups have a low disposable income and live in homes with low energy efficiency performance, they have a higher risk of experiencing energy unaffordability.

Not having property rights is another condition that puts households at higher risk of energy unaffordability. As tenants of private houses, residents do not have the power to decide whether to upgrade the house's energy efficiency. Only private landlords, the property owners, can decide to make changes to the property. This leads to landlords withholding investments in energy performance improvements because of the so-called 'split incentive', which refers to tenants wanting to minimize housing costs. At the same time, homeowners aim for profit [232]. The private rental sector in the Netherlands has no obligation to improve housing energy efficiency even though the country seeks only A-D energy-labeled houses by 2030 [233]. This situation may change with the government's measures for the built environment published in November-December 2023 [234]. Yet, these policy measures target homeowners and homeowner associations, leaving tenants without legal resources to act. The quote from a civil servant below illustrates how lacking property rights can put citizen groups under energy vulnerability.

"We know that energy poverty is (found), particularly in those neighborhoods where there is a lot of ownership with (social) housing associations" Municipality Civil Servant, 2023).

Based on the stakeholder perceptions from the interviews, the available policy instruments to tackle energy unaffordability and energy poverty thus far fail to positively address mitigating vulnerabilities of some energy-vulnerable groups like low-income and non-Dutch speakers. The first policy discussed is personalized advice to households via energy coaches and fixers. This intervention involves professionals visiting underprivileged neighborhoods to advise households on energy-efficient behavior and energy-saving equipment like LED lights and sealing strips. These professionals can help residents understand their energy bills and acquire subsidies. However, the reach of this approach so far is limited due to a lack of human capacity required by municipalities.

Another policy addressed concerns energy allowance and loans. Energy allowances are one-time financial aid for low-income families to help them afford their energy bills. However, interviewees representing municipalities mentioned that some families (mis-)used the aid for non-energy-related purposes. Low-interest loans are other measures to help citizens invest in insulation and sustainable energy self-generation. However, low-income families do not qualify for these loans because they are considered untrustworthy. Despite the low-interest rates, some families still hesitate to access these loans because of a lack of trust, as shown in the following quote.

"Well, some distrust also gets back about the (nation-wide)' childcare allowance affair' (which caused widespread distrust in government in 2022 regarding national government maltreating citizens) and such that people are like. Yeah, yeah, free, but then I'll definitely have to pay it back" (Civil servant in the RDH-RES, 2023).

As described by the quote below, the groups suffering from the unaffordability of energy are diverse and cannot be clustered into one homogenous group. Rather, they can be described based on the intersection of group characteristics and vulnerability conditions that create energy unaffordability. For example, some group characteristics are associated with spending long times at home, like being women or older adults. Other characteristics related to low income are being single parents or students. When these groups also experience conditions that limit their ability to live in an energy-efficient household (e.g., the dwelling's poor energy level, low income, not having property rights or unemployment), the likelihood increases that they face energy unaffordability. Moreover, not being able to speak Dutch is an additional reason, as Dutch is the official language used with regard to how policy instrument implementation is communicated to target groups in society. This, for example, proves difficult for non-Dutch speakers who wish to apply for a subsidy or measure that comes with a tax deduction.

"So It is very complex. It is not just a group of people where you can point to it like, well, we have to do something with that. No, It is much bigger, and there are also people who live in a very large house and own it who can just about live there, [for] whatever the reason, but who do not have the money to make it more sustainable while they have a fantastic house. For some people, it's just not feasible, so it is very diverse". (Civil Servant Middle-large municipality, 2023).

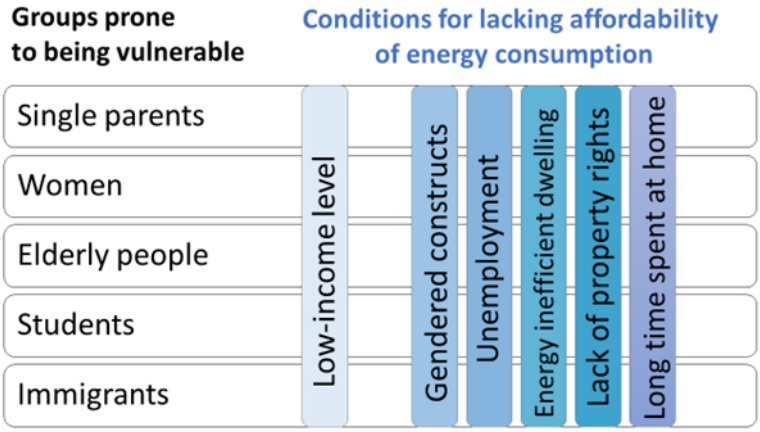

Figure 3.2: Intersectionality lens applied to the lack of affordability of energy consumption. The intersection of groups prone to being vulnerable (horizontal) and one or more conditions for energy vulnerability (vertical) puts these groups at higher risk of lacking energy affordability.

LACKING THE OPPORTUNITY TO (CO-)OWN SELF-GENERATION TECHNOLOGIES

In the RES-RDH region, some citizen groups are restricted from owning clean energy technologies like solar panels and heat pumps for self-consumption purposes. This is another type of distributional (in)justice. Lacking the opportunity to (co-)own clean-energy technology is an energy vulnerability type from an energy prosumer perspective because it can create more inequality and restrict vulnerable citizens in the way they can participate in the energy transition [235]. Lacking access to self-generation technologies jeopardizes citizens' right to become energy prosumers and their desire to reduce one's carbon footprint.

The RES-RDH region hosts community energy initiatives and projects where residents, businesses, and organizations collaborate to invest, install, and own renewable energy technologies in their locality. These local-ownership projects can give partial or complete control to citizens and businesses to financial participation via shares or bonds. Members of these projects, that is, citizens who own self-generation technologies, have the opportunity to participate in planning, landscape integration, and revenue allocation and can benefit from lower energy bills.

However, many households do not have the opportunity to participate in community energy projects nor to access clean-energy self-generation technologies. Four groups lacking the opportunity to (co-)own self-generation technologies were found, who experience one or more of the four vulnerability conditions described in Figure 3.3. = One of the main concerns found in the newspaper articles analyzed concerned residents' struggles to afford clean energy technology due to a low disposable income. Self-generation technologies such as heat pumps and solar panels are currently too expensive for many citizens. Residents who are more well-off generally benefit more from the energy transition than those with less disposable income.

Yet, focusing only on the disposable income level is not sufficiently specific to identify nor broad enough to cover all citizens with limited access to clean-energy technologies. According to the results of the analysis of the interviews and newspapers, single parents, students, and older people are prone to having a low disposable income. Moreover, lacking property rights also impedes tenants from investing in and installing clean energy technologies, as well as not speaking Dutch because residents can find it more challenging to access information about subsidies and how to apply for them. If the groups shown in Figure 3 intersect any of the vulnerability conditions, they are likely to face this energy vulnerability type.

"Well, it is indeed often the less affluent households anyway. It's (especially) the households that may not be able to speak the language. It's households that, yes, have other problems on their plate, making it less interesting for them that they have him as the priority. So, It's very complex. It's not just a group of people where you can point it out, but we need to do something with that." (Alderman of a municipality in RDH, 2023). Municipal policies aim to promote citizens' financial participation. Some municipalities in the RDH region offer citizens subsidies and the opportunity to invest in specific energy

projects, benefit from their investments and participate in the decisions of the projects. Although this mechanism supports the development and operation of energy initiatives, the stakeholders interviewed acknowledged that many citizens cannot invest because of financial constraints, not having property rights or language barriers.

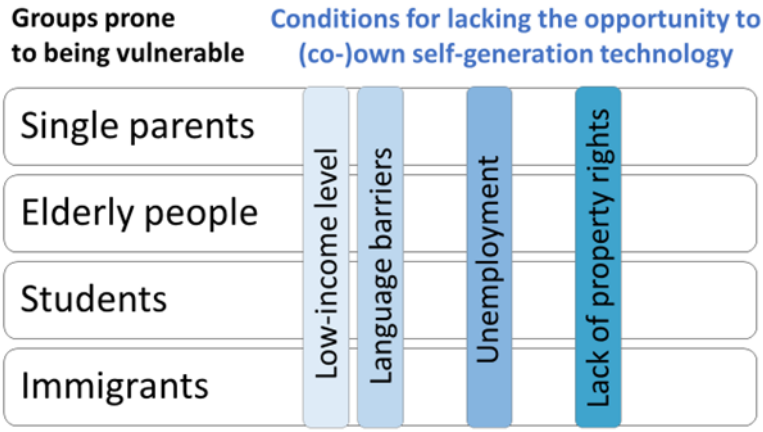

Figure 3.3: Intersectionality lens applied to the lack of opportunity to (co-)own self-generation technology. The intersection of groups prone to being vulnerable (horizontal) and conditions for energy vulnerability (vertical) puts these groups at higher risk of lacking the opportunity to (co-)own self-generation technology.

Lacking inclusion in decision-making processes

The third energy injustice that we identified is associated with procedural justice: A lack of decision-making inclusivity, as presented in Figure 4. Several entities play a role in the RES-RDH- decision-making. We find municipal councils, councilors, alderpersons, City mayors, and citizens among these. For example, the energy transition regional energy strategy plan (RES 1.0) was approved by municipal councils, Provincial States, and general boards of the water authorities [236]. Yet, the RES-RDH organization stresses that it is the responsibility of the parties involved themselves to engage with residents and local stakeholders in undertaking this process [237], which shows that social engagement is not organized nor prioritized by the energy region. Public hearings and other citizen involvement initiatives are organized at the municipal level, which become integral to the decision-making process. For example, the council establishes general policies like environmental regulations and energy targets in a wind park project. The alderperson prepares the groundwork, including details about the proposed wind farm project. Citizens can then raise their opinions and concerns during the public hearing. Yet, this citizen participation approach does not allow a two-way and long-term exchange of information and opinions. Moreover, this approach lacks transparency in how public opinions are considered or not in the decisions, and it lacks fairness because citizens engage in conversations only after the projects have been defined.

From the newspaper article analysis, we noticed that stakeholders at both the regional and local levels mentioned the lack of citizen participation in the energy transition decision-making process. The newspaper articles highlight that even when citizen participation exists, it is often unclear how input is utilized, and there are concerns about the government neglecting to engage with hard-to-reach groups.

We identified four vulnerability conditions addressing decision-making inclusivity that five groups tend to experience as presented in Figure 3.4. The first pertains to low disposable income because it also reduces citizens' time to engage in energy transition discussions. Lack of knowledge, interest, or time from either citizens or decision-makers also limits the inclusion of citizen groups in the decisions. Previous studies have highlighted that mostly male citizens participate in meetings, which points out the importance of gender. Moreover, not speaking Dutch is considered a big limitation since it is the official language of how citizens are invited and where meetings are held. Lastly, traditional gendered constructs of women as stay-home caregivers, who have experienced political discrimination throughout generations, limit female involvement in public decision-making spaces [238]. Therefore, women raised with traditionally gendered constructs and who are also prone to other vulnerability conditions like low-disposable income or lack of time are less likely to have access to decision-making spaces.

One crucial distinction made by the majority of municipalities is the involvement of citizens in energy transitions and their inclusion in the RES decision-making processes. This differentiation is important because while the government encourages citizen participation in the energy transition by adopting more sustainable behaviors and technology, citizen participation in public decision-making is scarce. One reason is that governments lack knowledge on how to engage citizens in decision-making. Another reason is that most local government civil servants find that the decision-making process regarding the design of energy systems is considered "too abstract" and think that citizens do not want to be involved.

Municipalities employ several measures to engage citizens and encourage participation in energy transitions. The first measure corresponds to information sharing. Municipalities employ various communication channels such as newspapers, flyers, websites, social media platforms, and public stands. Local governments share information about upcoming energy projects and policies through these channels with citizens. By engaging in conversations with citizens, authorities seek their opinions and perspectives, which can be utilized as input for policy making. Another measure used concerns running advisory councils. Some municipalities have established advisory councils for decision-makers and civil servants regarding energy-related matters. In this way, civil servants indirectly represent citizens' opinions in decision-making. However, there is a concern that several groups in society are inadequately represented or reached by civil servants. Moreover, whereas the afore mentioned measures are rather successful in achieving communication in one direction - i.e., from the municipalities to the citizens -as described in the quote below, they are less successful in enabling deliberation to

encourage any meaningful discussions.

"Yes, we started last year with a group of energy ambassadors. I think they went to a total of 1,700 households and installed energy-saving measures or gave information about them. More than 70% of the residents where they've been pictured off of the households they've been in. And that's just because we've put a lot of time into it, so not ringing the doorbell once, but knowing after that come again and not yet come again the week after and then put a bill in the box and the neighbors' question of you know who that's and we're really trying to actively those people. [...]Personalized approach, that's just very important." (Alderman of a municipality in RDH, 2023)

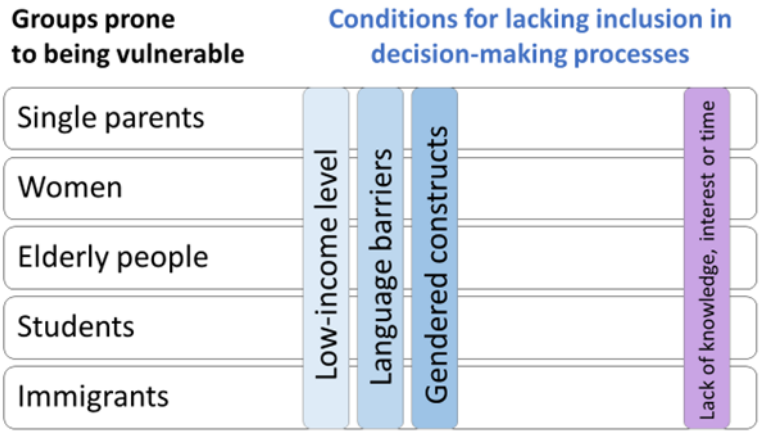

Figure 3.4: Intersectionality lens applied to the lack of inclusion in decision-making processes. The intersection of groups prone to being vulnerable (horizontal) and conditions for energy vulnerability (vertical) puts these groups at a higher risk of being excluded from decision-making processes.

3.4.2. Barriers to addressing or mitigating the identified energy vulnerabilities

The thematic analysis of stakeholders' perceptions and policy briefs helped identify four barriers that ('RES') decision-makers in energy regions, mainly municipalities, face when implementing energy transition policies seeking citizen participation.

The first mentioned barrier refers to municipalities' limited (financial) capacity. The national government is the main funding body that distributes resources to municipalities. However, no national program is dedicated to addressing energy injustices or vulnerabilities of the mentioned citizen groups. Energy vulnerabilities are not evenly distributed among municipalities but rather concentrated in some neighborhoods, such as neighborhoods with mostly social housing. This translates into bigger barriers for some municipalities, which do not necessarily match certain municipality's availability of resources and decrease their capability to act. Furthermore, the method used to

allocate financial means to municipalities is changing, as the national government increasingly provides SPUKs (subsidies specific benefits), which can only be used for specific instances and earmarked purposes. This limits the maneuvering space of municipalities in addressing energy injustices. In addition to financial constraints, lack of manpower capacity, particularly within municipalities, represents another barrier. Engaging citizens in decision-making regarding the energy transition and addressing energy unaffordability by the existing communication mechanisms (e.g., providing advice and organizing thermal insulation programs for households) demands manpower, which is scarce in most municipalities, especially in small and medium-sized ones. Moreover, effective engagement strategies tailored to each community require customized approaches.

Another barrier that municipalities face is a lack of data about vulnerable groups. The analysis of the interviews revealed that municipalities face difficulties in spatially identifying the groups at higher risk of energy vulnerability. Municipalities lack access to adequate data, particularly concerning energy-vulnerable residents, as highlighted by a previous in Utrecht, the Netherlands [239]. They heavily rely on the data provided by TNO (The Netherlands Organisation for Applied Scientific Research) to identify, locate, and address vulnerable groups in society.

Furthermore, municipalities and citizens often have limited understanding and awareness about just transitions. This challenge lies in two key aspects. First, there is limited awareness among both citizens and the government regarding energy justice. The municipality's understanding of just transitions tends to be limited, stressing energy affordability, leaving clean-energy accessibility and decision-making inclusivity aside. Second, citizens are often unaware of municipalities' policies to mitigate energy unaffordability, like subsidies and thermal insulation programs. Similarly, citizens are commonly uninformed about channels for engaging in participation. In addition, many exercise a general distrust of the government, which also contributes to limited awareness or interest in energy transition projects. In the cases of wind farms, citizens have shown interest, and sometimes opposition, when farms are developed nearby [240]. There are many reasons citizens do not participate, as illustrated by the quote below.

"Again, there are various reasons. Some people just don't want to participate because they think it's nonsense. Some people are 80 (and think) it will take my time [. . .]. Some people who just don't speak the language, and then they just don't manage to get in [...] It can also have to do with people who just distrust the government and are like. Yeah, it is all fine and dandy, but I just don't want you guys in there." (Alderman of a municipality in RDH, 2023)

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3.5. Discussion: Establishing an intersectional energy vulnerability analysis approach

Our study agrees with previous energy poverty and justice studies in the Netherlands, which identified similar conditions and household characteristics for energy vulnerability (see Figure 3.1). These conditions include insufficient income, lack of property rights, dwellings' energy efficiency quality [187, 203, 213], gender [241], and language barriers [203]. Living in social housing [187, 213] was also found, but we did not include it in Figure 1 because of its interdependencies with a low household income and lack of property rights. Other conditions that our study did not identify are living in densely populated areas [187, 242] and under-consuming households [187, 213], possibly because of our coverage of municipalities (see Appendix B). Our study also confirms the prevalence of certain characteristics among the groups that experience energy vulnerability in the Netherlands: Gender identity, single-parent families, age, employment status, family size, and disability [241]. This study did not reveal the last two characteristics. Other group characteristics we identified are students and immigrants, possibly because of the high percentage of students and expats in the RDH region.

The conceptual and methodological gap this study addressed in intersectional energy studies is the description of vulnerable group characteristics and a method to identify them. Previous studies describe vulnerable groups in terms of overlapping categories like group needs [194], capabilities [199], and characteristics like gender, race, and class [38]. We described these groups based on two dimensions to make the approach more operationalizable: 1) Groups prone to vulnerability and 2) vulnerability conditions. This is an important distinction because it allows one to disentangle the complexity of intersectional energy vulnerability. Previous studies stated that the causes of energy poverty are a combination of energy prices, building stock infrastructure, and socio-economic and demographic factors [194, 241]. Although this conceptualization is comprehensive, it does not prove practical when it comes to identifying the groups who experience energy poverty. Similarly, focusing on group characteristics can lead to the conclusion that one should look for gender, power, ethnicity, and class to identify vulnerable groups [182, 188, 241]. However, families could meet these socio-economic and demographic characteristics yet still not experience energy vulnerability, for example, because they live in a high-performance, energy-efficient house. That is why we believe that our distinction between groups prone to vulnerability and vulnerability conditions is a step toward building policy-making tools to identify and target vulnerable groups.

The empirical gap in intersectional energy studies we addressed is the skewed selection of communities near the development of energy projects [243]. Our focus on general citizens, regardless of their location, makes our findings more applicable to other regions, going beyond NIMBY framings and the limited citizen representation of community energy projects.

We consider that the applied theoretical framework and the methodology can be ap-

plied to other contexts where there are energy transition policies aiming for citizen participation, and they have a subnational governance layer that covers a manageable number of municipalities. This is the case in most European countries because of the phenomenon of regionalization and the availability of regional developing funds, which promote regional initiatives [13, 72]. Similarly, the findings on vulnerable groups and barriers can be used as a reference for future studies in other Dutch or Western urbanized regions, as some overlapping vulnerable groups have been previously reported [244].

3.5.1. Policy recommendations

Representation in decision-making

Following Crenshaw's intersectionality rationale [46, 245], to address energy vulnerabilities, it is necessary for the participation and leadership of representatives of the intersectional groups that are currently marginalized by the sociotechnical energy system. The National Program of Regional Energy Strategies (NP RES) recognizes that besides financial participation, citizen participation in decision-making is necessary for social acceptance, especially to avoid opposition [246]. Although NP RES offers tools for municipalities and RESs to carry out citizen participation, there is a lack of citizen involvement and, therefore, a lack of representation of vulnerable groups in the RESRDH regions and municipalities' decision-making process [247]. In this region, citizen participation has been limited to top-down information dissemination activities.

The representation of vulnerable citizens is needed at the municipality level, and all vulnerability issues among municipalities are needed in the RES. A study in the province of Gelderland (another region in the country) also reported that municipalities struggle to reach diverse groups in the events they organize [203]. According to Riverenland region administrators, an effective way to achieve inclusion is not about including as many people but rather as many opinions and perspectives as possible [247]. Two-way communication spaces in municipalities where citizen representatives and stakeholders can co-create pathways to address energy vulnerabilities are needed. An effective but time-consuming avenue to initiate the engagement of diverse citizens is door-by-door communication, as reported by some municipalities in the RES-RDH. Other regions like Arnhem-Nijmegen have engaged university students in sustainability projects, investing resources in long-term communication platforms [247]. However, if there is distrust, the communication process can be mediated or conducted by a third party with access to vulnerable communities like social work agencies and welfare organizations. Alternative ways have been proposed, such as narrative creation workshops with residents in the Drenthe-RES, sustainability projects with university students in the Arnhem-Nijmegen region [247], and using online platforms because of their potential to be less time-consuming and reach out to young people [248].

According to the NP RES, a measure that can potentially help municipalities address the lack of access to clean energy technologies is to have clear agency when pursuing local ownership [249]. The NP RES has the goal of meeting the (national) Climate Agreement goal by achieving 50% local ownership of solar and wind energy, where implementation is the responsibility of municipalities [246]. One of the challenges that municipal-

ities face is the lack of clarity on how to achieve local ownership. For this, the NP RES states that local ownership should be part of municipal policy, with established goals and obligations, so that there is clarity about the roles and contributions to the energy transition. This is, however, only an initial step, as civil servants need more preparation to understand the topic, its challenges, and how to organize regional energy strategies. Representing vulnerable groups at the municipality level is key to overcoming the barriers that prevent some citizens from participating in local ownership projects.

TARGETED POLICIES

Energy transition policy measures tend to overlook the citizen groups at higher risk of energy vulnerability. We discussed several policy measures, including energy advice to households, energy allowance and loans, subsidies for self-generation projects, and information dissemination and public hearings organized by municipalities. These policies are blind to specific groups of vulnerable citizens. This finding agrees with previous qualitative studies in the Netherlands, which revealed that mechanisms aiming to address household energy vulnerability are largely unknown by the groups that commonly experience it [203, 250, 251]. In accordance with our findings, Kaufmann *et al.* [203] state that policy instruments (e.g., focused on energy efficiency, subsidies, and financial aid) can fail to reach some groups because of language barriers, not being legally eligible to access energy efficiency measures, and not being able to afford the loan after receiving it (Ibid). Therefore, there is a need for energy transition policy measures to consider particular vulnerability conditions that prevent vulnerable groups from participating in the policy programs.

Applying an intersectionality lens to citizen participation in energy policies can be both practical and effective. First, applying an intersectionality energy justice lens to a qualitative case study analysis with stakeholder and citizen participation helps identify several vulnerable groups and the policy instruments that overlook these groups. The intersectional nature of energy vulnerability should not be understood as a continuum where the more conditions, the more vulnerability because some vulnerability conditions can be more relevant than others. Therefore, the list of vulnerability conditions should be used for qualitative and descriptive purposes instead of quantitative interpretations. With this information, policy and decision-makers can focus on the revealed intersectional groups, meaning they can zoom into the five groups prone to being vulnerable and who also have one or more vulnerability conditions. Reaching a representative sample of vulnerable groups in the analysis is necessary to avoid overlooking groups. Since a team of two researchers working full time for three months and one supervisor were enough to cover several municipalities in this study, we think that a small team can make a representative study of one region. Therefore, we do not say that issuing one tailor-made policy per vulnerable group is necessary, but applying an intersectional justice lens can make existing policies sensible to vulnerable groups.

STRENGTHENING MUNICIPALITIES' CAPACITIES

Municipalities have been responsible for addressing energy vulnerability in the Netherlands. Most interviewed municipal agents considered this topic to lie within the

municipality domain. At the same time, they considered that their capabilities were oversaturated, so they were not able to reach out to vulnerable groups. We reported four main barriers municipalities face when implementing policies pursuing citizen participation in the transition: Limited (financial and human) capacities, lack of data and knowledge about vulnerable citizen groups, limited understanding and awareness about what just transitions mean, and political instability around energy projects. These findings are, to a certain extent, generalizable to other regions in the Netherlands, as they have been observed in geographically different regions like Arnhem-Nijmegen, Drenthe, among others [203, 247, 252]. Therefore, local governments are in need of more human capital, resources, and capacity [252].

Most municipalities need more expertise and staff, especially in the implementation phase of energy counters, fixers, and insulation campaigns. Similarly, they report a lack of expertise in the planning and development of district heating networks. During the interviews, many municipalities expressed interest in citizen participation but lacked expertise on the topic. We suggest that instead of relying on consultancy firms for this, municipalities could hire citizen participation experts and work more closely with social workers who are knowledgeable about vulnerable groups.

THE ROLE OF ENERGY REGIONS

Other barriers that impede the alleviation of energy vulnerability are a predominantly top-down governance approach and the limited agency of energy regions. In the Netherlands, energy transition policies are not framed as striving to reach just transition goals, but some aim to (partially) contribute to this by stressing citizen participation. These policies have been defined at the national level and implemented by municipalities. Most RESs, like the RES-RDH region, have followed a predominantly top-down oriented approach, with the exception of the five pilot regions [167], despite the fact that energy regions were designed to function as a link between municipalities and the central government. RES' objective is to contribute to the national 35 TWh goal, and they have some room to decide relatively autonomously how to design and implement a strategy despite being highly dependent on national government policy support frameworks.

The RES-RDH region has remained distanced from energy vulnerability issues. Energy vulnerability and citizen participation topics were not even mentioned in the strategic governing document of the RDH region, the so-called 'RES1.0 RDH', despite the region being densely populated and home to an above-average rate of energy poverty [213, 253]. This is striking because other energy regions in the country, like the West-Brabant-RES, are less densely populated have a lower rate of energy poverty, and still address citizen participation in their strategic 'RES1.0' document. This is why we cannot generally conclude that all energy regions are ready to address energy vulnerability; they need prior knowledge, experience, and (political) interest in this topic. Still, we can anticipate that if focused on energy vulnerability and justice, energy regions could strengthen municipalities' efforts.

A potential measure for energy regions (i.e., 'RES regions') to help municipalities is

the capacitation of civil servants on energy vulnerability topics. The NP RES provides support to municipalities by offering a range of communicative policy instruments. For example, webinars are organized to show municipalities how they can develop local policies to pursue goals like local ownership in solar or wind projects [249]. Since January 2023, the National Local Heat Transition Program was launched to provide funding to regions (total budget: €9 million annually) to support municipalities [254]. Through this program, RESs were involved in sharing knowledge and good practices on initiatives to municipalities within the region via official websites, helpdesks, and social media, as well as by organizing thematic meetings. The focus of this program was to accelerate and scale the sustainable heat transition. Although this information has been valuable for preparing civil servants, they also require training on addressing energy vulnerability. Addressing energy vulnerability requires a joint effort between decision-makers, academia, social workers, and citizens. The RES can lead this joint effort, not with individual municipalities, but with representatives of each municipality to promote cross-learning and synergies.

From an energy justice and multi-level governance perspective, municipal cooperation is needed to promote a fair distribution of costs and benefits, and energy regions can be the intermediates for this cooperation. The energy region can have an overview of energy justice issues and inequalities between municipalities in the region. For example, residents of the City of Wassenaar may be more privileged than in Rotterdam or The Hague because Wassenaar has more financial capabilities and policy agencies due to the high tax income paid by wealthy citizens. With energy regions as intermediates, policies could be tailored to local contexts. For example, energy regions could inform policymakers about municipalities' needs, capacities, and potential municipality pairing for cooperation. Then, policies could allocate resources for regions to enable the sharing of manpower, knowledge, and household data between paired municipalities to ultimately identify and engage with vulnerable households.

3.5.2. Limitations and future research

The interviews and newspaper articles of this case study may not necessarily offer a representative view of the public opinion in the RES-RDH region. We cannot state that the identified group characteristics and vulnerability conditions are the only or most representative of the region. However, our findings coincide with previous Dutch case studies [187, 203, 213, 241]. The conclusions presented would highly benefit future research employing a representative survey that manages to engage with hard-to-reach groups, including the groups identified in this study in the list of municipalities of Appendix B.

Given our time constraints, we used Microsoft Teams and Word to transcribe interviews. This could have altered the meaning of some paragraphs, as the software separates sentences. However, to mitigate this, we followed good practices and procedures for thematic analyses [255]. For example, two researchers coding interview transcripts in parallel found similar interpretations. Moreover, peer debriefing was applied throughout the data treatment and analysis process to assure sound coding

practice and inter-coder reliability.

Future intersectional energy justice studies can apply our framework (Figure 1) in different contexts to understand the role of context and analyze the framework over time to assess policy effectiveness. Energy justice can have different meanings other than the three identified vulnerabilities. For example, Mejía-Montero *et al.* [182] focused on individual and collective views on justice in Zapotec Indigenous communities in Southern Mexico, where wind turbines have been installed. Their study reveals the importance of including care of birds and bats and a more collective ownership model in the concept of energy justice [182]. We think special focus must be given to municipalities hosting large-scale energy projects like wind farms in the Netherlands and elsewhere. Another study combined feminist gender studies with socio-technical transition frameworks to study the evolution of just transitions over time in Kenya, Canada, and Spain [188]. This study conceptualizes just transitions in terms of the diversity of perspectives incorporated in the transition [188]. We recommend that future longitudinal studies apply our framework along the energy transition stages to assess the progress of just transitions. Furthermore, future studies can combine qualitative with quantitative approaches [256] to provide a more comprehensive overview of intersectional energy injustices.

3.6. Conclusion: Towards the operationalization of just transitions

We conducted a case study in the Rotterdam-Den Haag energy region (RES-RDH) to: I) Identify energy vulnerabilities in a regional transition context, II) understand what citizen groups experience them and why, and III) identify barriers that prevent policies from engaging with these groups in regional transitions. We met these objectives by analyzing stakeholders' interviews and newspaper articles with a qualitative thematic analysis drawing from theoretical perspectives on intersectional energy justice and governance. First, the findings show that citizen groups can be vulnerable in the energy transition context in three main ways: i) By being unable to afford energy bills; ii) by lacking access to clean-energy technologies, and; iii) by not being included in public decision-making processes. Second, the groups prone to being vulnerable share one or more vulnerability conditions (see Figure 1). Third, we overview the barriers to engaging vulnerable groups in Section 4.2 and suggested policy recommendations to address them: A representation of vulnerable citizens in decision-making, designing intersectional energy policies targeting vulnerable groups, strengthening of municipalities, and a more active role of energy regions. These empirical findings can be considered to some extent generalizable to other Dutch and Western urbanized regions (formal and informal), as similar vulnerability issues and groups have been reported [244].

Our findings contribute to just transitions literature by presenting a case that confirms that citizen groups do not experience the costs and benefits of energy transitions equally. This supports the statement by Dubois & Meier (2016) that energy transitions are embedded in an unequal socio-economic system. An energy justice and intersectional lens in governance is required to identify and address inequality in energy

transitions. Therefore, we suggest that future studies and policies focus on operationalizing just transitions and consider societal intersections. For example, we think including vulnerable tenants and homeowner groups is necessary when evaluating the effectiveness of policies (e.g., focused on regulating the energy level if dwellings). Without an intersectional perspective, energy policies will continue to overlook the groups at higher risk of vulnerability.

Based on our results, we recommend municipalities engage with vulnerable groups by visiting them at home while sharing information in native languages (i.e., also in languages used by minorities), as this method has proven effective. Then, two-way communication methods like transdisciplinary tools [257] could be considered to foster participation and cross-learning with citizens. For example, municipalities could invite citizen representatives to jointly create a rich picture consisting of a drawing of the problem framing, which can help reach a shared understanding of the problem in a group setting [258]. External parties like social work agencies and welfare organizations may be helpful in cases where citizens lack trust in the government by intermediating discussions between citizens and the government. Although these organizations are already present in countries like the Netherlands, they need more outreach. Finally, regional governance can coordinate cross-municipal collaboration to exchange expertise, capabilities, and other (human and material) resources.

4

When does the energy transition impact household affordability? A mixed-methods comparison of fourteen coal and carbon-intensive regions

This chapter presents a comparison of fourteen CCIRs to identify the conditions that influence energy affordability. Three research fields, regional energy governance, energy justice, and sociotechnical transitions frameworks, were used to identify such conditions, their proxy indicators, and their relationship with energy affordability. This study addresses objective C, "Understanding what possible contextual conditions influence a region's transition pathway and the creation or correction of energy injustices". However, due to data constraints, the study is focused on energy unaffordability. By the end of this chapter, readers will have a comprehensive understanding of how the context, which goes beyond the realm of a sectoral energy transition, impacts not only the transition progress but also society.

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ABSTRACT

Understanding what conditions promote or hinder energy affordability in energy transitions is crucial for coal and carbon-intensive regions (CCIRs) dealing with the trade-off between phasing out fossil fuels and deepening social inequalities. While previous studies have included household and national-level conditions, this paper addresses the research gap covering regional-level conditions by drawing from regional energy governance, energy justice, and sociotechnical transition frameworks. A mixed-method approach consisting of a fuzzy-set qualitative comparative analysis and case-study analysis is applied to 14 CCIRs in Europe, Asia, and North America. Results show that energy affordability in CCIRs is influenced by combinations of regional and (inter)national conditions. Whereas the existing literature and transition policies do not differentiate between the CCI sector's transition type, this paper highlights that conditions underlying energy (un)affordability differ when the CCI sector is phased out or has the option to transition. Based on the findings, this study calls for a multi-level governance approach to alleviating and preventing energy unaffordability and recommends that policy mixes like the EU Just Transition Fund consider the different types of CCIR transitions.

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4.1. JUST TRANSITIONS AND ENERGY AFFORDABILITY IN COAL AND CARBON-INTENSIVE REGIONS

THE Intergovernmental Panel on Climate Change has recognized that energy transitions could worsen socioeconomic inequalities unless justice is embedded into their design [260]. This acknowledgment has contributed to increasing scholarly attention to just energy transitions [15, 33, 206, 261].

Energy affordability is a key dimension of a just energy transition and has received attention in two major energy justice frameworks. First, the tenets framework distinguishes among recognition of marginalized voices, distribution of benefits and losses, and procedural inclusion of diverse stakeholders in the energy transition [13, 15, 33, 146, 261–264]. Second, the classification of energy justice based on eight main dimensions: Affordability, availability, due process, information, sustainability, intragenerational equity, intergenerational equity, and responsibility [265–268].

Coal and carbon-intensive regions (CCIRs) are subnational territories with socioeconomic dependence on fossil-fuel sectors, which can cause or accentuate energy unaffordability when pursuing a low-carbon energy transition. CCIRs can be classified as upstream sectors where fossil fuel resources are extracted (e.g., coal mining, oil or gas extraction) or as downstream sectors where fossil fuels or fossil-fuel-generated energy are intensively used as input for industrial processes (e.g., steel production) [13, 269](p. 5). Energy transitions in CCIRs come with socioeconomic impacts, as jobs, livelihoods, and shared identity can be tied to the industrial sector [269, 270]. Thus, the transition or decline of CCI sectors may impact the energy affordability of households at the regional level, making just transitions particularly difficult to achieve in CCIRs. This challenge has received political attention around the world, for instance, in the European Union (EU) [91, 271] and Canada [272].

A regional governance level is necessary for the transition of CCIRs. Governance of energy systems refers to a collection of ways in which groups of (energy sector) actors, both formal and informal decision-makers, organize themselves and make decisions about the distribution of energy resources and provision of energy services [273, 274]. Energy governance is affected by decision-making bodies at different levels and with varying powers of decision-making, like the local (e.g., municipal), regional (e.g., provincial), national, and international levels (e.g., EU-level). Particularly, a regional governance level is essential to address regional transition challenges, like socioeconomic dependency on a fossil-fuel sector, which are not represented in national policies but are shared by multiple municipalities. Comparative studies have been conducted to understand the drivers of energy affordability in multiple cases. Qualitative Comparative Analysis (QCA) has been applied as a methodology for comparison as it can consider theoretical expectations in the analysis and capture the interdisciplinary, quantitative, and qualitative nature of transitions in a medium-size number of cases (N= 10-100) [275]. A few QCA studies have analyzed the drivers of energy affordability [276, 277].

Yet, two research gaps remain in the comparison of energy affordability [206, 262, 278]. First, although previous research has shown that geographic inequities entrenched in (regional) energy systems can cause injustices such as energy poverty [262], studies focusing on the latter have prioritized either household or national-level factors, leaving a disconnect with the regional scale [262, 265, 276, 277, 279]. To our knowledge, no peer-reviewed study has analyzed the causal relationship between macro- and mesolevel (or regional-level) conditions and energy affordability. Second, while the energy justice literature has differentiated between regional influence in the case of energy production and consumption [280], thus far, no study has explored upstream and downstream CCIRs [206]. Arguably, a key reason for these gaps and limitations is the logistical and methodological complexity of collecting data from numerous regional cases and systematically analyzing a large and varied dataset.

Therefore, to address those gaps, this study analyzes the meso- and macrolevel conditions that assumably influence energy affordability in fourteen CCIRs. We think the coverage of meso- and macrolevel conditions can improve one's understanding of energy affordability in CCIRs [281]. The contribution of this paper is twofold: theoretically, by identifying regional conditions that influence energy affordability, and empirically, by comparing energy affordability in different CCIR contexts, such as upstream and downstream regions [13]. Further, policymakers and practitioners in CCIRs could benefit from a better understanding of the possible impacts of transitions on affordability across different regions.

The paper is structured as follows: Section 2 introduces the theoretical framework and the selected conditions, followed by the research design and methodology section in Section 3. Section 4 presents the QCA solutions and discussion based on the qualitative case-study approach of three CCIR examples. Section 5 presents the conclusion and contribution of this study to relevant academic debates on the development of comparative methods and energy affordability alleviation policies. This section also presents limitations, a future research agenda, and policy recommendations.

4.2. Theoretical framework: Energy affordability and its conditions in CCIRs

Energy affordability has been defined as "the ability of households to purchase a necessary quantity of energy or level of energy services (to reach thermal comfort and to be able to fulfill daily activities) without suffering undue financial hardship" [177, 282]. It is the most commonly studied and operationalized dimension of energy poverty [283–285], a multidimensional construct also incorporating energy access and availability [286, 287]. Energy affordability has been measured with indicators [283–285].

The drivers for energy affordability can be categorized into aggregation levels, such as macrolevel (international and national), mesolevel (regional or subnational), and microlevel (household) (Dubois and Meier, 2016). Some commonly reported drivers for energy affordability are defined at the microlevel, such as household efficiency and

income, and at the macrolevel such as energy prices, energy services deprivation, and policies [177, 283, 288].

Previous QCA studies focused on energy poverty also covered macrolevel conditions such as gross domestic product, type of climate, energy prices to final consumers, energy poverty policies, and microlevel ones like household ownership status, education level, labor force status, household size, type of building, central heating system, and the presence of solar collectors and heat pumps [276, 277]. This study concluded that energy poverty arises from a combination of poor energy-inefficient households (microlevel) and labor market problems (macrolevel) [276]. Nonetheless, drivers at the meso- or regional level remain underexplored.

4.2.1. Conditions for energy affordability

A literature review was conducted to discern relevant conditions for energy affordability as dependent on selected conditions at the regional, national, and international levels. This review covered the main research domains related to energy justice [42] and energy poverty [265, 289] as overarching frameworks that explain energy affordability and sociotechnical transitions [98, 102, 196, 290] and regional energy governance [19, 291]. Moreover, findings from a research project that focused on the energy transition of CCIRs were considered to identify contextual conditions for energy affordability (reference to be provided upon acceptance).

CCIND: Regional economic independence from the coal and carbon-intensive sector

The first selected condition for the fs-QCA was regional economic independence from coal and carbon-intensive sectors [292]. CCI upstream sectors like coal mining and oil and gas extraction, and downstream sectors like the chemical industry and steel and cement production can be important to a region's economy. For example, employment in coal mining sectors can create new towns and cities. Still, dependency on the industry can also lead to a population decline once the sector shrinks or shuts down, as seen in the case of Carbonia, Sardinia, in Italy [293]. Upstream coal-mining regions are among the most negatively impacted by energy transitions due to potential job losses and economic decline [13, 91, 272]. These impacts can directly affect the socioeconomic well-being of households in the region, including energy affordability [292]. Similarly, regions dependent on downstream carbon-intensive economic sectors such as steel, chemical, or cement production may present a low level of economic diversification and, therefore, be negatively impacted when CCI sectors shrink as a result of a sectoral transition [13].

Regional diversification theories help describe the relationship between CCI sector economic independence and energy affordability. Indirectly, when a region is economically independent of a CCI sector, this may indicate that the region has more economic diversity than when a CCI sector is dominant in the region. However, this does not hold true when the region suffers high unemployment, outmigration, and other socioeco-

nomic struggles due to the decline of the CCI sector. These theories suggest that regions with higher economic diversity experience lower unemployment and more stable economic growth as more diverse economic sectors can absorb a sector's unemployment by another sector, if sectors do not fluctuate simultaneously [294]. Yet, economic diversity and growth do not have a linear relationship [294, 295]. Regional diversification studies also distinguish between economic diversity and diversification. The latter refers to the process of diversifying the economy [295], which is the case for transitioning CCIRs. Therefore, it can be hypothesized that a high degree of regional economic independence from the CCI sector increases the likelihood of households having energy affordability when the region undergoes a sectoral transition.

TECHFEA: TECHNICAL FEASIBILITY OF THE CCI'S SECTOR TRANSITION

The type of transition a CCI's sector follows impacts household energy affordability. According to transition studies and regional diversification theory, a region can experience related or unrelated diversification or an on-stream or off-stream pathway [188, 296]. Regional diversification can be related to existing sectors and institutions, also described as an 'on-stream transition pathway'; for example, when the same electric utility replaces coal-based with renewable-energy-based power generation with no significant changes in institutions and actors. Alternatively, diversifications can be unrelated to the previously dominant sector, for example, when the region shuts down coal mines and promotes tourism [296]. Related diversification and on-stream pathway transitions are the dominant approaches adopted in regions due to the transferability of capabilities, infrastructure, skills, and institutions. These on-stream pathway transitions have a lower risk of closing operations and causing unemployment. However, both types of diversification, related and unrelated, are needed for the long-term economic stability of a region because relying on related diversification can only lead to path dependency and lock-ins [296]. Thus, this hypothesis states that CCI sectors with the technical possibility to transition will affect less households' income and so energy affordability than CCI sectors that cannot find or develop the technical feasibility to transition.

DECARBONIZATION OF THE REGIONAL ENERGY SYSTEM

The level of decarbonization of the regional energy system can affect energy affordability. Deploying low-carbon/renewable energy technologies is necessary to phase out fossil-fuel-based power and heating generation. Without affordable alternatives for energy generation, energy prices can increase and affect households' energy affordability. For example, a study in the United Kingdom showed that a rapid energy system decarbonization does not necessarily help alleviate energy poverty [297]. Several studies have revealed that distributed generation from renewable energy sources is positively related to energy poverty alleviation in Western and majority world countries [298, 299]. A distributed energy system with renewable energy technologies may perform better on energy justice compared to a centralized energy system [300]. However, community ownership and incentives for low-income households are essential to bridge the energy poverty gap [267]. Thus, a high degree of decarbonization can lead to energy affordability if there is local energy ownership, but it can also affect energy affordability in regions where the costs of decarbonization are high and transferred to citizens.

INTERNATIONAL POLICY MIXES

A multi-level governance approach to the energy transition is required to meet and align objectives at different administrative levels [301]. Particularly, in CCIRs, external influences like energy market prices can halt a low-carbon transition, depending on the country's type of energy system, its technologies, and whether it is a net exporter or importer. For example, the 2022 natural gas price surges left many European residents with unaffordable energy bills due to the Russian-Ukraine conflict escalation commencing in February 2022. This international event clearly shows the impact that a fossil-fuel-dependent energy system can have on energy affordability.

In response, several countries (e.g., the Netherlands) issued and implemented policy mixes, including price compensations, subsidies, and energy caps [302, 303]. Additionally, the European Union launched the REPowerEU program in 2022, aimed at reducing members' dependency on Russian fossil fuel imports and boosting the adoption of renewable energy technologies by 2030 [304]. These policy mixes at the national and international levels can influence the course of regional energy transitions and impact (positively or negatively) households' energy affordability through energy prices, subsidies, etc. Therefore, it can be hypothesized that for (inter)national policy mixes to ensure a positive impact on energy affordability, they need to align with regional energy transition efforts and consider dimensions of energy poverty, for example, the EU-level energy poverty initiatives [208].

4.2.2. CONDITIONS AND THEIR PROXY INDICATORS

A list of four conditions that can lead to regional energy affordability was used as the theoretical framework for the fs-QCA. Three of these conditions are defined at the regional level, including the 1.1 level of CCI independence, 1.2 regional decarbonization level, and 1.3 technical transition feasibility of the CCI sector. The fourth condition is defined at the national and international levels, the 2.1 impact of (inter)national policy mixes in the regional energy transition. Other conditions like regional innovation, transition strategy, polycentricity, market competition, market price fluctuations, and an energy region's degree of polycentricity were initially considered but later disregarded to meet the maximum number of conditions and because some conditions do not have a straightforward logical relationship with energy affordability and others were considered less influential for our set of cases. The operationalization of each condition is described in detail in Figure 4.1.

4.3. MIXED-METHODS APPROACH: FS-QCA AND CASE-STUDY ANALYSIS

The most common methods to assess energy affordability are statistical analyses [283–285, 287]. For example, a recent study analyzed the conditions for energy and transport poverty using descriptive statistics and regression analysis of national surveys in four cases [305]. However, statistical analyses can have limitations when it comes to analyzing complex phenomena, including interdependence among variables, relatively large

Outcome (code)	Conditions (code)	Expected influence on the outcome
Energy affordability of households in the region Indicator: Percentage of household income spent on energy services (electricity and heating) at the regional level, median value from 2012 to 2022 (MEAFFO)	1.1 Level of regional economic independency from the CCI sector up to 2022 (CCIIND)	Positive: The more CCIIND, the more household energy affordability.
	1.2 Level of decarbonization based on the regional power generation, median value of 2012-2022 (DECA)	Positive: The more DECA, the more household energy affordability if there is local energy ownership.
	1.3 Degree of technical feasibility for the CCI sector transformation in the region up to 2022 (TECHFEA)	Positive: The more TECHFEA, the more household energy affordability.
	1.4 Level of positive impact of (inter)national policy mixes on the regional energy transition, up to 2022 (NATINTPOL)	Positive: The more NATINTPOL, the more household energy affordability.

Figure 4.1: Operationalization of dimensions with proxy indicators

case samples, difficulty in handling non-linear relationships, and the consideration of empirical or theoretical knowledge in the analysis. QCA is considered a robust method that can help understand the non-linear casual relationships between conditions and the outcome while considering theoretical assumptions in the analysis [306]. In particular, fuzzy sets (fs-QCA) are helpful in giving nuanced qualitative meaning to the values of variables or the membership of sets [275, 307].

A mixed-method approach was adopted to explore the relationships between conditions for energy affordability in CCIRs. Fs-QCA was chosen as it allows for a configurational analysis that combines qualitative and quantitative elements, intrinsic of just transition studies [275, 308–311]. Then, fs-QCA was combined with qualitative case study analysis to gain an in-depth understanding of causal relationships between conditions and the outcome. Fourteen cases and four conditions were selected to identify the configurations that lead to energy affordability, as described below. Next, the fs-QCA intermediate solutions (combinations of conditions linked with) were analyzed for high and low energy affordability and validated with three in-depth case studies. Finally, the findings were discussed according to current debates on energy affordability and poverty, especially concerning regional energy transitions.

4.3.1. Case selection

Cases were selected using a purposive sampling strategy [312]. A diverse range of cases representing seventeen CCIR contexts and variations in energy affordability was included. However, at a later stage, this number was reduced to fourteen due to a lack of accessible and consistent data. As presented in Figure 4.2 and Figure 4.3, four regions were non-European, and two were from majority-world countries (Mexico and In-

donesia); the rest covered regions recognized by the European Commission as CCIRs [13]. Nine regions had upstream CCI sectors, with seven coal mining and two oil extraction (Alberta and Northern Norway). The case of Northern Norway, up to 2022, had not started the exploration of oil resources, although the narrative for its exportation has been a highly disputed issue since 2008 [313]. Five regions are home to downstream carbon-intensive sectors such as steel production and power generation using fossil fuel energy sources.

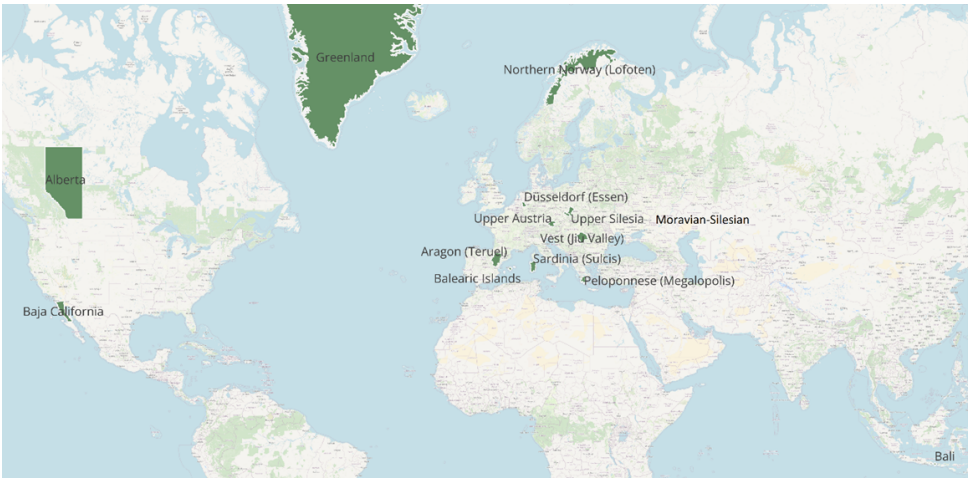

Figure 4.2: Map of the CCIRs included in the study.

4.3.2. Data selection

The assigned fuzzy values, presented in Figure 4.4, of three conditions were obtained from a research project on CCIRs and expert validation (conditions 1.1, 1.3, 1.4, and, for some cases, 1.2). For condition 1.2, public databases such as Eurostat and IEA were used mainly [36, 314–316].

Measuring energy affordability

The most used indicators for energy affordability are objective and composite indicators with or without weighing factors [283–285, 287]. The 10% energy expenditure threshold has been widely applied to measure the number of energy-poor households even though it fails to account for households with low energy consumption due to energy poverty [317, 318]. Some limitations of this indicator are that the 10% threshold is context-dependent, which was originally defined for the UK in the early 1990s, and that it does not show the income level of households [319]. Yet, the advantages of the 10% indicator are its relatively simple calculation, its ease to be communicated, and the availability of data for its calculation, which makes it accessible for case comparison studies [319]. Other indicators of energy affordability are minimum income standards (MIS), which calculates a household's net residual income after energy expenses and

Upstream CCIRs (Code: NUTS2, NUTS1)	Upstream CCI sector	Downstream CCIRs (Code: NUTS2, NUTS1)	Downstream CCI sector
CZ: Moravian-Silesian, Czech Republic	Coal mining	AT: Upper Austria, Austria	Coal consumption for steel production
DE: Düsseldorf (Essen and Duisburg), Germany	Coal mining	BES: Balearic Islands, Spain	Fossil fuel consumption for power generation
GR: Peloponnese (Megalopolis), Greece	Coal mining	IDN: Bali, Indonesia	Fossil fuel consumption for power generation
TES: Aragon (Teruel), Spain	Coal mining*	GREE: Greenland, Denmark	Oil consumption for back-up heating and power generation
IT: Sardinia (Sulcis), Italy	Coal mining	MX: Baja California, Mexico	Natural gas and diesel for power generation
NO: Northern Norway (Lofoten), Norway	Potential for oil extraction		
PO: Śląskie (Upper Silesia), Poland	Coal mining		
RO: Vest (Jiu Valley), Romania	Coal mining		
CA: Alberta, Canada	Oil extraction**		

Figure 4.3: CCIR cases included in the fs-QCA.
*Teruel region also has fossil-fuel-based power generation; however, only the evolution of the coal mining sector was considered in this study.
** Alberta's energy sector also largely relies on gas and coal; this study mainly considered the oil sector.

living costs [320], and the low income/high cost (LIHC) indicator, which considers a high/low income threshold of the 10% indicator. These two indicators, however, require additional data like household income level and living costs that can be difficult to collect.

The outcome' energy affordability' (MEAFFO) was measured as the median value from 2012 to 2022 of an average household's energy expenditure. Calculating the number of households in energy poverty (with energy expenditure over 10% of the household's income) as the standard indicator [317, 318] was not possible due to a lack of data. Thus, the values for an average household were obtained instead. The median value was chosen because it is less affected by the extremes and can better represent a non-symmetrical distribution than a mean value. However, a sensitivity test was performed by comparing the results using the median and the average outcome values, resulting in no difference. The formula for the outcome is shown in equations 1-3, where the household's energy consumption was considered an input variable. The total

household sector's energy consumption for electricity and heating at the NUTS-2 level was obtained from the 'Ffe' database, an independent energy research organization that calculated energy demand as described by Pellinger *et al.* [321] [321, 322]. The energy prices at the NUTS-1 or country level were gathered from the Eurostat database for the EU regions and official government websites for the other regions (see Appendix A). Since the energy consumption of 2017 (the median of the range of years) was available for all cases, this value was taken as fixed from 2012 to 2022. However, this can overlook a growing energy demand in the household sector.

However, some dimensions related to the affordability of energy services were not considered; for example, households' thermal insulation or access to efficient energy technologies [265, 285].

$$\text{MEAFFO} = \text{median}(x_i) \tag{eq. 1}$$

$$x_i = \frac{HEX_i}{HI_i} = \frac{\text{household's expense in energy services in year } i}{\text{household's income in year } i} \times 100\% \tag{eq. 2}$$

$$HEX_i = \sum_j \text{household\_energy\_demand}^{j}_{\text{NUTS-2,2017}} \times \text{energy\_price}^{j}_{\text{NUTS-1},i} \tag{eq. 3}$$

$$i = \{2012, 2017, 2022\}, \quad j = \{\text{coal, natural gas, oil, electricity}\}$$

4.3.3. Data analysis

The data analysis used the fs-QCA method to examine the complex relationships between the four conditions and energy affordability in transitioning CCIRs. The study was conducted using the fs-QCA 4.1 free software made available by the University of California [323], which allows for assessing necessary and sufficient conditions and solutions for the outcome of interest. QCA best practices were followed to strive for robustness and transparency: being transparent about the methodological steps to ensure reproducible research, specifically, providing information on the data calibration; being clear about methodological choices like consistency thresholds and selection of conditions; discussing how these choices influence the results, and; a being familiar with the cases, among others [311, 324].

First, data on the four selected conditions for all cases were prepared by converting the qualitative data into fuzzy set membership scores. For this step, each condition was measured with an indicator, as presented in Figure 4.4, and each indicator had between 3 and 4 possible levels. Each level received a fuzzy value ranging from 0 to 1, each with a different meaning. The fuzzy values were assigned according to their qualitative meaning and not to achieve variation among the cases as recommended [311].

Next, the fs-QCA analysis was performed to identify the conditions associated with the outcome of energy affordability (high as MEAFFO and low as meaffo). The sufficiency

Dimension	Indicator	Levels and related fs-QCA values	Fuzzy values
Outcome: energy affordability	Median of the percentage of household income spent on energy services (electricity and heating)	A. The percentage of household income spent on energy services over the last 10 years is less or equal to 3.33%. B. The percentage of household income spent on energy services over the last 10 years is between 3.33 and 6.66%. C. The percentage of household income spent on energy services over the last 10 years is between 6.66 and 9.99%. D. The percentage of household income spent on energy services over the last 10 years is equal or more than 9.99%.	A: 1.00 B: 0.66 C: 0.33 D: 0.00
Regional conditions	1.1 Regional economic independency from the CCI sector	A. The CCI sector has been closed or the employment contribution has decreased by 90% or more. B. The CCI sector is in the process of closing due to a binding policy and its employment contribution has decreased. C. The CCI sector has no binding plans to close but its employment contribution has decreased more than 10%. D. The CCI sector has no binding plans to close and its employment contribution has not decreased by more than 10%	A: 1.00 B: 0.80 C: 0.40 D: 0.00
	1.2 Decarbonization of the regional energy system	A. More than 40% of the regional electricity consumption comes from renewable sources. B. More than 30% and less than 40% of the regional electricity consumption comes from renewable energy sources. C. More than 20% and less than 30% of the regional electricity consumption comes from renewable energy sources. D. Less than 20% of the regional electricity consumption comes from renewable energy sources.	A: 1.00 B: 0.80 C: 0.60 D: 0.00
	1.3 Technical feasibility for the CCI sector transformation in the region	A. Low-carbon energy sources are available and have been proven (e.g.. steel industry going from coal to hydrogen). B. More than 2 options are available but have not been explored. C. Less than 2 options are available but have not been explored (e.g.. oil wells with geothermal potential). D. No options are available to explore or not feasible (e.g.. coal mines where geothermal energy cannot be used).	A: 1.00 B: 0.70 C: 0.30 D: 0.00
(Inter)national conditions	2.1 Policy mixes at the national and international level	A. There are binding international or national policies promoting an energy transition that the region has already met. B. There are binding international or national policies promoting an energy transition that the region has to meet eventually. C. There are international or national policies promoting an energy transition but they are not binding for the region. D. There are no international nor national policies promoting an energy transition.	A: 1.00 B: 0.70 C: 0.40 D: 0.00

Figure 4.4: Generation of fuzzy values for the outcome and conditions

and consistency of the prime implicants were then assessed to determine their robustness and relevance. The tied prime implicants found for low affordability are presented in 4.9. All conditions were assumed to be positively associated with high affordability. This directionality was considered in the intermediate solution computation. The results were interpreted using set-theoretic logic, examining the combination of conditions that led to the outcome and the degree of coverage and consistency achieved by the identified configurations [310]. A raw consistency threshold of 0.8 was used as the cut-off point to determine the presence of the outcome. This means that whenever the combination of conditions (row) has a raw consistency equal to or higher than 0.8, MEAFFO gets a score equal to 1, and 0 otherwise. Then, each condition's degree of necessity and sufficiency was identified, and the results were presented using truth tables and logical remainders. A case-study analysis was performed to validate the fs-QCA results and improve the robustness of QCA results [281]. Specifically, solutions for high and low affordability were analyzed in-depth to discuss potential inaccuracies from the QCA approach.

4.4. Conditions for energy affordability in CCIRs: Fs-QCA and case study results

The fuzzy values for the outcome ranged from 0 to 1, as shown in Tables 3, 4, and Appendix A in more detail. Eleven cases received high energy affordability values (MEAFFO), whereas three received low values (meaffo). Results from the fs-QCA reveal potential synergies and trade-offs between the conditions of the research model are presented in Figures 4.7 4.8 4.9 4.10. None of the conditions proved individually necessary nor sufficient for high or low regional energy affordability (see Figures 4.8 4.10).

Figure 4.6 4.8 show the truth tables when the outcome is present and absent, respectively. The rows in the truth tables show the logical remainders, which describe the possible combinations of conditions that are sufficient or not for the outcome. These results present the relationships between the combinations of conditions with assigned cases and the outcome. The combinations of conditions are sorted from the highest to the lowest raw consistency value.

Figures 4.7 4.9 represent the standard analysis with the complex, parsimonious, and intermediate solution terms for the fs-QCA when the outcome is present and absent, respectively. Although the three solutions terms are discussed, more attention can be paid to the intermediate solution because it considers the theoretical framework's assumptions presented in Section 2. The complex solution term shows the combination of conditions, considering the pool of cases. The parsimonious solution shows the minimal combination of conditions after performing a logical minimization [275, 325]. Finally, the intermediate solution terms are presented in the lower section of Figures 4.7 4.8. For this solution, no tied implicants were found. In this framework, a primary assumption is that each condition positively associates with the outcome, as described in the intermediate solution. All tied implicants of Figure 4.9 were kept because they were all considered plausible.

Coal and carbon-intensive region	Outcome Household's energy affordability	Level of CCI sector independence (CCIND)	Level of decarbonization (DECA)	Transition's technical feasibility (TECHFEA)	Support from (inter)national policies (INTNATPOL)
	High-energy affordability (MEAFFO)				
Upper Austria (AT)	0.66	0.00	1.00	0.70	0.70
Bali (IDN)	0.66	0.00	0.00	0.70	0.70
Düsseldorf (DE)	1.00	1.00	0.00	0.00	1.00
Baja California (MX)	0.66	0.00	0.60	1.00	0.70
Balearic Islands (BES)	1.00	0.80	0.00	1.00	0.70
Teruel (TES)	0.66	1.00	1.00	0.00	1.00
Sulcis (IT)	1.00	1.00	0.80	1.00	1.00
Lofoten (NO)	0.66	1.00	1.00	1.00	1.00
Upper Silesia (PO)	1.00	0.80	0.00	0.70	0.70
Jiu Valley (RO)	0.66	0.80	0.00	0.00	0.00
Alberta (CA)	1.00	0.00	0.00	0.70	0.70
	Low-energy affordability (meaffo)				
Megalopolis (GR)	0.33	0.80	0.80	0.30	0.70
Greenland (GREE)	0.33	0.40	1.00	1.00	0.00
Moravian-Silesian (CZ)	0.33	0.80	0.00	0.00	0.70

Figure 4.5: Regional cases, fuzzy values of their outcome (regional energy affordability) and four conditions (CCIND, DECA, TECHFEA, and INTNATPOL).

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CCIND	DECA	TECHFEA	INTNATPOL	MEAFFO	Cases	raw consist.	PRI consist.	SYM consist
1	0	1	1	1	CZ(0.70) DE(1.00)	1.00	1.00	1.00
0	0	1	1	1	GR(0.70) TES (1.00)	0.98	0.97	1.00
0	1	1	1	1	CA(0.70) IDN (0.70)	0.97	0.94	1.00
1	1	1	1	1	BES(0.70) PO(0.70)	0.84	0.77	1.00
1	0	0	1	1	AT(0.70) MX(0.60)	0.83	0.78	0.79
1	1	0	1	0	IT(0.80) NO(1.00)	0.58	0.31	0.49
1	0	0	0	1	RO(0.80)	0.91	0.82	1.00
0	1	1	0	1	GREE(0.60)	0.81	0.00	0.00
0	0	0	0		No cases			
0	1	0	0		No cases			
1	1	0	0		No cases			
0	0	1	0		No cases			
1	0	1	0		No cases			
1	1	1	0		No cases			
0	0	0	1		No cases			
0	1	0	1		No cases			

Figure 4.6: Truth table for the presence of the outcome MEAFFO = f(CCIND, DECA, TECHFEA, INTNATPOL).

MEAFFO = f(CCIND, DECA, TECHFEA, INTNATPOL)	Raw coverage	Unique coverage	Consistency	Cases with greater than 0.50 membership in term
Complex solution				
TECHFEA*INTNATPOL	0.61	0.43	0.93	IT (1.00), NO (1.00), PO (0.70), CA (0.70), BES (0.70),IND (0.70), MX (0.70), AT (0.70)
CCIND*~DECA*~TECHFEA	0.25	0.20	0.80	DE (1.00), CZ (0.80), RO (0.80)
~CCIND*DECA*TECHFEA	0.18	0.03	0.85	AT (0.70), GREE (0.60), MX (0.60)
frequency cutoff: 1 consistency cutoff: 0.81				
solution coverage: 0.84 solution consistency: 0.86				
Parsimonious solution				
~DECA	0.65	0.26	0.83	CZ (1.00), DE (1.00), PO (1.00), RO (1.00), CA (1.00), BES (1.00), IDN (1.00)
TECHFEA	0.67	0.28	0.82	IT (1.00), NO (1.00), PO (0.70), CA (0.70), BES (1.00), GREE (1.00), MX (1.00), AT (0.70), IND (0.70)
frequency cutoff: 1 consistency cutoff: 0.81				
solution coverage: 0.93 solution consistency: 0.77				
Intermediate solution				
Assumptions: CCIND (present) DECA (present) TECHFEA (present) INTNATPOL (present)				
CCIND*~DECA	0.40	0.22	0.87	DE (1.0), CZ (0.80), PO (0.80), RO (0.80), BES (0.80)
DECA*TECHFEA	0.34	0.03	0.76	NO (1.00), IT (0.80), GREE (1.00), AT (0.70), MX (0.60)
TECHFEA*INTNATPOL	0.61	0.16	0.93	IT (1.00), NO (1.00), PO (0.70), CA (0.70), BES (0.70), IND (0.70), AT (0.70), MX (0.70)
frequency cutoff: 1 consistency cutoff: 0.81				
solution coverage: 0.86 solution consistency: 0.83				

Figure 4.7: Standard Analysis of the fs-QCA: Complex, parsimonious, and intermediate solutions for high energy affordability (MEAFFO).

CCIND	DECA	TECHFEA	INTNATPOL	number	cases	raw consist.	PRI consist.	SYM consist
1	1	0	1	2	CZ(0.70) DE(1.0)	0.59	0.33	0.52
0	1	1	1	2	GR(0.70) TES(1.0)	0.59	0.00	0.00
1	0	0	1	2	CA(0.70) IDN(0.70)	0.40	0.20	0.21
0	0	1	1	2	BES(0.70) PO(0.70)	0.37	0.00	0.00
1	1	1	1	2	AT(0.70) MX(0.60)	0.31	0.00	0.00
1	0	1	1	2	IT(0.80) NO(1.00)	0.11	0.00	0.00
0	1	1	0	1	RO(0.80)	1.00	1.00	1.00
1	0	0	0	1	GREE(0.60)	0.53	0.00	0.00
0	0	0	0	0	No cases			
0	1	0	0	0	No cases			
1	1	0	0	0	No cases			
0	0	1	0	0	No cases			
1	0	1	0	0	No cases			
1	1	1	0	0	No cases			
0	0	0	1	0	No cases			
0	1	0	1	0	No cases			

Figure 4.8: Truth table for lower energy affordability: meaffo = f(CCIND, DECA, TECHFEA, INTNATPOL).

~MEAFFO = f(CCIND, DECA, TECHFEA, INTNATPOL)	Raw coverage	Unique coverage	Consistency	Cases with greater than 0.5 membership in term
Complex solution				
~CCIND*DECA*TECHFEA*~INTNATPOL	0.35	0.35	1.00	GREE (0.60)
frequency cutoff: 1.00 consistency cutoff: 1.00				
solution coverage: 0.35 solution consistency: 1.00				
Parsimonious solution				
~CCIND*~INTNATPOL	0.52	0.10	0.75	GREE (0.60)
DECA*~INTNATPOL	0.39	0.00	0.83	GREE (1.00)
TECHFEA*~INTNATPOL	0.46	0.00	0.60	GREE (1.00)
frequency cutoff: 1.00 consistency cutoff: 1.00				
solution coverage: 0.56 solution consistency: 0.65				
Tied implicants: ~CCIND~INTNATPOL DECA~INTNATPOL TECHFEA~INTNATPOL				
Intermediate solution				
Assumptions: ~CCIND (absent) ~DECA (absent) ~TECHFEA (absent) ~INTNATPOL (absent)				
~CCIND*~INTNATPOL	0.52	0.52	0.75	GREE (0.60)
frequency cutoff: 1.00 consistency cutoff: 1.00				
solution coverage: 0.52 solution consistency: 0.75				

Figure 4.9: Standard Analysis of the fs-QCA: Complex, parsimonious, and intermediate solutions for low energy affordability (meaffo).

4.4.1. Interpreting fs-QCA results with qualitative case study validation

According to the complex and intermediate solutions, CCIRs' (low or high) energy affordability does not depend on only one condition but rather on combinations of the four conditions. A case study validation effort was made to understand the nuances of fs-QCA results. An overview of fs-QCA results and case study validation for high and low energy affordability is presented in Figure 4.10 and interpreted in the following sub-sections.

According to the complex and intermediate solutions presented in Figure 4.7, CCIRs' high energy affordability appears to be associated with the technical feasibility of an energy transition and support from (inter)national policy mixes. When present, this configuration was linked with high energy affordability for four upstream regions, Sulcis (IT), Upper Silesia (PO), Lofoten (NO), and Alberta (CA), and four downstream regions, Balearic Islands (BES), Upper Austria (at), Bali (IDN), and Baja California (MX).

The complex and intermediate solution terms shown in Figure 4.9 overlap with two conditions for low energy affordability. These are a low level of independence from the CCI sector and little or no support from (inter)national policies. Moreover, the complex solution also includes a high level of decarbonization and technical feasibility. The model with four conditions only converged for Greenland, one of the three CCIRs assessed with low energy affordability. Megalopolis (GR) and Moravian-Silesian (CZ) were not described by the model and required consistency values.

Case study validation of high energy affordability: When the CCI sector's transition is technically feasible

Two CCIRs were selected to dive deeper into the meaning of the fs-QCA results for high energy affordability. In Baja California (MX), the downstream carbon-intensive sectors mainly operate gas and diesel-fired power generation, while in Alberta (CA), oil and gas extraction represent the upstream carbon-intensive sectors. A similarity observed between these North American regions is their relationship with the United States' natural gas market. While Baja California (MX) imports natural gas from the United States, the latter is Alberta's (CA) most important trading partner, importing a large portion of its natural gas.

The technical feasibility of the CCI sector's low-carbon energy transition (1.3 TECHFEA) was associated with high energy affordability in transitioning CCIRs. This condition indicates that the sector's transition is technically feasible because these regions have one or more clean energy sources available to replace fossil fuels. In the case of Baja California (MX), the technical feasibility is related to the local availability of renewable energy sources to replace fossil fuel (natural gas and diesel) power generation. In this region, renewable energy-based power generation has a median value of around 27% of the total regional power generation from 2012 to 2020 (own calculation based on official data), with geothermal energy the most utilized renewable energy source [326, 327]. Renewable energy development in Baja California (MX) is market competitive,

Coal and carbon-intensive region	fs-QCA solution terms	Qualitative case study validation
High energy affordability (MEAFFO)		
Four upstream regions: Sulcis (IT) Lofoten (NO) Alberta (CA), and Upper Silesia (PO). Four downstream regions: Balearic Islands (BES) Upper Austria (AT) Baja California (MX) and Bali (IDN).	The complex and intermediate solutions agree on the presence of two conditions for high energy affordability: 1.3 Technical feasibility of the CCI's sector transition (TECHFEA). 1.4 Support from the (inter)national policy mixes to the regional transition (INTNATPOL).	Case study validation reveals 1.3 Technical feasibility as the most relevant condition for high energy affordability in downstream regions. The example of fossil-fuel-based power generation in Baja California, Mexico: High energy affordability in Baja California can be due to a highly subsidized energy bill. There are top-down, multi-level governance efforts for the transition. However, the national transition agenda is unclear and binding at the regional level. Yet, renewable energy sources are available in the region, and their prices are competitive. They could help avoid or loosen natural gas lock-ins. The chosen average household energy affordability indicator did not accurately reflect the high energy poverty levels previously reported in Alberta. Alternatives to transition the oil and gas sector in Alberta, Canada, exist but are not yet commercially viable or competitive. Decarbonization policies in Canada fall short of driving a sustainable transition in the oil and gas sector, and they do not cover household affordability issues.
Low energy affordability (meaffo)		
One downstream region: Greenland (GREE).	The complex (with higher consistency) and intermediate solution terms agree on two conditions for low energy affordability: 1.1 A low level of CCI sector independence (~CCIND). 1.4 Little support from the national and international policies for the energy transition of Greenland (~INTNATPOL). The complex solution also includes: 1.2 A high level of decarbonization (DECA). 1.3 Technical feasibility for the transition (TECHFEA).	Case study validation reveals lack of condition 1.4 Support from international policies as Greenland's most relevant condition for low energy affordability. The CCI sector in Greenland is based on fossil-fuel imports for heating and electricity generation. Greenland is highly dependent on the CCI sector. High energy import prices are reflected in energy bills. International policies have promoted oil exploration, while the local government wants to follow social and sustainable development.

Figure 4.10: Comparison of findings from the fs-QCA and case study approach.

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especially since the levelized cost of electricity (LCOE) of geothermal and wind energy has proven competitive compared to highly efficient gas-fired power plants [88, 328]. However, the region's share of renewables decreased over the last decade despite its widespread but underutilized energy sources [88]. The consequences of relying on natural gas were perceived in 2022, when the Electricity Federal Commission (CFE), the Mexican state-owned electric utility, and TSO, reported a 19% increase in energy costs due to natural gas price fluctuations [48, 329].

In the case of Alberta (CA), technical feasibility is related to the potential to repurpose Alberta's idle oil and gas wells with geothermal energy for heating [330]. However, this technology is in the early research phase. Currently, the region lacks economic feasibility as well as any political and policy support whilst lacking an immediate transitioning strategy for the CCI sector [330]. According to the province's electric system operator, the LCOE of renewables in Alberta (CA) is reported to be significantly lower than coal and natural gas. Yet, capital investments in oil and gas continue, amounting to CAD 18 billion alone in 2021 [331].

The second condition of the solution term is 1.4 INTNATPOL, meaning that national or international policy mixes supporting the regional energy transition positively impact energy affordability. In Mexico, national policies on energy poverty focus on achieving households' energy efficiency by supplying energy-efficient electrical appliances and lighting [332]. Although this measure is considered to have effectively decreased households' energy consumption [333], it may overlook the needs of households with extra low consumption levels [265]. The governmental effort that has greatly impacted household energy affordability is the national subsidy on the electricity tariffs for the residential sector, with a yearly median spending of €4562 MEUR in the last ten years [334]. However, several empirical studies have revealed that electricity subsidies fail to reach households suffering from higher rates of energy poverty, and instead, most of the subsidies are consumed by the wealthiest people [265].

Moreover, the Mexican Federal Commission of Electricity has reported these subsidies as economically unsustainable over the last decades [282, 335]. Generally, Mexican energy transition policies at the national level failed to address energy poverty directly [336], even more so at the regional level. The Baja California State's Energy Commission has initiated a project to address energy poverty in the state in collaboration with research institutions [337, 338].

In Canada, national policies do not formally recognize energy poverty as an issue, even though between 6% and 19% of households live in energy poverty [339]. Energy poverty awareness also varies between Canadian provinces. As a relatively wealthy province and large energy producer, energy poverty in Alberta was more seriously acknowledged in 2015 after the report - "Energy Poverty: An Agenda for Alberta" - was published. According to 2016 figures, one in seven families was considered energy-poor; however, the poorest households spent 14.9% of their disposable household income on energy costs, which was 8.1 times more than the wealthiest households [340].

Another aspect of policy mixes at the national and international level concerns the risk they pose of reinforcing carbon lock-ins when no transition policy targets the CCI sector particularly. While climate policies aim for decarbonization goals have been enacted in Canada and Mexico, these policies do not necessarily lead to the sustainable transformation of the CCI sectors. In Mexico, the Energy Transition Law aims for 35% and 50% of clean electricity generation by 2024 and 2050, respectively, whereas the General Law on Climate Change aims for a 50% GHG emission reduction by 2050 compared to the year 2000 [341, 342]. Although the goals can be ambitious, these policy mixes have not helped to overcome structural lock-ins that reinforce Baja California's (MX) dependency on natural gas for power generation. Alberta (CA) has policies to reduce carbon emissions for large industries and capping emissions in the oil sands, mainly through increased efficiency in production processes and carbon capture and storage [331]. However, these GHG emission reduction policies have not placed sufficient pressure to transform CCI sectors, so they fail to ensure the energy sector's decarbonization. Such an absence of CCI sector policies is also observed in the steel and iron industry in Upper Austria [343].

Our measure of energy affordability reflects the situation of an average household. According to the fuzzy value calibration described in Figure 4.4, all cases with average household spending of less than 6.6% of their income on heating and electricity were classified as experiencing high energy affordability. Since the outcome indicator (see equations 1-3) was based on the energy expenditure of an average household in the region, the results do not describe households experiencing more energy poverty. In the case of Baja California (MX), high energy affordability does not correspond to the sub-sections of the population spending significantly more due to higher energy tariffs or difficult access to energy services. In Mexicali, the capital city of Baja California (MX), around 35% of the household income was spent on electricity only for air conditioning due to temperatures surpassing 50°C in summer [344].

Furthermore, a 2020 survey revealed that 26,000 people lived in energy poverty in Baja California (MX) because they lacked access to electricity, mainly due to irregular land permissions [338]. In the case of Alberta (CA), energy poverty was reported as a major issue for 14% of households [340] and may even worsen due to high unemployment of 5.8% [331]. Among the previously described reasons are expensive energy services, low household income, high unemployment, and thermal-inefficient homes [340].

Although the CCI sector contributes to the region's economy, it may worsen energy poverty. The region's economic dependency on a still profitable CCI sector may offer jobs in the region, such as in the case of Alberta (CA). Alberta employed 138,000 people in its upstream energy sector, which remains lower than its peak in 2014. The province's oil and gas sectors are of key economic importance, contributing 72% of the revenues from non-renewable resources in 2021-2022 [331]. Notwithstanding its contribution to the region's wealth and household income, the oil sands sector may also contribute to energy poverty in Alberta (CA), as most energy poverty in Canada and Alberta is not

found among low-income households. A study revealed that 7.5% of low-income and 13.4% of non-low-income households are in energy poverty, based on how many households struggle to pay their energy bills [345]. For this reason, the present study's fs-QCA study's measure of energy affordability in Alberta must be cautiously interpreted to consider contextual conditions in the province, as these results may be misused to counteract local efforts to raise awareness of energy poverty experienced by a growing number of households.

Case study validation of low-energy affordability: international policies hindering CCIRs energy transitions.

To discuss the configuration of conditions for low energy affordability (meaffo), the case Greenland (GREE) was selected for further elaboration because it was the only one covered by the standard analysis (see Figure 4.9). The fs-QCA results partially describe the relationship between conditions and low energy affordability, for which our outcome formula calculated 7.3% of household income spent on energy services. The complex and intermediate solution terms agree on two conditions for low energy affordability: a low level of CCI sector independence (C̃CIND) and little support from national and international policies for the energy transition of Greenland (ĨNTNATPOL). Additionally, the complex solution contains a high level of decarbonization and technical feasibility for the transition.

The CCI sector in Greenland (GREE) has declined over the last decade (2012-2022); however, its participation in the energy system remains significant. The CCI sector in Greenland (GREE) imports diesel oil for backup heating and power generation, especially in the areas with no hydroelectric energy projects [346]. In 2020, Greenland (GREE) produced 70% of its energy (electricity and heating) for the public sector's consumption from renewable energy sources, such as hydropower 66% and waste 4%, and small-scale wind and solar energy generation [347]. Yet, 30% and 56% of energy generation for the public and private sector was fossil-fuel-based, with diesel oil as the primary source. Diesel oil is imported from abroad, which the Greenlandic energy utility, Nukissiorfiit, reports as expensive. For this reason, the utility is looking for a replacement with local renewable energy sources (Ibid). The high diesel costs threaten the ability of communities in Northern Greenland to afford food and housing [346]. In general, the energy system's dependence on diesel negatively impacts the energy affordability of Greenlandic people.

The last condition for Greenland's energy affordability is the alignment of (inter)national policy mixes and the regional transition strategy. Greenland (GREE) presents one of the few cases where the energy policy mixes at the international level do not support the regional-level energy transitions. Instead, international policies and global trends promoted oil exploration on the island for exportation purposes [348]. This opposes the Government of Greenland's efforts to become economically independent and achieve social and sustainable development [120]. In 2021, the new Government of Greenland banned oil drilling for environmental and financial reasons [349]. Here, international policy mixes counteract support for regional transition; in fact, they hinder the development of local renewable energy projects and indirectly negatively impact energy

pricing.

4.5. Discussion and conclusion: The impact of regional energy transitions on household affordability

This study analyzed the relationship between regional, national, and international conditions and energy affordability of 14 CCIRs in Western and majority world countries. Overall, the analysis confirmed the influence of the four selected conditions on affordability. Contextual differences between the regions may be why none of the four conditions resulted as necessary or sufficient for energy affordability. Yet, the fs-QCA model converged, so it could reveal the combinations of conditions that are associated with energy affordability. Furthermore, our cases confirmed the theoretical expectations for energy affordability described in Section 2. An important finding of this study is the distinction of conditions for regions phasing-out or transitioning the CCI sector.

This study shows the importance of certain regional conditions, which had not been included in previous energy affordability studies. The conditions associated with energy affordability for upstream and downstream CCI regions were the regional sector's technical feasibility to transition and the alignment with the (inter)national policies. The presence of a high degree of a region's independence from the CCI sector was observed when there was no technical feasibility to transition. These regional conditions are key to understanding energy affordability in energy regions, especially in CCIRs.

Additionally, a sector's technical feasibility to transition appears to be associated with affordability in transitioning CCIRs. These results differ with most regions phasing-out coal, except for regions like Sulcis and Upper Silesia, which consider CCS or CCT for the sector's transition. The terms phasing-out (with no technical feasibility) and transitioning CCIRs (with technical feasibility) can be employed to distinguish between these regions. One could conclude that if a carbon-intensive sector does not have alternatives to decarbonize, it might risk a decline if a low-carbon regional transition strategy is adopted. Furthermore, upstream regions like oil sands and downstream regions like fossil-fuel-fired power sectors can be part of a slow-paced energy transition, also referred to as an on-stream transition pathway [188], since there is no evidence of a transformative policy for the CCI sectors in these regions.

Regional and (inter)national conditions were always combined in all fs-QCA results, highlighting a multi-level governance nature of energy regions. This suggests that it may be necessary for policymakers to synchronize an energy transition strategy with regional economic development plans to avoid negative socioeconomic impacts during the CCI sector's transition or phase-out. This is in line with results from a study by Kern and Rogge [350] who found that it is important to align sectoral plans with (inter)national transition policies. This was also observed in the Greenland region case, where international policies were found to support oil exploration, posing a carbon lock-in risk in the

region. It is important to note that transition policies may negatively impact affordability in the long term if they overlook regional challenges like carbon lock-ins or energy poverty, as also concluded in a previous study [279]. Therefore, it should be considered that national and regional levels of government coordinate their strategies to combat energy poverty and avoid path dependencies. This applies to both the EU and non-EU regional cases studied [351].

4.5.1. LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The indicator measuring an average household's energy affordability can indicate energy poverty when most of the population is affected, or a section of the population is severely affected, but not when there is a high level of economic inequality. Thus, future studies on energy poverty should consider not only affordability but also accessibility and household-level conditions [265]. For a more comprehensive analysis of just transitions, it is suggested that dimensions like recognition, procedural, and distributional justice be included. As the data required to capture energy poverty and justice are typically quantitative and qualitative, adopting a fs-QCA research approach with expert validation can be handy, as shown in this study. Future studies can analyze other conditions of carbon-intensive industries. For instance, fossil fuel subsidies, often indirectly funded by taxpayers, were not included as the energy prices for electricity and heating available in public databases like Eurostat do not consider such subsidies. Yet, it is worth analyzing the impact of these subsidies in countries with high energy subsidies, like Indonesia and Mexico [282]. Additionally, different factors need to be considered for relatively wealthy regions, like the impact of high unemployment and the costs and quality of housing stocks, which impact energy affordability differently across income groups [340].

Access to comprehensive databases at the regional level for case studies from different parts of the world is an important constraint. Another way to achieve variability may be to compare regions within the same country with high data availability. An assumption in QCA is that the conditions must be identified before the analysis, or the QCA needs to be run iteratively. An approach to offset this limitation is to apply fs-QCA ex-ante and ex-post to a (limited) number of case studies where verification can still be feasible, with the possibility for adjustment during the study.

The major policy implication of these findings lies in the need for energy poverty alleviation policies to consider the contextual differences between phasing-out and transitioning CCIRs. The EU Just Transition Fund offers the same resources to all CCIRs indistinctively. This programme encourages CCIRs to tackle energy poverty using bottom-up strategies (territorial just transition plan) that each region oversees [352]. In return, some CCIRs may not easily embark on a just transition pathway because their challenges go beyond what a regional transition strategy or program may attain. This may be due to the availability of low-carbon energy sources and technologies, market rules, global energy prices, or (inter)national policies. Therefore, regional strategies should be supported by a multi-level governance and cross-sectoral economic development approach, not only through funds. Furthermore, if the Just Transition Mechanism enables cross-learning

between similar CCIRs, their strategies might become more effective. Besides the industry similarity, the temporality of each region's transition is also essential to consider when clustering regions, as the challenges they face may be related to the transition stage.

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ENERGY JUSTICE AND CITIZENS' WILLINGNESS TO PARTICIPATE: A DISCRETE CHOICE EXPERIMENT IN A MEXICO-UNITED STATES CROSS-BORDER REGION

This chapter analyses what types of governance arrangements and justice conditions would motivate citizens, including vulnerable groups, to participate in a regional energy transition. The applied method is a Discrete Choice Experiment (DCE) of a representative sample in a US-MX cross-border region. It begins with an overview of the theoretical foundations of citizen participation, governance arrangements, and energy justice, which helped select three attributes and their possible of values. The analysis considered three types of participation and measured the impact of including justice factors in citizens' participation. Results reveal citizens' preferences on energy projects, which provide insights into the type of governance arrangements that would incentivize diverse citizens to get involved. Thus, this study helps address objective D "Understanding what institutional arrangements can be formed in energy regions to achieve social inclusion and advance the low-carbon transition". By the end of this chapter, readers will gain an understanding of trade-offs citizens perceive when deciding to participate in a transition or sustainable development plan and what groups are more prone to becoming local leaders.

An article based on the information presented in this chapter is under review

ABSTRACT

Socio-economic inequalities hinder citizen participation in regional energy transitions. To address this, policymakers should prioritize energy justice and the citizens' level of knowledge. While justice-driven policies may enhance participation, this assumption remains untested. This study examines whether citizens are more inclined to participate in projects that consider justice factors or not. The methodology follows a discrete choice model survey (N = 768) in the Mexico-US cross-border region. This experiment used the Multinomial Logit Model and Latent Class choice model to identify preference variations across groups. Findings show that citizens, especially disadvantaged groups and youth, are more willing to participate in energy transition programs that consider justice aspects related to the distribution of benefits in the form of energy affordability and access, and a decentralized and citizen-inclusive decision-making process. Our findings verify that considering justice in energy transition programs can improve citizen participation, especially of disadvantaged groups and youth.

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5.1. INTRODUCTION

TRANSITION processes to achieve the energy system's decarbonization may create or exacerbate inequalities if special attention is not given to vulnerable groups experiencing energy injustices [203]. Studies have shed light on the importance of diversifying economic and decision-making power among organizations and citizens for the energy transition to address injustices [353–356]. Western countries tend to rely on formal institutions to aim to resolve socio-economic inequalities and socio-cultural tensions that emerge during the transition while addressing climate change mitigation targets; some related concepts are just transitions and energy democracy [15, 20]. It is believed that to address energy injustices, vulnerable groups have to participate or be represented in the energy transition, as their preferences, needs, and experiences are essential to understanding injustices [15]. Conceptualizations of energy justice in decolonial contexts, like in Latin America, recognize that unsustainability and injustices have been embedded in the energy system and formal institutions since colonization times [357]; some associated concepts are energy sovereignty and autonomy [35, 358]. Therefore, problematizing and addressing energy justice depends on the case context, yet both approaches recognize vulnerable groups and the moral need to repair injustices.

However, the involvement of vulnerable groups in energy governance has been challenging because of obstacles in the communication between decisionmakers and citizens [51, 52, 359]. Some of these barriers on the citizens' side are: a) limited knowledge of energy transition strategies, their potential impacts, and the roles that they could have in the transition; b) different interests, needs, and views than what the energy transition represents, and c) limited time availability to participate in engagement activities. Whereas on the decisionmakers side, some identified obstacles are: a) lack of knowledge on how to reach these groups; b) limited understanding of what roles citizen groups may be interested in taking in the transition; and c) limited funding and time availability to effectively reach diverse citizen groups. Although studies have identified numerous barriers to the involvement of vulnerable groups, little knowledge is available on what can motivate these groups to participate.

The knowledge gap addressed in this study is understanding what energy project characteristics and governance arrangements associated with justice would increase citizens' (including vulnerable groups) willingness to participate in the energy transition. Citizens' perception of energy projects influences their relationship with projects [16]. When project characteristics are perceived as (un)just, certain psychological traits (un)favoring acceptance are evoked. For example, a local-scale energy project can evoke trust due to locality and place attachment [360]. Other traits that can promote acceptance, as well as possible willingness to participate, are a sense of ownership [361], effortless participation [362], and the alignment of citizens' and project values [92]. Particularly, in a decolonial context, Indigenous values, knowledge, and authority representation determines how citizens approach projects (supporter, opponent, other) [92, 357].

According to studies on social acceptance of renewable energy and justice perception,

the perception of fairness in energy projects can lead to citizens' support [16, 363]. Wüstenhagen et al., 2007 describe social acceptance in terms of three pillars, namely socio-political, market, and community acceptance. They state that the latter is influenced by trust and the citizens' perception of distributional and procedural justice [16]. This means that if citizens can choose between a project that benefits only already privileged people and another that benefits disadvantaged people, they would choose the latter because it is perceived as more just. However, this is not always the case, as some people who feel threatened would select the project that benefits themselves instead of the broader population [363]. Yet, no study to our knowledge has explored whether energy transition strategies that consider justice factors can improve citizens' active support as engagement in its various forms (e.g., adopting sustainable behaviors and becoming a prosumer or decision maker) [2]. Thus, in this study, we answer the research question: To what extent do projects that include justice dimensions (participatory and distributional) motivate or not citizens to participate?

To address the research question, we interviewed stakeholders to identify energy injustices and diverse citizen groups, including hard-to-reach (HTR) and vulnerable ones. The results from these interviews helped design a representative survey of citizens and a targeted sample of HTR groups that included a Discrete Choice Experiment (DCE), where diverse citizens' willingness to participate in the energy transition was measured. The options to participate covered: a) adopting sustainable measures at home, b) becoming an organizer of community energy projects, or c) not participating at all.

The following section presents the research framework, connecting key concepts to answer the research question: energy justice, justice perception, level of information, and citizen participation. Section 3 describes the conducted survey with a focus on covering HTR groups and the applied DCE to analyze the results. Section 4 outlines the results: citizen groups reached, their answers, and the impact that the perception of fairness had on their willingness to participate. Section 5 discusses the extent to which the perception of fairness triggered equitable participation and compares the results with previous studies on triggers for participation. Finally, section 6 answers the research question, addresses limitations, and proposes a research agenda.

5.2. Research framework: Energy justice and citizens' participation behavior

The three attributes described in Section 2 are introduced below. These are distributional justice, procedural justice (subsection 2.1), and citizen participation (subsection 2.2). The connection between justice and citizen participation is described in subsection 2.3.

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5.2.1. DISTRIBUTIONAL AND PROCEDURAL ENERGY JUSTICE

Citizens' acceptance of energy projects is influenced by procedural and distributional justice and trust [16]. Procedural, recognition, and distributional justice are three tenets widely accepted by Western scholars as a requirement to move toward just transitions [33, 43]. Distributional justice refers to an equitable share of the risks and benefits. For example, the distribution of solar energy subsidies can account for justice if households with energy poverty benefit from such subsidies [364]. Procedural justice refers to the level of social inclusion and representation in the decision-making process of the energy transition [33]. Procedural justice is associated with decision-making processes in the energy transition, which should consider or aim for energy democracy and sovereignty [35, 355]. These concepts propose that diverse citizens should have the opportunity to choose to be consumers, prosumers, owners, and decision-makers in the energy transition [2]. Thus, an energy project that considers procedural justice may offer diverse stakeholders and citizens a platform to choose their role in an energy transition project [356]. Although these justice tenets influence citizens' relationship with renewable energy projects, limited empirical knowledge is available on to what they affect citizens' willingness to participate, especially vulnerable groups, in the energy transition [359].

5.2.2. CITIZEN PARTICIPATION IN THE ENERGY TRANSITION

Citizen participation in the energy transition can be framed from different narratives [2]. The most common one is the consumerist narrative, where citizens can have the role of a consumer or prosumer. The former is the most common and effortless type of participation, where citizens can influence their energy consumption. For example, energy consumers can reduce their consumption by implementing energy-efficient measures at home [333]. The latter refers to when citizens are involved in energy generation and not only as clients consuming energy [235]. Another narrative is the deliberative one, where citizens are involved in all levels of decision-making and have (some) power to make choices. For example, citizens can be leaders in community energy projects [41]. Critiques to participatory and transdisciplinary approaches to the energy transition claim that more participation leads to more complex and slower decision-making processes, thus becoming a barrier to today's urgent climate change mitigation and adaptation measures. However, at the project scale, citizen participation can widespread the adoption of sustainable measures, for example, through community energy projects [50].

There is a limited understanding of the role(s) of different citizen groups, especially vulnerable citizens. In the energy system, there are citizen groups that are more prone to being vulnerable [12]. In climate justice literature, vulnerability is conceptualized with three dimensions: Exposure, sensitivity, and adaptive capacity [365]. Vulnerability does not equal poverty and does not have the same relationship with income. Some vulnerable groups that have been reported are women, the rural population, children, inhabitants of small islands, immigrants, and Indigenous peoples. It is assumed that vulnerable groups lack time, resources, or interest to participate in energy projects [204]. Yet, little evidence for this assumption is available.

5.2.3. JUSTICE PERCEPTION AND CITIZEN PARTICIPATION

Perceiving justice in renewable energy projects can determine peoples' opinions and attitudes towards projects [16]. Such perception can influence citizens' acceptance, neutrality, or opposition to energy projects, which can vary over time [92].

Some citizen groups are sensitive to their perception of justice, influencing their cooperation behavior. According to justice sensitivity theory, citizens sensitive to justice will be more prone to cooperate as observers, whereas as victims, sensitive citizens will have more egoistic behavior [363, 366]. Additionally, some ways to trigger people's sensitivity to justice are telling a story, establishing a personal connection, and showing the impacts on affected people [367]. A volunteer's dilemma states that one volunteer is needed to benefit everyone, but volunteering has a high cost [368]. Volunteers prefer settings of smaller groups, which can be applied in the context of energy project scales (Ibid). Citizens benefiting from inequality will be more willing to volunteer than those suffering from inequality, who will be unlikely to volunteer [366]. This suggests that energy-poor citizens are less likely to volunteer in energy projects.

According to equity theory, the way groups and individuals perceive the rewards they get from their work determines their sense of justice. For example, if someone feels that they do not receive enough for their work, they feel unfairly treated, and vice versa [369]. Similar to social acceptance, equity theory states that fairness perception has three dimensions: 1) distributive, 2) procedural, and 3) interaction fairness. The third dimension tends to overlap with procedural fairness. The first dimension is based on the level of returns as materials, social status, or other benefits. The second one refers to decision-makers being independent, the process being transparent, unbiased, inclusive, and coherent. Perceiving fairness can lessen risks of cooperation and promote long-term collaborations in sustainable innovations (Ibid).

5.2.4. LEVEL OF KNOWLEDGE AND SOCIAL ACCEPTANCE

The relationship between citizens' level of knowledge and their acceptance of renewable energy projects is complex and context-dependent: greater factual understanding and energy literacy often increase perceived benefits (e.g., climate mitigation, local economic gains) and thereby support, but detailed knowledge can also highlight trade-offs (e.g. land-use impacts, noise, procedural shortcomings) that reduce acceptance unless accompanied by fair decision-making and trust in authorities. Empirical reviews and case studies show that knowledge improves acceptance when it is paired with transparent processes, perceived distributive benefits, and opportunities for meaningful local participation [370]. Conversely, low knowledge sometimes coexists with high stated support (social desirability or abstract environmental attitudes) yet hides vulnerability to local opposition when projects become concrete. In particular, a comprehensive review of 25 European case studies found that dissemination of information and transparent communication by project developers strongly correlate with higher local acceptance of renewable energy projects [370]. Moreover, several studies emphasize that beyond mere awareness, trust in responsible actors and opportunities for public participation significantly shape whether knowledge translates into acceptance [92, 371]. Systematic

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frameworks of social acceptance show that awareness and knowledge remain central dimensions, but they interact with perceived fairness, risk-benefit assessments, and community engagement processes [372].

5.3. METHODOLOGY

5.3.1. CASE STUDY DESCRIPTION

Our case study is located in the cross-border region between Baja California (Mexico) and Southern California (United States), as shown in Figure 3.1. This case is of particular interest to study the relationship between citizen participation and energy justice because citizen participation in energy-related topics in this cross-border region is scarce, and yet, numerous citizen groups struggle with energy services as explained in Section 5.3.2.

Citizen involvement in energy projects could potentially advance the low-carbon transition in this region. The region shows potential to develop a cross-border regional energy transition. Besides its interconnections in terms of migration, trading, businesses, and culture, this region is energetically interconnected with gas pipelines and electricity transmission lines for exports and imports [373]. This region is fascinating to study as a potential energy region because Southern California and Baja California have a history of international environmental protection agreements, especially on the topics of water, energy, air, and waste management [374]. There are two 230 kV electricity interconnections with a total capacity of 800 MW and natural gas pipelines with a total rate of 23.4 MSm3/d between California and Baja California, as shown in Figure 3.2. Electricity generation in California comes from 48,6% of renewable energy sources, of which 46% is imported. In Baja California, electricity consumption in 2023 was 16 TWh, a local generation of 15.3 TWh, out of which 13.9% comes from renewable energy sources (geothermal 12.5%, wind 0.6%, and solar 0.8%) [375]. There is technically-proven renewable energy potential, which requires the development of policy and market support [88].

Citizen participation in energy projects in the cross-border region is limited to one-way communication approaches (i.e., informing). In Mexico, citizen participation is not mandatory for all projects or stages [92, 376]. It is formally organized as a public consult as part of the Environmental Impact Assessment only if the consult has been requested shortly after the energy project has started [377]. Similarly, in the US, citizens are involved during the public hearing and review of Environmental Impact Statements, which are not required for all projects [378].

5.3.2. DATA COLLECTION: ONLINE AND IN-PERSON SURVEY

To answer the research question (to what extent do projects that include justice dimensions (participatory and distributional) motivate or not citizens to participate?), we combined two data collection methods, an online and in-person questionnaire. The questionnaire details are presented in Appendix A. We used the same questionnaire for both Spanish and English samples, which we designed in Qualtrics XM, an online licensed

Figure 5.1: Aimed area for the survey (respondent's place of residency). Baja California, Mexico and Southern California, USA.

platform to design surveys. We exported and printed the questionnaire for the in-person sample. This questionnaire follows the structure of a choice experiment in which respondents participate in either a control or treatment group. The control group answered the survey without a detailed introduction, whereas the treatment group received an introduction on energy, sustainability, and justice topics. After excluding speeders (i.e., those who took less than four minutes to complete the survey) and incomplete surveys, the response time was between 5 and 20 minutes. In the online sample, the average was 7.4 for the treatment group and 7.0 minutes for the control group, possibly because of the extra introduction text in the treatment group and because the introduction might have incentivized respondents to think more thoroughly. For the in-person sample, the average time was 15 minutes (control and treatment group), which was longer than the online sample because in-person respondents could ask clarifying questions. Dynata, a market research company with coverage in Mexico and the US, collected the online sample by distributing the questionnaire to an online panel in Southern California and Baja California with the characteristics described in Figures 5.31 and 5.4. This online panel consists of Dynata subscribers, which covered a representative sample of the cross-border region. Additionally, an in-person sample was pursued to reach a non-representative sample of vulnerable and HTR groups and, thus, ensure diversity.

Including vulnerable and HTR groups

Diverse vulnerable households and justice attributes can be identified in Southern California and Baja California. The justice attributes of this study are related to the energy vulnerabilities in the region: Lack of affordability of electricity, gas, and transportation despite subsidies and lack of electricity connection in Baja California [379]; water scarcity, see water pollution, and wildfires on both sides of the border [380]. The HTR and vulnerable groups that experience those vulnerabilities are diverse. For example, Indigenous communities in several municipalities in Baja California lack electricity connections and public transport [379].Inhabitants in Mexicali have a high electricity

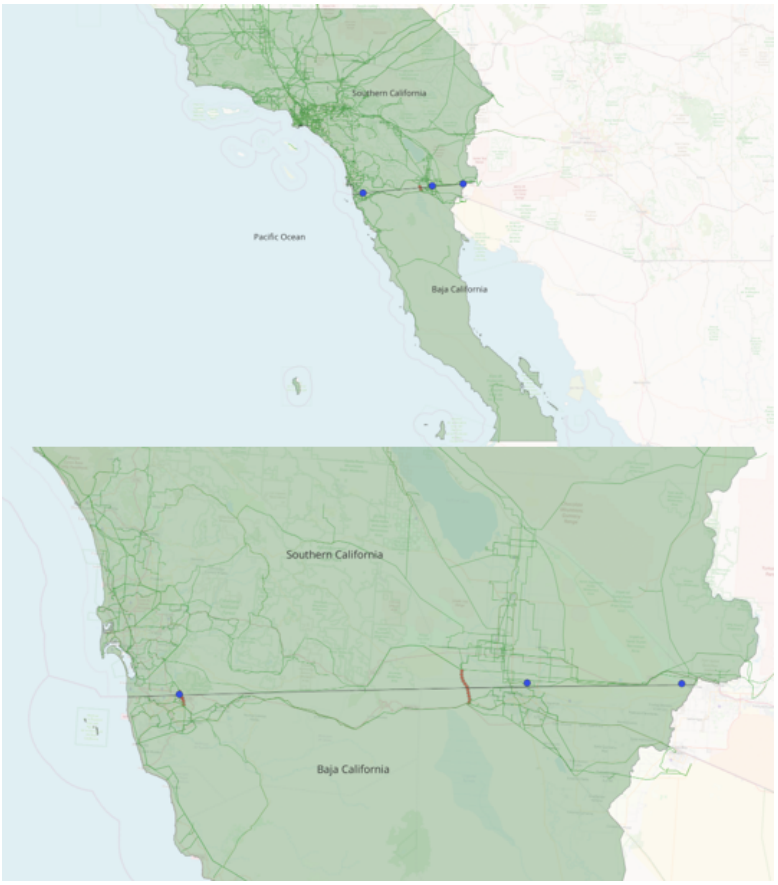

Figure 5.2: Transmission lines (in green) of Southern California and Baja California, their interconnecting electricity (in red), and natural gas pipelines (in blue).

consumption in Summer due to climate conditions and an energy inefficient behavior (e.g., leaving the window open when the air conditioning is running) (First author's fieldwork notes, 2024).

The in-person survey was pursued to include HTR groups with a targeted snowball sampling because of its effectiveness in reaching hidden populations such as homeless people, prostitutes, and drug addicts [381]. This in-person sampling method identified local networks to reach HTR groups through their networks [382]. Thus, the first author contacted reference persons of each vulnerable group, who agreed to have people interviewed. Additionally, some groups like a feminist group and Indigenous community leaders were initially contacted via social media like Facebook and WhatsApp, as social media have been proven successful in reaching HTR groups [383, 384]. To make the in-person questionnaire accessible to participants, a team of three local survey assistants

Data collection method	Citizen groups reached	Number of complete answers	Control sample	Treatment sample
Online Qualtrics questionnaire with online panel Dynata	General representative sample.	N = 651	N = 352	N = 299
Printed and online Qualtrics questionnaire with the in-person snowball sampling method	HTR and vulnerable groups.	N = 118	N = 52	N = 66

Figure 5.3: Comparison of online and in-person sampling methods.

Online questionnaire	Female	Male	Other gender or did not want to say	18 to 44 years	More than 44 years
Online control	181	146	25	189	163
Online treatment	121	118	60	149	150
HTR control	33	19	0	28	24
HTR treatment	39	27	0	41	25

Figure 5.4: Reach of HTR and vulnerable groups in the cross-border region.

and the first author assisted participants in reading and explaining the questions. Additionally, in-person participants received monetary compensation to reward their valuable input. The questionnaire was available in Spanish and English. Yet, participants who spoke a different language (Indigenous language) were assisted by a translator from the same social network. This approach is supported by previous survey studies working with HTR groups, which recommend collaborating with participants in the survey design and implementation [383]. Similarly, participants who could not read the questions themselves were read all the questions and text so that they could answer verbally. The in-person survey required significantly more effort and similar funding compared to the online survey.

5.3.3. Discrete Choice Experiment

The survey consisted of a discrete choice experiment (DCE) that helped explain how the perception of justice impacts the willingness of diverse citizens to participate in the energy transition. DCE has become popular in obtaining individuals' preferences in the context of energy transition [385–387]. In a DCE, participants answer a number of choice tasks in which they select between mutually exclusive alternatives (e.g. different

levels of engagement, high/low) characterized by a set of attributes (e.g. impacts related to inclusion/justice). The participants' choices are analyzed using discrete choice models [388], allowing identification of the individuals' preferences for the discrete alternatives and their attributes.

The experimental design of the DCE was done in three stages, inspired by the procedure suggested by Hensher, Rose, and Greene [389]. The first stage involved framing the choice question, as well as the core elements of the DCE, namely the number of alternatives, attributes, and attribute levels. Participants were asked to choose between three forms of energy projects, which were labelled by their participation form. Alternative 1 was always "You do not participate"; alternative 2 was always "You adopt sustainable measures in your house (LED bulb lights, recycling waste, etc.)"; and alternative 3 was always "You become a local leader by helping coordinate a sustainable energy project in your community (5h/week)". Each alternative was characterized by three attributes: the form of participating in the project (i.e., the "label" attribute); which groups are receiving clean technologies (solar panels) for free; and the actors who decide on what households can receive the clean technologies. Details of the attributes and levels are provided in Table 5.5.

Attributes	Levels
How you (respondent) participate in the project	You do not participate
	You adopt sustainable measures in your house (LED bulb lights, recycling waste, etc.)
	You become a local leader by helping coordinate a sustainable energy project in your community (5h/week)
Groups receiving clean technologies (solar panels) for free	5% of households that struggle the most to afford their energy bill
	30% of households, based on a random selection
	30% of households that struggle the most to afford their energy bill
	All households with no electricity connection
Actors who decide on what households can receive the clean technologies	Federal government
	State and local government
	Civil organizations
	Regions: civil organizations and local and state government
	Local, state, and federal government levels
	Civil organizations at local, state, and federal government levels

Figure 5.5: List of attributes and their levels.

The second stage consisted of determining the number of possible treatments and constructing the experimental design. We use a D-efficient design (Rose & Bliemer, 2009) of 60 choice tasks, allocated in 10 blocks. Hence, each respondent faced a subset of six choice tasks or scenarios, each one with three options to choose from. The D-efficient design is a type of experimental design in which the possible attribute levels of each choice task are selected such that the determinant of the asymptotic variance-covariance matrix of a specific choice model (in our case, a Multinomial Logit Model) is minimized, hence maximizing the statistical efficiency of the choice models that will be

used once the sample is collected. In the final stage, we allocated the resulting experimental design to the choice tasks that will be shown in the survey, by using the "Conjoint analysis" feature of Qualtrics. An example of the survey choice task is shown in Figure 5.6.

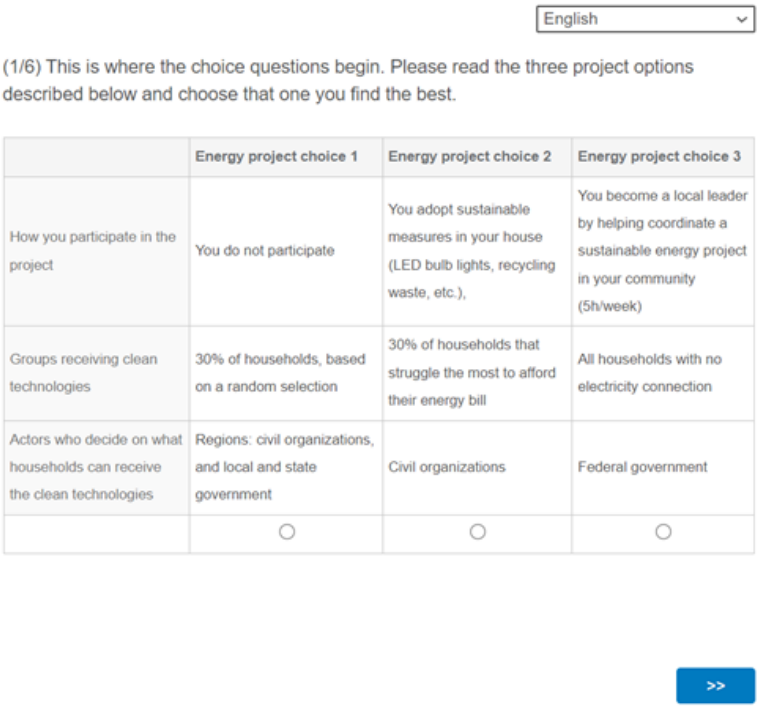

Figure 5.6: Example of a choice scenario extracted from Qualtrics.

We designed two different DCEs, the treatment and control survey, to contrast their outcomes. The treatment group consisted of the six steps outlined below. The control group consisted of the same sequence of steps without Step 2.

The survey instrument that embedded the DCE was divided into two groups, namely the "treatment" and "control". In the first section of the survey, respondents agreed to participate in the survey via an online consent form, which was integrated in the questionnaire. We followed GDPR standards by anonymizing responses and protecting the identity of participants; and participants were aware that they could stop the survey and skip questions at any time. The second section was only administered to the "treatment" group, in which participants read a description of crucial energy concepts to help participants understand the questions. These concepts covered: Sustainable energy projects, renewable energy and fossil fuel consumption in Mexico and the US, primary energy decision-makers in Mexico and the US, the way citizens could participate in energy projects, and energy affordability benefits from renewable energy projects. Fur-

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thermore, we inserted a bias toward energy justice as well as general information on the energy transition in this description (see Appendix A, part 1), describing the status quo and what aspects could make the energy system fairer based on the energy justice framework [33]. This introduction allowed us to assess the impact of previous knowledge and justice framing. The third section contained the DCE choice tasks. The fourth section consisted of nine short questions on demographics, including gender, place of origin, place of residence, income level, age, and education level. In the fifth section, the participants had to answer two open-ended questions to collect people's general opinions on the topic of sustainability: (1) What do you consider to be the most important issues in your locality that should be taken into account when creating an environmentally friendly development plan? and (2) Do you have any final comments or questions about this survey? (optional). Finally, in the sixth section, participants were thanked for their time and effort, and the questionnaire ended.

5.3.4. Data analysis: Discrete choice models

The data analysis is done through discrete choice models based on the Random Utility Maximization (RUM) model. We estimated different choice models to compare their results. For example, we calculated the effect that incorporating an introduction with information on energy topics and justice elements had on people's willingness to participate, in contrast to not including such information. The RUM model is a behavioral and econometric framework based on the notion that individuals seek to maximize the utility obtained from mutually exclusive alternatives and their attributes. In the RUM model, the utility of each alternative is commonly modelled as a linear-in-parameters function that depends on its respective attributes, a set of parameters that account for the preferences for increases of each attribute, and a stochastic error term. Mathematically, for a given individual n that faces J alternatives, the utility obtained from alternative j is given by equation (1):

$$U_{nj} = V_{nj} + \varepsilon_{nj} = \delta_j + \sum_{k}^{K} \beta_k \cdot X_{njk} + \varepsilon_{nj}, \tag{5.1}$$

where V_{nj} is the observed part of the utility function U_{nj} and ε_{nj} is the stochastic error term, which represents an unobserved part of the utility. V_{nj} depends on δ_j, which is an alternative-specific constant parameter, and β_k is a parameter associated with the k-th attribute X_{njk}.

Under the RUM model, an alternative i is chosen if $U_{ni} > U_{nj}$, for all $j \neq i$. However, the utility values are not perfectly observable since they depend on stochastic error terms. Instead, the analyst can derive an expression of the probability of choosing alternative i by assuming a distribution for the error terms. Given such probability, the analyst obtains the estimated parameters using maximum likelihood estimation. Following Train (2009), by assuming an i.i.d. Gumbel distribution for ε_{nj}, the probability of choosing alternative i follows a Multinomial Logit (MNL) model, as shown in equation (2):

$$P_{ni} = \text{Prob}(U_{ni} \geq U_{nj}, \forall\, j \neq i) = \frac{\exp(V_{ni})}{\sum_j \exp(V_{nj})}. \tag{5.2}$$

The estimated parameters of the MNL model have a behavioral interpretation. Firstly, the alternative-specific constants δ_j inform the individual preferences for choosing alternative j, compared to other alternatives, and irrespective of the attributes of such alternative. For instance, if $\delta_j > \delta_l$, then, on average, alternative j is preferred over alternative l, without considering their respective attributes.

Secondly, the attribute-specific parameters β_k inform about the individual preferences for the increase of the associated parameter k. If $\beta_k > 0$, then increases of attribute k are preferred, on average. Conversely, if $\beta_k < 0$, then decreases of attribute k are preferred, on average.

In addition, we estimate a Latent Class (LC) choice model. The LC choice model extends the MNL model to account for discrete heterogeneity of preferences across individuals. In the LC choice model, it is assumed that the sample is divided into C classes. The unconditional probability of choosing alternative i is given by equation (3)

$$P_{ni}^{LC} = \sum_{c=1}^{C} \pi_{nc} \cdot P_{ni|c}, \tag{5.3}$$

π_{nc} is the class membership probability, which is the conditional probability of being in class c. This class is modeled as a linear-in-parameters function that depends on constant and individual-specific characteristics (e.g., gender, education, etc.). $P_{ni|c}$ is the MNL probability of choosing alternative i, conditional on being in class c. Hence, for each class c, the term $P_{ni|c}$ is similar to equation (2), but it depends on an independent set of parameters δ_c and β_c.

Therefore, equation (3) is a weighted sum of the probability of being in each class. In turn, in the LC choice model, each class is described by its own set of conditional parameters, both from the class membership function and from the conditional choice probability.

5.4. RESULTS

Figure 5.7 presents the results of the discrete choice model (MNL) for the online and in-person panels in the cross-border region, which encompassed a sample of 768 answers and 4,608 observations. All the estimated parameters are statistically significant at a 95% confidence level. The first set of parameters accounts for the preference for participating in the project in two forms, compared with not participating. The second set of parameters reflects respondents' preferences for increasing the coverage of people who can receive clean technologies, compared with a minimum of 5% of households with difficulties paying their electricity bills. The third set of parameters illustrates the

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preferences for actors involved in the decision-making process, compared with solely involving the federal government.

Attributes	Estimate	Standard error	P-value
How you participate in the project (citizen participation):			
Do not participate (baseline)	0	-	-
Adopt sustainable measures	**1.045**	**0.038**	**0.000**
Become a local leader	**0.118**	**0.045**	**0.009**
Groups receiving clean technologies (distributional justice):			
5 % with issues with paying the bill (baseline)	0	-	-
30 % randomly assigned	**0.102**	**0.049**	**0.037**
30 % with issues to pay the bill	**0.383**	**0.049**	**0.000**
All households without electricity	**0.246**	**0.049**	**0.000**
Deciding actors (procedural justice):			
Federal government (baseline)	0	-	-
Local and federal government	**0.148**	**0.063**	**0.019**
Civil organizations (with citizen participation)	**0.226**	**0.064**	**0.000**
Civil organizations, local and federal government	**0.359**	**0.062**	**0.000**
Local, state, and federal government	**0.257**	**0.063**	**0.000**
Civil organizations, local, and state government	**0.212**	**0.063**	**0.001**
Number of individuals	768		
Number of observations	4608		
Log-likelihood	-4468.63		
Rho-Squared	0.12		
Akaike Information Criterion	8957.25		
Bayesian Information Criterion	9021.61		

Figure 5.7: MNL model estimation results, whole sample.

5.4.1. Preference for citizen participation

Regarding the preferences for participating in the project, all estimates have a positive sign, indicating that respondents prefer to participate in any form rather than not participate. The magnitude of these parameters suggests that respondents are more willing to participate at the household level (e.g., adopting sustainable measures at home, such as changing bulbs to LED and recycling waste) than participating as local leaders. This was expected, as participation at the household level is a measure that is familiar to many families, as explained by some participants (in-person sample). Thus, this level was perceived to require less effort than being a community leader. Becoming a local leader represents another energy citizenship role [2] that requires the most considerable effort among the attribute levels, five hours of work per week.

5.4.2. Preference for distributional justice

There is a general preference for distributional justice, that is, projects distributing clean technologies to different vulnerable groups. All estimated parameters for distributional justice have a positive sign. This suggests that respondents prefer all proposed increases, compared with the minimum 5% of households with issues paying their energy bills. In

terms of the magnitude of the estimated parameters, it is observed that respondents prefer to focus on the provision of technologies to those who have issues paying the bill, followed by all households without electricity, and lastly, a random selection of households was selected. Notably, the level "30% of households with issues paying their energy bill" represents a larger share of inhabitants than the level "all households without electricity connection". In Mexico, there is 98.95% of electrification [390], but it is well known that some families struggle to afford their energy bills. Conversely, the level "30% of randomly selected households" represents a bigger population than "30% of households with issues paying the energy bill". However, we did not verify if respondents were aware of these facts. Therefore, we can only conclude that participants prefer projects that benefit citizens with energy affordability issues.

5.4.3. Preference for procedural justice

Regarding the preferences for procedural justice, that is, the involvement of diverse groups in decision-making, the estimated parameters have a positive sign, which suggests that all alternatives over solely involving the federal government are preferred. A potential explanation for this result is that having the federal government as the sole decisionmaker may have been perceived as a top-down approach, with little understanding of the local context. In reality, energy project planning is managed by governmental organizations in federal, state, and private-public partnerships in the US and Mexico. However, in Mexico, the National Secretariat of Energy (SENER) is the central organization in charge. Furthermore, the most preferred involvement strategy was the combination of civil organizations, local (municipal), and federal government, showing that participants prefer that decision-making involves multiple administrative levels and citizens, which is not the case in Mexico and the US. This result shows that citizens prefer projects that include different government levels and citizens, that is, a decentralized and citizen-inclusive decision-making process.

5.4.4. Differences between the control, treatment, and in-person groups

In this section, we compare how preferences vary across the control (online plus in-person), treatment (online plus in-person), and in-person (control and treatment) groups to evaluate the effect of having a higher knowledge level and a bias toward justice in the treatment group and the differences between the online and in-person samples. Figure 5.8 summarizes these differences in terms of the estimated parameters. The differences between these groups were assessed with a T-test to identify statistically significant differences. Significant differences between the control and treatment groups are observed only in procedural justice. The treatment group preferred two decision-making or procedural justice levels (attribute 3): Civil organizations, local and federal government, and civil organizations, local and state government, for which the control group showed a smaller magnitude of the associated parameters. This could be a result of being informed and/or introducing a bias towards more decentralized decision-making in the treatment introduction. Contrary to our expectations, we found that the introduction did not motivate the experimental group to participate more actively. Table

5.8 shows that there was no difference in people's willingness to participate between the control and treatment groups (P-value greater than 0.05); both preferred participating at the household level, as described in Section 4.1.

	Control - experiment		Control - In-person		Experiment - In-person	
How you participate in the project:	Difference	P-value	Difference	P-value	Difference	P-value
Do not participate (baseline)		-		-		-
Adopt sustainable measures	-0.134	0.109	0.049	0.679	0.183	0.133
Become a local leader	-0.011	0.912	-0.451	**0.000**	-0.440	**0.001**
Groups receiving clean technologies:						
5 %, with issues to pay the bill (baseline)	0.000	-	0.000	-	0.000	-
30 % randomly assigned	-0.045	0.675	-0.165	0.267	-0.120	0.431
30 % with issues to pay the bill	-0.090	0.401	-0.295	**0.044**	-0.205	0.174
All households without electricity	-0.028	0.795	-0.600	**0.000**	-0.571	**0.000**
Deciding actors:						
Federal government (baseline)	0.000	-	0.000	-	0.000	-
Local and federal government	-0.215	0.120	-0.144	0.446	0.071	0.715
Civil organizations (with citizen participation)	-0.097	0.492	-0.432	**0.021**	-0.335	0.086
Civil organizations, local and federal govt.	-0.326	**0.018**	-0.682	**0.000**	-0.357	0.059
Local, state and federal government	-0.179	0.198	-0.264	0.166	-0.085	0.667
Civil organizations, local and state government	-0.295	**0.034**	-0.654	**0.000**	-0.359	0.061

Figure 5.8: Differences between control, experiment, and in-person sample..

The analyses revealed differences between the control, in-person, and treatment groups in their willingness to participate, as shown in Figure 5.8. The control group is less willing to participate (-0.451 difference, P-value 0.000) as a local leader than the in-person group. The same occurs for the preferences for distributional justice or the groups receiving clean technologies. Specifically, the levels "30% of households with affordability issues" and "households without electricity" are more preferred by the in-person group than the control and experiment groups. Since the in-person group covered only vulnerable groups, these results show that vulnerable groups have a stronger preference towards distributional justice, particularly energy affordability and access, and a stronger willingness to participate than an average citizen.

Interestingly, only two differences are observed between the treatment and in-person groups. The treatment groups show a lesser preference for becoming a local leader (-0.440 with P-value 0.001) and a lesser preference for the distribution of solar panels to all households without electricity (-0.571 with P-value 0.000). This finding reinforces the interpretation of the results (Section 4.4.2), showing that vulnerable groups have the strongest willingness to participate as local leaders compared to average and informed citizens. This suggests that vulnerable groups have knowledge of energy-related topics and that they value distributional justice the most because of their direct connection with distributional injustices like lacking electricity connection. This is also why they are more willing to volunteer as a local leader of energy just projects.

5.4.5. LATENT CLASS CHOICE MODEL

To identify the different groups of citizens regarding preferences, we conducted an LC choice model, which groups individuals into unobserved (latent) classes or groups

based on their choices and preferences. The optimal number of classes of the LC choice model is usually determined by estimating different models from two to four latent classes and keeping the model with the lowest Bayesian Information Criterion (BIC). From this procedure, the 4-class LC choice model reported the lowest BIC. Despite the latter, we decided to report the 3-class LC choice model as it is easier to interpret and communicate for the reader, and its BIC differences were not substantial. Appendix C provides details of the BIC per class of the LC choice model.

Figure 5.9 summarizes the estimation results of a 3-class LC choice model, which divides responses into three groups with similar preferences. These classes aggregate the control, treatment, and in-person groups. Based on the class membership parameters of the LC choice model, the class membership probabilities were computed for each class (see Figure 5.10) in terms of the socio-demographic characteristics.

Passive citizens

Class 1 consists of participants with an almost equal distribution of age groups but with more dominance of older adults (26% were older than 65 years old). This class is dominated by women (63%) who went to high school or university (78%) and reside in the US (67%). According to the attribute parameters, Class 1 (34% of the whole sample) shows the highest preference towards a moderate level of participation (i.e., adopting sustainable measures at home). Conversely, respondents of this class are not willing to be local leaders compared to those who do not participate. Regarding the involvement of more actors in the decision-making process, this class prefers having civil organizations and local and federal governments as decisionmakers over only the federal government.

Optimistic citizens

Class 2 comprises 47% women, 68% young respondents (younger than 45 years old), 71% highly educated (attended high school or university), and the most extensive presence of residents of Mexico among the three classes, with 38%. This class (54% of the whole sample) prefers to participate at the household level and as a local leader over not participating. This group represents the so-called 'optimistic citizens' who are the most sensitive to justice aspects, as this class showed a preference for projects with apparently more distributional and procedural justice.

Skeptical citizens

Finally, class 3 is conformed by 53% of women, almost equally distributed ages, more dominance of high school attendance (44%) and the lowest among the three with university studies (21%), and the biggest dominance of US residents (75%). Class 3 (11.8% of the sample) shows the largest preference for not participating. Furthermore, this class is the only one that shows preference towards a random selection of 30% of households to receive solar panels and the only one that is not influenced by the procedural justice attribute (involvement of more actors in the decision-making process). Hence, this group can be considered skeptical because it does not want to participate in projects.

	Class 1			Class 2			Class 3		
Class size:	*34.3%*			*54.0%*			*11.8%*		
	Est.	S.E.	P-val.	Est.	S.E.	P-val.	Est.	S.E.	P-val.
How you participate in the project:									
Do not participate (baseline)	-	-	-	-	-	-	-	-	-
Adopt sustainable measures	**2.779**	**0.211**	**0.000**	**0.790**	**0.074**	**0.000**	**-0.951**	**0.263**	**0.000**
Become a local leader	**-0.866**	**0.319**	**0.007**	**0.743**	**0.082**	**0.000**	**-2.864**	**0.469**	**0.000**
Groups receiving clean technologies									
5% with issues to pay the bill (baseline)	-	-	-	-	-	-	-	-	-
30% randomly assigned	0.021	0.202	0.919	0.011	0.075	0.886	**0.918**	**0.301**	**0.002**
30 % with issues to pay the bill	0.398	0.212	0.061	**0.435**	**0.070**	**0.000**	**0.780**	**0.242**	**0.001**
All households without electricity	-0.338	0.236	0.153	**0.444**	**0.072**	**0.000**	-0.027	0.247	0.913
Deciding actors									
Federal government (baseline)	-	-	-	-	-	-	-	-	-
Local and federal government	0.253	0.287	0.378	**0.224**	**0.088**	**0.011**	-0.127	0.246	0.606
Civil organizations (with citizen participation)	0.458	0.286	0.109	**0.300**	**0.092**	**0.001**	0.510	0.300	0.090
Civil organizations, local and federal govt.	**0.649**	**0.270**	**0.016**	**0.463**	**0.091**	**0.000**	0.163	0.266	0.539
Local, state and federal government	0.425	0.262	0.104	**0.311**	**0.092**	**0.001**	0.162	0.303	0.594
Civil organizations, local and state government	0.256	0.265	0.333	**0.301**	**0.091**	**0.001**	-0.019	0.285	0.946
Class membership parameters:									
Constant	-	-	-	**2.155**	**0.410**	**0.000**	-0.451	0.792	0.569
Is a woman				-0.663	0.204	0.001	-0.386	0.301	0.200
Age 25-34				-0.470	0.371	0.205	0.568	0.756	0.452
Age 35-44				-0.391	0.370	0.290	0.507	0.753	0.501
Age 45-54				**-0.969**	**0.375**	**0.010**	0.757	0.731	0.301
Age 55-64				**-1.667**	**0.400**	**0.000**	0.285	0.741	0.700
Age 65 or more				**-2.237**	**0.416**	**0.000**	-0.689	0.806	0.393
Has high school education				**-0.530**	**0.269**	**0.049**	-0.435	0.395	0.271
Has university education				-0.453	0.262	0.083	-0.804	0.421	0.056
Is from Mexico				-0.143	0.229	0.534	**-0.853**	**0.401**	**0.033**
Number of individuals	768								
Number of observations	4608								
Log-likelihood	-3979.14								
Rho-squared vs equal shares	0.214								
AIC	8058.28								
BIC	8380.06								

Figure 5.9: Latent Class Choice model.

5.5. DISCUSSION: HOW DOES THE PERCEPTION OF JUSTICE IN LOCAL ENERGY PROJECTS INFLUENCE CITIZENS' WILLINGNESS TO PARTICIPATE

This study aimed to answer the research question, "To what extent does perceiving energy justice influence diverse citizens' willingness to participate in the energy transition?" The surveyed regions were Baja California, Mexico, and Southern California, which are US cross-border regions.

We expected that projects perceived as fairer would motivate citizens to volunteer in those projects because of theoretical assumptions. According to a social acceptance framework, perceiving justice in energy projects in distributional and procedural justice can lead to community acceptance and cooperation behavior of citizens [16, 363]. Additionally, justice sensitivity theory states that citizens' preference for justice can be triggered by showing the impacts on affected people [367]. Thus, we showed the

Covariate	Class 1 (34.3 % = 263)	Class 2 (54 % = 415)	Class 3 (11.8 % = 91)
Is a woman	63.6%	47.3%	53.5%
Age less than 25	7.2%	16.8%	5.0%
Age 25-34	16.5%	24.7%	18.2%
Age 35-44	15.5%	26.7%	18.3%
Age 45-54	16.5%	15.5%	27.0%
Age 55-64	18.0%	9.0%	20.2%
Age 65 or more	26.4%	7.3%	11.3%
Has less than high school education	21.7%	28.7%	26.5%
Has at least high school education	39.6%	33.7%	44.3%
Has university education	38.7%	37.6%	29.2%
Is from USA	66.9%	59.0%	74.7%
Is from Mexico	30.0%	38.1%	20.9%

Figure 5.10: Class membership probabilities.

effects of distributional and procedural justice on the attribute (2 and 3, see Table 3) levels. These assumptions held for this analysis, where most citizens (89%) preferred those projects benefiting affected people (vulnerable groups) in terms of distributional (sharing of solar energy technology) and procedural justice (groups of decisionmakers).

No significant differences in the preferred type of participation were observed between people receiving or not receiving information about energy justice. This suggests that informing citizens on energy and justice-related topics does not influence citizens' willingness to participate. This may be because most citizens have some understanding of the topic, and they can perceive justice differences among a pool of project options, even without an inserted bias.

5.5.1. Perceiving distributional and procedural justice

As expected, the most influential attribute was the type of participation, followed by distributional (distributing the benefits among vulnerable groups) and procedural justice

(involvement of diverse groups in decision-making). This makes sense as participants can see the effort they need for each participation type. For example, not participating would require no effort, and adopting sustainable measures at home would imply a change in technology, such as more efficient bulbs and habits like recycling. Being a local leader would require five hours per week to assist with coordination tasks.

Out of the two aspects of energy justice covered in this survey, distributional justice had a higher influence on the participants' choice than procedural justice. The attribute representing distributional justice is the group of actors receiving solar panels for free, and for procedural justice, it was the attribute describing the decisionmakers. An in-person participant explained, "if only the government makes the decisions about the energy projects, they can make decisions that citizens disagree with. For example, the location where the technology is installed may not be supported by the house owner. Yet, the house owner (participant) will have to agree with the location because otherwise the government could cancel the installation at all and other neighbors may not benefit in the end" (Notes from the in-person survey, 2024). This explanation shows why distributional justice may be preferred over procedural justice because of the direct connection of distributional justice with energy access and poverty. However, if citizens do not have the possibility to be involved in the decision-making process, technologies may not fulfill their purpose. The same respondent explained that "in a public project building houses in remote areas, the government chose a location that the owner disagreed with. In the end, this house was not used." (Notes from the in-person survey, 2024).

In decolonial contexts, a governance approach where other forms of knowledge and authority are recognized is necessary [357]. For example, the Kumiai, Paipai, and Cucapah Indigenous communities in Baja California, Mexico, have their traditional authority, which the Mexican government does not formally recognize as such. Instead, the formal institutions determine who is recognized as Indigenous people and who has Indigenous community rights. Energy governance in this context requires that Indigenous communities make decisions and influence the shape of local transition pathways.

5.5.2. Citizens willing to volunteer at the household level

We identified three groups of respondents: passive, skeptical, and optimistic. The passive group (class 1) represented citizens who wanted to participate at the household level but did not want to make the biggest effort. This class, dominated by older, educated women from the US, preferred participating from home and was inclined to projects where civil organizations, locals, and the federal government made the decisions. Although this group does not show radical behavior, its preferences for citizen involvement in the transition are more ambitious than the status quo in the US-Mexico cross-border region.

In Mexico and the US, citizen involvement in energy projects is limited to public consults as part of Environmental Impact Assessments and Statements and the ownership of renewables like solar energy. The State of California has a community solar program

that has offered subsidies to disadvantaged and low-income residents since 2007 [391]. In Baja California and Mexico in general, the National Energy Secretariat started a program in 2024 that subsidizes 25% of all solar panel costs, and 75% can be covered by a 5-year trust fund for households with an above-average energy consumption [375]. This subsidy in Mexico is likely not reaching vulnerable households because of the consumption threshold that overlooks average households and households with low consumption. Also, the governmental trust fund conditions may not be appealing to some citizens. Currently, Mexico and the US have policy instruments to incentivize households to acquire more energy-efficient appliances, although the reach of these efforts is not clear [392, 393]. In terms of waste recycling, the State of California has several programs that encourage the recycling of bottles, organic waste, and e-waste, and the 2010 ban on plastic bags was unsuccessful [394]. However, in Baja California, recycling is limited to tires and PET bottles, and the latter is not available everywhere in the state [395]. Moreover, neither Baja California nor California has the option for citizens to participate in the decision-making process beyond a public consult exercise. This restricts most citizens to only one energy citizen role, the traditional energy consumer, and some citizens can also be energy prosumers [2].

5.5.3. Citizens willing to volunteer as local leaders

According to justice sensitivity studies, observers sensitive to justice will be more prone to cooperate, whereas as victims, sensitive citizens will have more egoistic behavior [363, 366]. Based on this, we could expect that advantaged citizen groups (observers) would be the most willing to be local leaders. However, results showed that the most willing-to-be local leaders were the vulnerable groups and young citizens (the optimists or class 2). This suggests that these groups are more justice-sensitive than average and skeptical citizens. Contrary to theoretical expectations, victims (vulnerable groups) did not show egoistic behavior (not participating or preferring to participate at the household level) but rather more willingness to volunteer and help other vulnerable groups. This is likely because these groups could benefit if they volunteer, as they experience energy-related issues. This could also be related to vulnerable groups having a higher level of understanding of energy issues than average citizens. For example, some resident groups are aware of the legal and administrative difficulties of getting electricity connection; thus, they would like their voice to be considered in decision-making.

The role of youth

Class 2 represented optimist citizens, who are young women and men with at least a high school education and are willing to become local leaders. This finding has been tested by a number of studies, showing young people's capacity to self-organize to address environmental issues [396] and older people exhibiting more support for climate justice policies [365]. Surprisingly, this class represents the majority of the sample, as it shows that engaging with young people has the potential to widespread local sustainable energy projects. Yet, youth have been widely underrepresented in sustainability policies and decision-making in general, as policies and policy-makers have failed to include youth's interests in the political agenda [397–399]. This is also the case in Mexico and the

US, where there is no formal platform for citizens to be represented in decision-making other than public consultations on existing projects. Opening formal decision-making spaces for youth and other underrepresented groups is necessary for the support, continuity, and maturity of their initiatives. Supporting youth's involvement in local decision-making spaces can be enabled by ICT tools like e-participatory games in co-creation spaces [400].

The role of vulnerable groups

Interestingly, vulnerable groups are also willing to be local leaders and are more sensitive to justice perception. They prefer distributing the benefits among energy-poor and off-grid households and would include citizens in decision-making. This is striking because it has been assumed that HTR and vulnerable groups like energy-poor citizens care only about meeting their basic energy needs, and their behavior is driven by a sense of survival [401]. Yet, the results show that despite (or because of) their energy needs, they want more citizen involvement as leaders.

Vulnerable groups are more prone to experience energy poverty, and many of the surveyed vulnerable groups have been experiencing it for a long time, which can explain their sensitivity to distributional and procedural justice. These groups have already tried to change their situation, for example, by organizing their neighborhood to acquire solar panels and requesting governmental institutions and electricity companies to offer electricity connections and lower energy tariffs. Additionally, they show a preference for procedural justice or the involvement of more actors, especially citizens, in the decision-making process. Vulnerable groups are aware of the procedures for alleviating energy poverty, as they have already faced the struggles of a rigid and local decision-making process. Thus, they recognize the importance of having access to energy decision-making spaces.

Furthermore, some vulnerable groups are more informed about how decisions are made and what they would like to change. Their open-ended answers to the question evidence vulnerable groups' knowledge and interest: What do you consider to be the most important issues to include in a sustainable development plan for your region or community? For example, they say:

"All the people in this neighborhood should join together and pick up the trash from the streets so as not to pollute the environment. Where I live, there is no electricity. It would be nice if they put up light poles. There are students and they don't have light (illumination) to study. They use small [solar] panels that only charge when there is sun. They only serve for [to turn on] a light bulb." (First author's translation, In-person questionnaire respondent, 2024)

"Implementing the protection of animals, plants, and the territory. [There have been] invasions [of our territory]. The government should give us more work projects and training for self-generation here in the community so that we become self-sufficient. The leaders that the government selects do not advocate for the problems of the rural

community. When the government comes with projects, their conditions do not match our needs." (First author's translation, In-person questionnaire respondent, 2024)

5.5.4. Generalization of findings

The findings of this study can likely apply to other Global South and North regions. The first finding shows that the general population prefers projects with distributional and procedural justice, but it also prefers effortless participation at the household level. This pattern can be expected in most contexts where there is some degree of social awareness of energy poverty. Places where renewable energy projects have caused disturbances might show different results, as acceptance of renewables might be lower. The second finding shows that youth and vulnerable groups are more willing to volunteer as local leaders can be present in other Global South contexts, where vulnerable groups already make a considerable effort in trying to solve their energy service problems like lack of electricity access. Youth has widely been reported as more invested in sustainability initiatives [396, 398, 400], which suggests that youth might be more willing to lead local energy projects elsewhere. Decisionmakers could engage with youth via digital platforms and offer training to help address energy issues in their communities.

5.5.5. Methodological improvements and future research

The DCE method was effective in evaluating the influence of justice perception on people's behavior, so we recommend it for future studies testing energy justice aspects. However, socio-demographic and open-ended questions on respondents' priorities to tackle in a sustainable development plan helped confirm the relevance of the research and identify further issues not covered by the study. However, we cannot ensure that all groups interested in participating will actually do it in a real-world setting. Thus, future studies can validate citizens' willingness to participate using participatory methods like game-based scenarios or in a real project, where participants' behavior is observed to evaluate their actual level of engagement.

It is essential to acknowledge the challenges of reaching HTR and vulnerable groups in surveys, especially when the decision scenarios are highly complex. About the same funding was used for the online sample of 650 answers, recruited by a market research company, and the in-person sample of 118 answers with a group of five local assistants (led by the first author). Additionally, conducting the in-person survey required more previous work to identify the target groups and make connections with them through key stakeholders. Sometimes, these groups are located in remote areas or are available early in the morning on their way to work, requiring more effort from the assistants. It is worth mentioning the strong interest these groups had in participating in the survey, as many of them did not want to accept the monetary compensation. Yet, we consider this compensation necessary as a form of gratitude for the time they spent answering the questionnaire. Sometimes, they would respond during working hours. These challenges should be accounted for in future studies aiming to include HTR groups.

5.6. CONCLUSION

We answered the research question: To what extent do projects that include justice dimensions (participatory and distributional) motivate or not citizens to participate?. This study confirmed that procedural and distributional justice influence citizens' preference, acceptance, and willingness to participate in local energy projects [16]. This preference is also present when citizens do not receive additional information on justice, energy, and sustainability topics. In contrast, procedural justice preference is increased when further information is available. Remarkably, most citizens (88% of 768 respondents) are willing to participate in local energy projects by taking sustainable measures at home, especially when the projects are perceived as distributionally and procedurally just. This finding urges the creation of platforms supported by formal institutions where diverse citizen groups can participate or be represented in local energy decision-making in the US-Mexico cross-border region.

Governance arrangements that are most likely to motivate citizens, including vulnerable groups, to participate in a regional energy transition are decentralized, multi-level, and citizen-inclusive. The findings show a clear preference for decision-making structures that move beyond top-down, federal-only control and instead combine federal, local (municipal), and civil society actors, allowing citizens to meaningfully influence outcomes. Such arrangements enhance procedural justice by incorporating local knowledge and diverse perspectives, while distributional justice—particularly the fair allocation of benefits to vulnerable groups—plays an even stronger role in motivating participation due to its direct link to energy access and poverty reduction. Importantly, governance models that recognize non-state and Indigenous forms of authority, especially in decolonial contexts, are essential to ensure legitimacy and effectiveness. Overall, inclusive governance that balances low-effort household participation with genuine opportunities for shared decision-making can foster broader and more equitable citizen engagement in energy transitions.

Our empirical findings challenge current conceptions of roles in energy citizenship. Vulnerable groups and youth value energy-just projects the most and are the most willing to have a leading energy citizenship role. Despite their energy struggles in meeting basic energy needs [401] and far from being conflicted with other priorities, as has been previously reported [244], HTR groups like energy-poor, off-grid, immigrants, long-commuters, and female groups showed a strong interest in actively addressing local sustainability issues. Surprisingly, the largest demographic group, with 54% of the sample, the youth (mostly younger than 44 years), also showed more willingness to be local leaders. This finding shows great potential for widespreading local sustainable energy projects. Therefore, we recommend allocating resources and establishing a formal platform to support and empower these citizens in leadership roles.

6

CONCLUSION AND DISCUSSION

The thesis examines the governance arrangements in coal and carbon-intensive regions (CCIRs) required to address energy injustices while advancing low-carbon transitions. The findings reveal that energy regions can be classified into five main types, each following distinct transition pathways that require the support of formal institutions for long-term success. Additionally, this research shows that the impact of transitions on citizens is different if the CCIR sector has the possibility to transition or if it has to be phased out without an economic replacement.

My empirical findings showed that regional-level efforts are necessary to address energy injustices, especially in CCIRs. I conceptualized the energy injustices faced by citizens into four types of energy vulnerabilities. These vulnerabilities, for example, a lack of energy affordability, are influenced by regional, national, and international conditions. This research emphasizes the importance of inclusive governance arrangements that incorporate citizen participation, especially from vulnerable groups. Governance arrangements that adopt social innovations and involve citizen representatives can empower local organizations and citizens, whereas top-down approaches often fail to integrate diverse perspectives, particularly those of vulnerable groups. An interesting finding is that citizens, particularly young people, vulnerable groups, and hard-to-reach groups, have a willingness to take on leadership roles in energy transitions. This suggests a potential shift toward more active citizen involvement in energy governance.

This thesis contributes to the theoretical understanding of energy regions, social innovation, and energy justice, offering policy recommendations for practitioners to enhance cross-regional learning, support vulnerable groups, and align global policies with regional transitions.

6.1. RESEARCH PROCESS

At the beginning of my research, I agreed with scholars saying that the regional or sub-national scale makes sense to address energy transitions because economic sectors that are relevant for the energy transition tend to be larger than a municipality, but smaller than a country. Since previous studies described energy regions as a potential governance bridge to carry out a transition between the national and municipal levels [19], I thought I could use the same bridge to address energy injustices.

Therefore, this study began with the research question of how to understand energy justice in energy regions. At this point, the concept of energy regions was somewhat limited to a few cases in Europe, especially in the Netherlands, with the Regional Energy Strategies (RES). RES in the Netherlands is a national program in which sub-national territories (regions) are in charge of defining an energy transition strategy. The RES program is one of the first ones, known in the Global North, in addressing regional energy transitions, and it sounded as a promising approach for other regions elsewhere.

My PhD research was funded by the EU H2020 Tipping Plus project, which focused on the sustainable transition of CCIRs. In the Tipping Plus project, we were aware of the large literature field on coal regions, which studies how coal sectors phase out and their multidimensional consequences. I thought that a similar approach to the RES, focused on energy governance, could help CCIRs to develop a comprehensive transition strategy that minimizes negative impacts. However, the concept of energy regions and CCIRs was yet to be linked.

This led me to conduct a systematic literature review of energy regions (Chapter 2) that covered diverse sectors and contexts. To guide this review, I opened up the existing energy regions framework to other contexts by applying a framework based on sustainability transitions, regional and innovation studies. My proposed typology opened up the energy region definition to five types of regions, including CCIRs as a subgroup of peripheralized regions. The proposed typology of energy regions serves as a map to locate different energy regions in terms of their transition progress and type of governance arrangement. This typology helped me as a framework to classify regions in the explored case studies (see section 6.3.1 for further information).

Once I had a clearer idea of what energy regions entailed, I explored the energy justice dimension. When going deeper into the justice literature, I realized that much attention was given to the distributional dimension of justice, whereas less was studied on procedural and recognition justice. Especially, research on how to reach recognition justice is scarce, probably because the citizen groups that need or should have recognition in the energy transition are not the common target in energy transition studies. I have to remark here, saying that in my research I tried to include those groups that for injustice reasons should be included in a transition strategy, but also to come up with frameworks that allowed the inclusion of different groups; I refer to this pool of groups as diverse citizen groups. Another challenge is reaching these diverse citizen groups with transition strategies that go beyond a local project. In national-level transition

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strategies, there is little knowledge about who these diverse citizen groups are and how they could participate in the transition. Although at the local level it is more feasible to identify these groups, the reach of local projects is limited, and they cannot reach a nationwide transition. That is why addressing justice at the regional level sounded like a promising approach.

I delved into a case study to understand whether energy injustices could be addressed at the regional level. However, I was unable to answer this hypothesis until later in my research (see Chapter 5). Chapter 3 analyzed energy injustices experienced by citizens in a wealthy Dutch energy region that experts thought would not be relevant to identify citizen groups that struggle with energy injustices and have not been included in the regional transition strategy. Choosing this case was strategic because if I were able to find energy-vulnerable groups in this wealthy region, I could expect a similar trend in the rest of the country and other countries with less funding for the energy transition.

The Dutch case study not only confirmed that energy vulnerable groups are present in high-income regions, but it also helped describe the types of energy vulnerabilities and which groups tend to experience them. It described energy vulnerability as an intersectional phenomenon that occurs when certain social and economic characteristics and levels of knowledge are combined (see section 6.3.2 for further information). I believe the presented framework can be applied in other regions elsewhere to identify vulnerable groups in the transition. This was later proved when I added some dimensions to the framework from the Mexican case study (see Chapter 5).

Furthermore, I wanted to explore justice in multiple cases as I had the chance to do so in the H2020 Tipping Plus project. My goal was to prove that the progress of an energy transition and the status of energy justice affect each other. Given the available number of cases, I chose QCA as a method of comparison. However, I could not encompass all three justice tenets (distributional, procedural, recognition) in the study, as interpreting procedural and recognition justice with indicators, even fuzzy indicators, was not possible, at least not for the data that I had available at the moment. That is why I focused on a distributional justice aspect that is also related to energy poverty, that is, household energy affordability. The fs-QCA studied what conditions of regional transitions in CCIRs have an impact on households' energy affordability. From a wide pool of conditions, the relevant ones were selected and presented in the paper. The main conclusion of this study is that the regional and international conditions in which a region transitions have an impact on households' energy affordability. Particularly, the regions that have the techno-economic feasibility to transition their CCI sector have an advantage in energy affordability over regions that are forced to phase out their CCI sector without an economic alternative (see section 6.3.3 for further information).

After these studies, a missing piece in my research was going deeper into the previously identified vulnerable groups and understanding their potential role in a transition and at what transition scale. This gap was addressed with my last case study in an energy region in the cross-border region between Mexico and the United States. This region

shared a similarity with the Dutch case study in the carbon-intensive sector; both rely heavily on the import of oil and gas, and the bigger challenge in these regions lies in transitioning the oil and gas sector. Since the region in Mexico is my place of origin, I had the social network and knowledge to build a research team and reach vulnerable groups there. I also tried in the Dutch case study, but even with having a local student conducting interviews in the region, they lacked the preparation and time to reach vulnerable groups.

The study in the cross-border region was a long process that started early in my PhD. First, I did an exploratory study with surveys, interviews, and workshops to identify energy justice issues and potential vulnerable groups. In this exploration, I worked with high-school students who came up with regional transition strategies during workshops. This work has not been included in these due to time limitations, but the ideas raised during this study helped me design a better survey presented in Chapter 5.

Chapter 5 applied an online and in-person survey targeted to hard-to-reach (HTR) groups and a discrete choice experiment and a latent class choice model to describe their preferences. This study shed light on a methodology to reach HTR and vulnerable groups, which also requires the preparation of a researcher in the field and local knowledge. This study concluded that energy vulnerable groups can be hard to reach, but with suitable communication means, they are very much interested in having an active role in the energy transition (see section 6.3.4 for further information). According to intersectionality theory, having representatives of diverse groups, including energy vulnerable groups, is necessary to address the injustices that they have faced.

This study also revealed that energy projects governed through a combination of local, regional, and national authorities, with active citizen involvement, can incentivize greater public participation. This means that the regional scale as a governance bridge is positively perceived by diverse citizens. Furthermore, framing these projects in terms of justice can serve as an effective intervention to engage diverse citizen groups. However, projects framed with energy justice must not only appear to be more just but actually make efforts to be more just. Trust from citizens in transition strategies and governance arrangements is key to their participation.

6.2. Conclusion

The case studies and my involvement in the Tipping Plus project helped me reflect on whether the regional level is suitable to address injustices in CCIRs. First, I conceptualized the energy injustices faced by citizens into four types of energy vulnerabilities in Chapter 3: Access to energy; Affordability of energy consumption and transportation; opportunity to own self-generation technology, and; inclusion in decision-making processes. Although these vulnerabilities occur at the local or municipal level, they are heavily influenced by regional, national, and international conditions, as shown with the QCA study on energy affordability (Chapter 4). This influence suggests a

multi-level governance approach to addressing energy vulnerabilities. However, even in a multi-level governance case like in the Netherlands, energy vulnerabilities are mostly handled by municipalities, which struggle to have the resources to tackle them. This is where the regional level can come into play because it has the potential to identify the issues each municipality in the region faces, coordinate efforts across municipalities, and communicate to the national level what aid is needed in the region. In a context like the Netherlands, which is divided into 30 energy regions, handling requests from 30 parties is more manageable than listening to individual municipalities, as most energy vulnerabilities will be repeated across the country.

However, another important finding is the need to have diverse citizen representatives in regional energy strategies. My research emphasizes the importance of inclusive governance arrangements that incorporate citizen participation, especially from vulnerable groups (see 6.3.5). This focus should not be understood as suggesting that participation is the solution to energy injustices, since multi-level factors such as technical feasibility and international policies also influence justice, as discussed in Chapter 4. However, participation is proposed here as a channel to bridge formal and informal governance arrangements and, thus, open the door to collaborations that shape and help realize energy transitions.
Governance arrangements that adopt social innovations and involve citizen representatives can empower local organizations and citizens, whereas top-down approaches often fail to integrate diverse perspectives, particularly those of vulnerable groups. Integrating groups' perspectives is not only a normative decision, but it can help better understand energy vulnerabilities and open the door to collaboration between the government and vulnerable groups. An interesting and exciting finding is that citizens, particularly young people, vulnerable groups, and hard-to-reach groups, have a willingness to take on leadership roles in energy transitions. This reaffirms the need to shift transition efforts in energy regions toward more active citizen involvement in energy governance.

A positive effect of collaborating with diverse citizen representatives is the potential to spread the low-carbon transition. The participation of many actors in the energy transition has been criticized for slowing down the transition, for example, because reaching a consensus among actors with different interests is difficult [402, 403]. However, my results suggest that the formal involvement of citizens as local leaders can lead to the creation of more local energy projects. Similarly, the involvement of citizen representatives in regional energy governance can help find ways to reduce and mitigate energy vulnerabilities. Thus, by addressing energy vulnerabilities and spreading local energy projects, citizen involvement would indeed increase complexity in decision-making, but at the same time, it would offer the possibility to spread and thus advance low-carbon transitions.

6.3. Interpretation of main findings

The answer to the main overarching research question of this thesis (*what governance arrangements can be applied in coal and carbon-intensive regions to address energy*

injustices, while advancing a low-carbon regional transition?) is addressed after answering the research objectives and each paper's research question. This doctoral research project utilized a variety of methods, including a mixed-methods approach to answer each question.

6.3.1. ADDRESSING OBJECTIVE A

> Objective A: Understanding what institutional arrangements conform to and what characteristics energy regions have that influence their transition.

A systematic literature review, presented in Chapter 2, was conducted to identify energy region types and examples to meet objective A. This study proposes a typology of energy regions by drawing from sustainability transitions, regional studies, and innovation studies. The typology describes energy regions with one or more of the five identified energy region concepts. Among these five concepts, three are geographical concepts: City-regions, peripheralized regions, and coal and carbon-intensive regions. The other two concepts are related to the region's transition trajectory: Learning regions and (top-down) renewable energy regions. Each geographical energy region type can follow at least two different transition pathways (see Figure 6.1), following a learning or a top-down approach. The long-term success and stability of these transition pathways require support from formal institutions. Interestingly, the systematic review revealed that the type of innovation (technological and/or social) influences the justice aspects of transitions. For example, only those energy regions that adopted social innovations (during the learning phase) had the potential to empower their organizations and citizens; technological innovations alone do not necessarily contribute to just transitions. Regions following a top-down transition fail to integrate new perspectives, like those from vulnerable groups in the Rotterdam-The Hague region, described in Chapter 3. This study opened up the concept of energy regions to different geographical and governance contexts, including CCIRs.

6.3.2. ADDRESSING OBJECTIVE B

> Objective B: Understanding what energy injustices occur in transitioning energy regions in different contexts and identify what institutional arrangements (un)favour the correction of injustices and the inclusion of diverse citizen groups.

Chapters 3 and 5 use in-depth case studies and a representative survey to meet objective B. The Dutch case study was conducted to identify vulnerabilities and vulnerable groups in an energy region, in this case, the Rotterdam-The Hague region in the Netherlands. In this Dutch case study, a media analysis of local and regional newspapers was used as a proxy for social opinion on energy (in)justices. Additionally, stakeholder interviews were conducted and analyzed through an energy justice intersectional lens to identify vulnerable groups. However, vulnerable groups were not directly interviewed in the Dutch case study. This was later addressed in the US-Mexican case, in which vulnerable groups were surveyed, thus providing a broad perspective on energy injustices.

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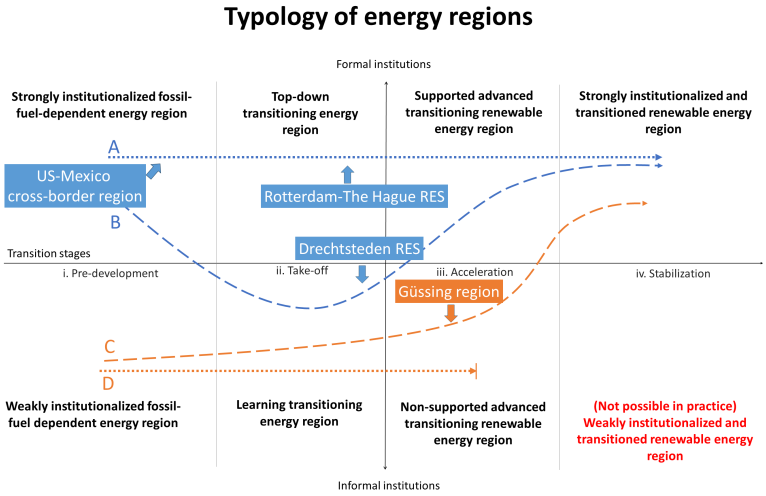

Curve	Transition pathway	Geographical energy region concepts	Transitioning energy region concepts
A.	Top-down and stable	City regions	Top-down renewable energy region
B.	Learning and stable	Peripheralized, CCIRs and city regions	Learning region and renewable energy region
C.	Learning and stable	Peripheralized regions	Learning region and renewable energy region
D.	Learning and non-stable	Peripheralized regions	Learning region

Figure 6.1: The energy region typology serves as a reference for the case studies.

The insights of the RDH-RES case study and the survey study in the Mexico-United States cross-border region show that citizen groups can face several types of vulnerability in an energy region, such as: Access to energy; Affordability of energy consumption and transportation; opportunity to own self-generation technology, and; inclusion in decision-making processes. The groups that experience these vulnerabilities are referred to as vulnerable groups. As presented in Figure 6.2, these vulnerabilities are concentrated in six groups, which present at least one of eight vulnerability conditions such as living in an energy-inefficient house. According to citizens' perception, energy poverty is more dominant in the transport sector, compared to poverty for cooking (with gas) and electrical appliances (with electricity).

Empirical evidence from the Dutch case study shows four barriers that prevent policies from engaging with vulnerable groups: 1) municipalities' limited (financial) capacity; 2) municipalities' limited manpower capacity and knowledge on justice and vulnerabil-

ity; 3) lack of data about vulnerable groups; and 4) mistrust of citizens toward the government. The findings on energy vulnerabilities (except for energy access, which was identified in the Mexico-US case) and barriers are likely to be repeated in other energy regions in the Netherlands. However, further vulnerabilities can be present in more rural regions, and the distribution of energy vulnerability types can vary from one region to another. Although vulnerability conditions may be similar across regions, it is important to examine the specific characteristics of each one, as their context, governance arrangements, and stage of transition (see energy region typology) influence how vulnerabilities can be addressed and how vulnerable groups can be included.

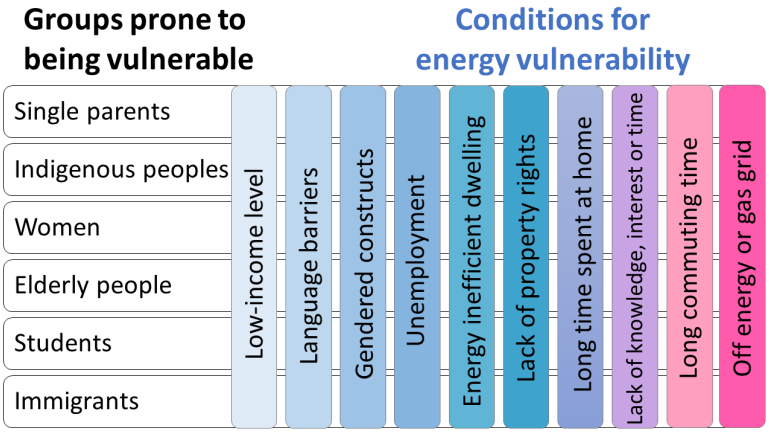

Figure 6.2: Overview of intersectional energy vulnerability in energy regions, based on the RDH-RES and the Mexico-US cross-border region.

6.3.3. Addressing objective C

Objective C. Understanding what possible contextual conditions influence a region's transition pathway and the creation or correction of energy injustices.

Chapters 4 addressed objective C by drawing from energy poverty, energy affordability, and regional studies. This study employed a fuzzy-set Qualitative Comparative Analysis of fourteen CCIRs to understand the impact of the contextual conditions of regional transitions on household affordability. The QCA determined that there is no one-fits-all combination of conditions that can lead to energy affordability in all CCIRs. Thus, a more in-depth qualitative case study analysis was performed to capture the nuances of the QCA results.

According to the QCA results, for all CCIRs, energy affordability was influenced by a combination of regional, national, and international conditions. Particularly, the CCI sector independence and policy mixes at the country or continent level were relevant for the energy affordability of CCIRs. In terms of transitioning carbon-intensive regions, the support of (inter)national policy mixes to the regional energy transition was always

present for energy affordability, an outcome supported by [350]. A sector's technical feasibility to transition is associated with affordability in transitioning CCIRs. The terms phasing-out (with no technical feasibility) and transitioning CCIRs (with technical feasibility) can be employed to distinguish between these regions. In general, phasing-out regions like some coal regions were found to have a more negative impact on energy affordability. Whereas in transitioning regions, regions with renewable-energy generation tend to perform better on households' energy affordability. Since these findings are based on CCIRs in different European countries as well as in Indonesia, Canada, Greenland, and Mexico, one can apply these findings to other similar CCIRs.

6.3.4. ADDRESSING OBJECTIVE D

> Objective D. Understanding what governance arrangements and interventions can be proposed in energy regions to address energy injustices experienced by diverse citizen groups while advancing the low-carbon transition.

Chapter 5 addressed Objective D by applying the energy justice frameworks and the concept of citizen participation. The method included a representative survey and a discrete choice experiment, which were applied to analyze the effect of perceiving justice on citizens' willingness to participate in the transition in the US-Mexican region. A combination of an online representative sample and an in-person targeted sample to vulnerable groups was used.

Any governance arrangement that seeks to address energy injustices requires the participation of citizen groups, particularly the representation of vulnerable groups in the decision-making process at the municipal and regional levels. In general, citizens (89%, see 5) are interested in participating in the energy transition in any form, instead of not participating. The majority have a stronger willingness to participate at the household level (e.g., adopting sustainable measures at home such as changing bulbs to LED and recycling waste) than participating as local leaders. Interestingly, vulnerable and hard-to-reach groups showed above-average knowledge of energy-service-related issues (energy injustices) and showed a stronger willingness to be leaders of community energy projects.

According to our findings, in terms of governance scale, vulnerable groups tend to prefer local and state-level projects organized by a combination of civil society, local, regional, and national organizations. The largest citizen group (54% of the whole sample) that showed willingness to be a local leader was youth. High school students in the US-Mexican case formulated their desired ideas for a future energy system. Their proposed ideas focused on diverse areas, including environmental protection, phasing out fossil fuel imports for the electricity and transport sector, addressing water and gasoline scarcity, and promoting citizen participation. They proposed decision-makers from national, state-level, and citizen organizations. They perceive the society with the role to supervise and organize local activities, and the government with the role to regulate and ensure actors comply with goals to ultimately reduce social inequality.

The effect of perceiving justice in energy projects was analyzed as a potential intervention to incentivize citizen participation. The perception of both distributional and procedural justice motivates citizens to participate, where distributional justice has more influence than procedural justice. Respondents prefer to focus on the provision of technologies to those who have issues paying the bill, followed by all households without electricity, rather than providing clean technologies to the 30 percent of randomly assigned households. Perceiving procedural justice as a decentralized and citizen-inclusive decision-making process motivates citizens to participate. All combinations of government levels and citizens were preferred over having only the federal government as the decision-maker, which is not the case in Mexico and the US.

My study shows that HTR and vulnerable groups value energy projects the most. Despite their energy struggles in meeting basic energy needs [401] and far from being conflicted with other priorities, as it has been previously reported [244], HTR groups like the energy-poor, off-grid, immigrants, long-commuters, Indigenous communities, and female groups showed a strong interest in actively addressing local sustainability issues. The respondents who belong to an Indigenous community raised the issue of fossil fuels and the high prices that people face. They also mentioned that the energy system should help families' economies and the environment by generating energy from renewable sources.

6.3.5. Answering the main research question

Chapters 2 to 5 helped answer the overarching research question as presented in Figure 6.3. The Discrete Choice Experiment and US-Mexico studies revealed that participants prefer governance arrangements where the three levels of government (municipal, state, and national) and citizens make the decisions on local energy projects. The results show that the majority of citizens are willing to adopt more sustainable measures at the household level, which indicates a big opportunity to accelerate the transition through household-level projects. Particularly, vulnerable and HTR groups prefer more involvement of citizens in the decision-making process at the local and regional level. Vulnerable, HTR, and young citizen groups are more willing to volunteer as local leaders in the energy transition, compared to the rest of the population. Regional governance arrangements have differences in non-Western contexts: A governance arrangement that acknowledges and bridges Indigenous and informal local governance structures. This is not fully described by the concept of polycentricity, which is mostly applied in Western contexts.

6.4. Research contributions

6.4.1. CCIRs and energy regions

In this research, I provide a first conceptualization of coal and carbon-intensive regions as energy regions in regional innovation and governance literature. CCIRs are defined as regions with socio-economic dependency on an upstream (extraction) or downstream (consumption) fossil fuel sector (Martínez-Reyes et al., 2025). CCIRs are a subgroup of

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peripheralized regions with carbon lock-ins and locked or limited formal institutions (e.g., written rules, laws, policies, and plans) that may be overcome with the support of informal institutions (like shared values, non-institutionalized ways of organizing). This has implications on the approach to address the sectoral transition in CCIRs.

More broadly, I opened up the definition of energy regions by constructing a typology. This research has contributed to regional energy governance studies by identifying conceptual differences between regions and connecting them with sustainability transitions literature. The proposed typology is composed of: three geographical concepts, city-regions, peripheralized regions, and CCIRs; and two transition concepts, learning regions and (top-down) renewable energy regions. The five energy region concepts differ in their governance arrangement, innovations they pursue, and stage of transition. The governance of energy regions was described by combining evolutionary governance theory, RIS, and TSI frameworks.

From a governance perspective, regional actors can develop and implement energy transition strategies with varying levels of institutionalization. This flexibility is particularly significant in peripheral regions, where informal institutions often play a key role in kickstarting the energy transition. In contrast, formal institutions have predominantly driven the transition in urban regions from the outset. Another important insight is that different forms of innovation—such as social or technological—contribute to initiating low-carbon transitions in energy regions. In urban areas, technological and policy innovations are especially critical, while in peripheral regions, social innovation tends to play an even more vital role. This study shows that city regions and peripheralized regions face different challenges to transition because of their unique characteristics. These barriers can be overcome depending on the innovations and governance approach adopted.

6.4.2. THE TRANSITION OF ENERGY REGIONS

The transition of energy regions, including CCIRs, requires a broader socio-economic transition approach to successfully bring the energy region to a prosperous path, while phasing out or transitioning a fossil-fuel-dependent sector. This means that a sustainability transition cannot focus solely on phasing out a sector, but on creating opportunities for the work force in the CCIR sector and the businesses surrounding the sector, while strengthening local economies. To explain this process, I combined the regional innovation systems (RIS) framework [109] and the transformative social innovation (TSI) framework [95] with regional governance [55]. To start transitioning, CCIRs, that face path dependencies should become learning regions to overcome limited resources and unsupportive formal institutions. However, to reach a stable transitioned phase, regions need the institutionalization of the new adopted visions and pathways. This research shows that the energy region framing goes beyond a particular sector and focuses on the regions' capacities and abilities to transition.

In terms of just transitions, the type of adopted innovation, whether technological or social, matters. An energy region's policy and development agenda determines the

type of innovation process the region follows: technological, social, or both. Social innovation is linked with promoting citizen empowerment in energy regions, whereas technological innovation has been more focused on economic growth. For instance, the transition process of renewable energy regions in Austria and Germany that aim for a shared regional autarky cannot be described by the RIS framework alone, focused on economic growth. Instead, these regions are better described with the TSI framework because of citizens' active role in defining visions and owning energy projects. The combination of social innovation practices and (in)formal institutions may enable the empowerment of collective actions like community energy initiatives (e.g., in Austrian and German 'Energieregionen').

The results of the fs-QCA study show that the contextual conditions that influence just transitions in CCIRs depend on the adopted transition pathway type. Regional conditions like CCI sector independence and technical feasibility are relevant for both types of pathways (when the CCI sector is phased out or has the option to transition). This had not been previously reported in regional energy transition studies. The terms phasing-out (with no technical feasibility) and transitioning CCIRs (with technical feasibility) can be employed to distinguish between these regions. One could conclude that if a carbon-intensive sector does not have alternatives to decarbonize, it might risk a decline if a low-carbon regional transition strategy is adopted.

Additionally, the alignment of international policy mixes with the regional transition was found to be highly associated with high energy affordability in transitioning regions. Regional and (inter)national conditions were always combined in all fs-QCA results, highlighting a multi-level governance nature of energy regions. This suggests that it may be necessary for policymakers to synchronize an energy transition strategy with regional economic development plans to avoid negative socioeconomic impacts during the CCI sector's transition or phase-out. It is important to note that transition policies may negatively impact affordability in the long term if they overlook regional challenges like carbon lock-ins or energy poverty. Therefore, it should be considered that national and regional levels of government coordinate their strategies to combat energy poverty and avoid path dependencies. This applies to both the EU and non-EU regional cases studied (European Commission, 2020).

6.4.3. JUSTICE AND VULNERABILITY IN ENERGY REGIONS

This research project conceptualizes and explains citizen energy vulnerability in energy regions as an intersectional justice phenomenon. The combination of groups prone to being vulnerable and conditions for energy vulnerability puts these groups at higher risk of experiencing energy vulnerability. Vulnerability occurs when one or more vulnerability conditions are met. This evidence-based finding advances just transitions frameworks in describing what distribution, procedure, and recognition justice look like for different citizen groups. This is an important distinction because it allows one to disentangle the complexity of intersectional energy vulnerability. Previous studies stated that the causes of energy poverty are a combination of energy prices, building stock infrastructure, and socio-economic and demographic factors [285, 404].

Although this conceptualization is comprehensive, it does not prove practical when it comes to identifying the groups who experience energy poverty. Similarly, focusing on group characteristics can lead to the conclusion that one should look for gender, power, ethnicity, and class to identify vulnerable groups. However, families could meet these socio-economic and demographic characteristics yet still not experience energy vulnerability, for example, because they live in a high-performance, energy-efficient house. That is why I believe that my distinction between groups prone to vulnerability and vulnerability conditions is a step toward building policymaking tools to identify and target vulnerable groups.

The research also identified four general types of energy injustices prevalent in these regions: Lack of access to electricity, gas, and transportation; lack of affordability in energy consumption and transportation; lack of opportunities to own self-generation technology; and exclusion from decision-making processes. Notably, energy affordability is typically lower in regions phasing out fossil fuels compared to those transitioning within the upstream and downstream CCIR sectors. Additionally, the study found a strong association between regional fossil-fuel dependency and energy affordability. Vulnerable groups identified include single parents, Indigenous peoples, women, older adults, students, and immigrants, with energy poverty being more prevalent among low-income and migrant groups, particularly in the Mexico-US cross-border region.

Perceiving justice in energy projects can increase citizens' willingness to participate in the transition. Especially, distributional justice had a higher influence on the participants' choice than procedural justice. The attribute representing distributional justice is the group of actors receiving solar panels for free, and for procedural justice, it was the attribute describing the decision-makers. This may be because of the direct connection of distributional justice with energy access and poverty. However, in decolonial contexts, the governance arrangement should recognize Indigenous communities as a local authority and allow them to make decisions and influence the shape of local transition pathways.

Citizens perceive their role as more active and leading, which does not fall under the stakeholder management theory categories nor the consumer-prosumer citizen dichotomy. Interestingly, youth and vulnerable groups stated that there should be more room for citizen participation in energy decision-making. Contrary to theoretical expectations, vulnerable groups did not show egoistic behaviour (not participating or preferring to participate at the household level) but rather a greater willingness to volunteer and help other vulnerable groups. This is likely because these groups could benefit if they volunteer, as they experience energy-related issues. This could also be related to vulnerable groups having a higher level of understanding of energy issues than average citizens. Thus, engaging with young people and vulnerable groups has the potential to spread local sustainable energy projects.

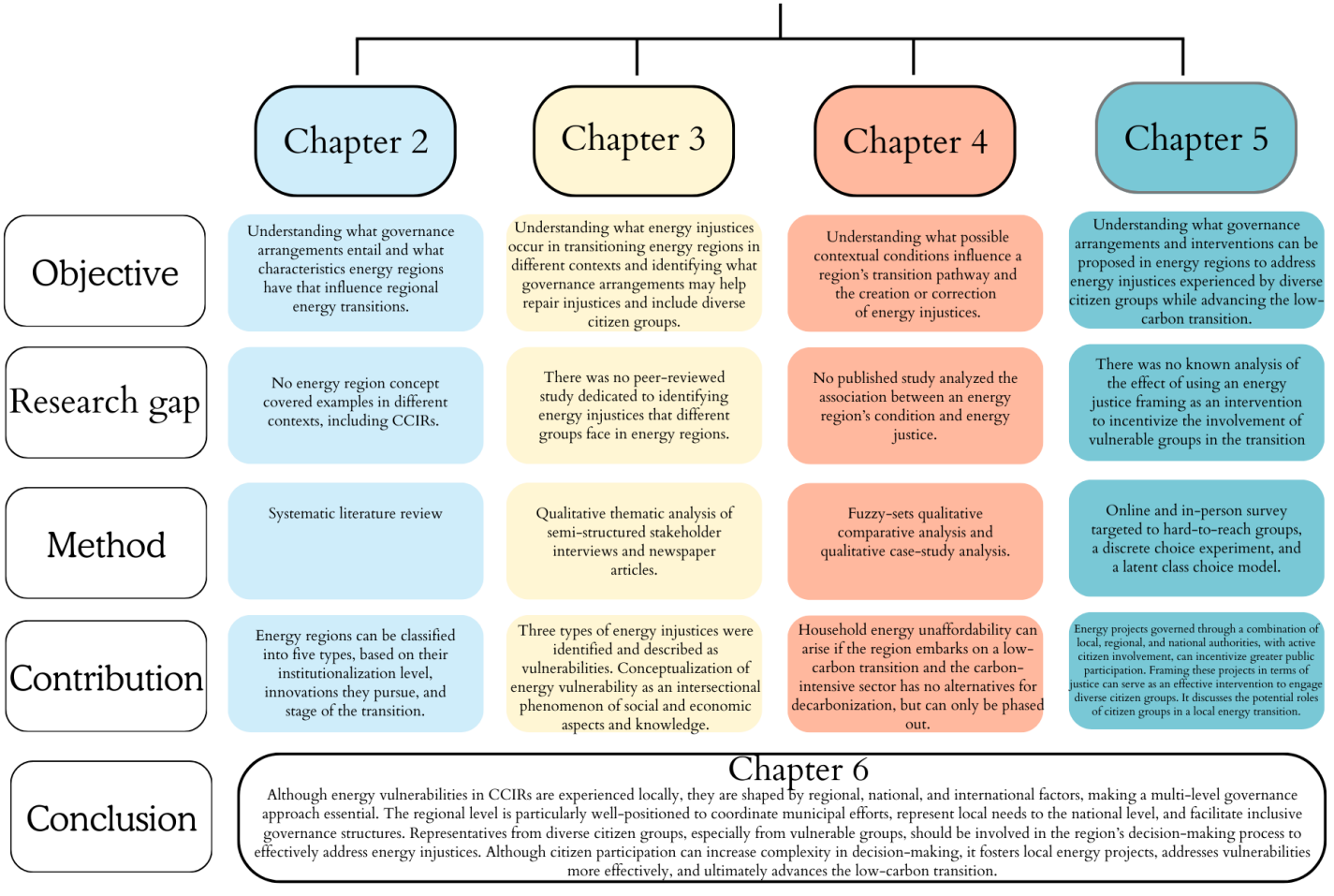

Figure 6.3: Research question and objectives

6.5. POLICY RECOMMENDATIONS

This research highlights the critical need for policymakers to develop strategies that are sensitive to the diverse characteristics and stages of energy transitions across different regions. The typology of energy regions identified in this study — city-regions, peripheralized regions, and CCIRs — offers a valuable framework for designing differentiated and regionally attuned transition pathways. As this typology distinguishes between the socio-economic and institutional specificities of each region, this tool can inform decision-makers about their region's potential transition trajectory and thus, make adjustments accordingly.

One of the primary recommendations emerging from this research is the establishment of regional innovation platforms in a country to facilitate cross-regional learning and collaboration. Such platforms would enable regions at different stages of transition to exchange insights, best practices, and resources, fostering a collaborative environment that accelerates innovation and strengthens the social fabric of energy transitions. The creation of these platforms would also contribute to building capacities within less-privileged regions, allowing for more equitable progress across different regional contexts.

In peripheralized regions, while informal institutions and emerging grassroots agents play a critical role in initiating transitions, long-term stability requires the sustained engagement and support of formal institutions, particularly national governments. Policy interventions should therefore focus on reinforcing the capabilities of informal actors through consistent political and financial support, while fostering an environment where social innovation practices can thrive. The experiences of peripheralized regions in Germany and Austria offer valuable lessons, demonstrating how informal institutions can be leveraged effectively when embedded within supportive formal frameworks.

City-regions, on the other hand, must prioritize the empowerment of local economies and citizens, embracing the role of new agents in the energy transition. A focus on inclusivity is essential, ensuring that citizen-led initiatives and decentralized energy solutions become central elements of urban transition strategies. Strengthening mechanisms for citizen participation not only enhances the democratic legitimacy of energy transitions but also promotes more resilient and socially sustainable urban energy systems.

Addressing energy vulnerabilities is another crucial dimension of an equitable energy transition. Active leadership and participation of intersectionally vulnerable groups, particularly youth and marginalized communities, must be at the forefront of policy designs. Youth, in particular, have demonstrated a strong commitment to leading community-level projects, yet often lack formal channels for participation. Municipal governments can consider establishing inclusive spaces that facilitate such engagement while simultaneously receiving the necessary human capital, expertise, and resources to address energy justice issues effectively. Regional governance structures can play a critical coordinating role, supporting municipalities by focusing specifically on energy vulnerability and justice.

Furthermore, energy justice policies must be broadened beyond the narrow aim of ensuring affordable electricity. A comprehensive approach should be adopted that guarantees accessibility and affordability across a wide range of energy services, including natural gas, gasoline, and public transportation. This broader understanding of energy justice is particularly important for rural and marginalized communities, whose energy needs are often overlooked in narrowly defined policy frameworks.

Finally, global and supranational energy policies should be flexible enough to enable or not disable a region's low-carbon-transition efforts. When global policies (indirectly) set hurdles for a transition strategy, local realities risk undermining both affordability and justice, with long-term adverse consequences. Therefore, global energy governance should strive to promote CCIRs' transitions, as well as offer flexibility and resources that help transform the diverse socio-economic and political landscapes of energy regions.

6.6. Limitations and recommendations for future research

The developed typology of energy regions presented in Chapter 2 was drawn from peer-reviewed studies, which were mostly focused on Western European cases. This limits the generalizability of the proposed typology. Studying cases in other regions worldwide with a focus on energy regions can help expand the list of geographical energy region concepts beyond the peripheralized, CCIRs, and city-regions. Additionally, regions that follow different or more nuanced energy transition trajectories can help refine the transition processes (e.g., learning and top-down trajectories) that the typology describes. Increasing the robustness of the typology can help other regions identify their energy region type as well as potential changes that help correct their transition trajectory. Particular attention should be given to coal and carbon-intensive regions (CCIRs), which remain relatively understudied within the broader discourse on regional energy governance. There is a pressing need for more recent and diversified empirical evidence on how peripheralized CCIRs can transition towards becoming learning and renewable energy regions. Further exploration of these dynamics would not only enhance theoretical frameworks but also offer practical insights for policymakers seeking to steer complex transition processes. An open and critical question that warrants deeper investigation is the capacity of energy regions to simultaneously navigate and align local and national agendas, especially in the face of competing interests and priorities.

Although this doctoral thesis shed light on the operationalization of recognition and procedural justice in Chapters 3 and 5, a comprehensive review or comparison of different regions' recognition and procedural injustices and measures to mitigate them was not performed. My fuzzy-set Qualitative Comparative Analysis (fs-QCA) study could only cover one aspect of energy justice: household's energy affordability because of the complexity of recognition and procedural justice. Although fs-QCA helps systematically compare different cases, I can only recommend it to study recognition

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and procedural injustices, once there is a better understanding of what conditions may cause or reinforce such injustices. At this point, these two tenets need focused deep qualitative studies with an intersectional lens to disentangle the conditions or factors that are associated with them. These case studies should cover different regional and socio-political contexts, as they influence the impact on energy justice (QCA finding). Once more understanding is available on these two tenets, quantitative and qualitative data ex-ante and ex-post a fs-QCA will help understand the complex causal relationships around procedural and recognistion justice.

The intersectional energy justice approach I developed in Chapter 3 and expanded in Chapter 5 describes energy injustices as an intersectional phenomenon, where certain conditions make citizen groups vulnerable. However, these findings are based in two energy regions. This empirical limitation can be overcome by applying the proposed framework in diverse cultural, political, and economic contexts. To deepen our understanding of energy injustices and to identify ways to mitigate them, researchers should discuss with those groups that experience energy injustices. Involving hard-to-reach (HTR) communities, including Indigenous peoples and other marginalized groups is essential for capturing a wider range of experiences and insights that are typically underrepresented in mainstream energy transition studies.

Finally, there is significant value in validating citizens' willingness to participate in energy transition processes through participatory and innovative methods. A limitation of the survey presented in Chapter 5 is that although it describes how justice influences citizens' willingness to participate, it cannot prove what the actual participation level would be in a real-world energy transition project. It is recommended to study the involvement of intersectional groups in a regional-scale energy project. However, such studies require a long timeframe that may exceed a PhD's research duration. Another tools that can give a perspective a bit closer to reality are game-based scenario techniques like actor constellation and scenario integration [405]. These participatory methods offer a promising avenue for generating more accurate and realistic insights into public engagement. Applying such engagement techniques can help bridge the gap between theoretical assumptions about citizen participation and actual behavioral patterns, thereby informing the design of more effective and inclusive transition policies and interventions.

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Propositions

accompanying the dissertation

SOCIAL INCLUSION IN THE GOVERNANCE OF ENERGY REGIONAL TRANSITIONS:
THE CASE OF COAL AND CARBON-INTENSIVE REGIONS.

by

Amanda MARTINEZ REYES

1. The energy transition can only be just if governed by vulnerable groups "(This Thesis)".
2. The energy transition is conservative.
3. Cats don't mind rain, just like the Dutch.
4. Energy companies are not competitive in an environmentally conscious society.
5. Pursuing a full decarbonization of the energy system slows down and impedes the energy transition.
6. Borrowing concepts from the natural world and applying them to the social world is misleading, such as the concept of 'tipping points.
7. Social inclusion in the energy transition is instrumental "(This Thesis)".
8. Nowadays, being more efficient does not mean consuming fewer resources.
9. Today's political instability leads to a greater desire for self-sufficiency.

These propositions are regarded as opposable and defendable, and have been approved as such by the promotor Prof. dr. G. de Vries, promotor Prof. dr. T. Hoppe, and copromotor Dr. J. Lieu.

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Social Inclusion in the Governance of Regional Energy Transitions: The Case of Coal-and-Carbon-Intensive Regions

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