Heating up the energy transition

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Heating up the energy transition: Comparing energy justice and energy decision-making in individual and collective heating systems to support a just heat transition

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ABSTRACT

This paper explores how individual and collective heating systems influence citizen agency and energy justice in the heat transition. Drawing on interviews with stakeholders knowledgeable about or involved in these systems across eight European countries, we examine how different types of heating systems influence energy decision-making capabilities and justice outcomes. Combining the Energy Justice Decision-Making Framework with the Capability Approach, we analyze differences in availability, affordability, due process, good governance, sustainability, equity, and responsibility.

Our findings reveal that collective heating systems, while limiting individual autonomy, offer advantages in efficiency, affordability, and environmental sustainability. Their centralized management and economies of scale may support the integration of local renewable energy sources and can protect vulnerable populations from energy poverty, thus advancing distributive justice. However, realizing these benefits requires transparent governance and citizen-inclusive processes.

In contrast, individual heating systems provide greater autonomy and flexibility, allowing households to tailor solutions to their preferences and financial circumstances. Yet this decentralization can lead to operational inefficiencies and fragmented efforts, which may slow down the pace of the heat transition. Additionally, high upfront costs for sustainable technologies may exacerbate inequalities, particularly for low-income households.

This study identifies justice gaps across both system types and highlights the trade-offs between autonomy and equity. We argue for institutional adaptation and regulatory innovation to enable capability-sensitive, socio-technical arrangements that support inclusive, sustainable heat transitions.

1. Introduction

The heat transition is a key part of the broader energy transition, which involves shifting away from conventional heating methods to less carbon-intensive alternatives. The heating sector contributes significantly to global greenhouse gas emissions and is a major challenge for decarbonization, primarily due to its reliance on fossil fuels such as natural gas, oil, and coal. Within the European Union, 79 % of the total final energy use by households is for providing space heating and hot water, while 84 % of both heating and cooling loads are serviced by fossil fuels, primarily natural gas and oil [1]. The industrial sector was directly responsible for a quarter of global energy system carbon dioxide emissions in 2022 [2], and space heating in the built environment accounted for 10 % of the total carbon dioxide emissions [3]. Alternative solutions such as individual household-level systems like heat pumps and solar thermal technologies, as well as collective systems such as district heating networks and thermal energy communities that use renewable energy sources, offer more sustainable pathways for decarbonizing the heating sector, while also contributing to improved air quality [4,5].

Central to realizing the heat transition is not only the adoption of alternative technologies but also the integration of energy efficiency measures across the built environment, the development and integration of smart technologies as part of the next-generation heating systems [6], and the provisioning of basic energy needs and efforts to decrease energy poverty, considering the increasing number of energy-poor people

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or people that are at risk of falling into energy poverty [7,8]. There is also a need for transformation of the existing infrastructure, policies, markets, and consumer attitudes and behaviors [9], to ensure that the transition supports broader societal goals related to inclusivity, environmental sustainability and justice — what we define as a 'just' energy transition, and by extension, a 'just' heating transition. However, achieving a society underpinned by principles of environmental sustainability and justice that are deeply embedded in all aspects of energy use, requires viewing this transition not merely as a goal to be reached, but as a continuous process of transformation that addresses technological, social, and economic dimensions in an inclusive manner.

In realizing this just energy transition, the role of citizens and the diverse forms of citizen engagement become crucial, especially in the context of energy justice. Energy justice is typically conceptualized through three dimensions: distributive justice, which concerns the equitable distribution of the benefits and burdens of energy systems [10]; recognitional justice, which emphasizes acknowledging and respecting the rights and perspectives of all societal groups, especially those historically marginalized [11]; and procedural justice, which calls for fair and inclusive decision-making processes that engage all stakeholders [12]. However, the recognitional and procedural aspects require more attention as compared to its distributional aspects. Citizen participation is a lens through which the procedural and the recognitional aspects of energy justice can be more fully developed. It is widely recognized in the literature as a cornerstone of a successful energy transition [13–16] and is supported by national and EU policies, such as the 'Clean energy for all Europeans package' [17] and the 'Citizen-led renovation' support service [18] that ties directly to the heat transition and the need for improving the building stock efficiency [19].

Citizen engagement and participation can take different forms, including a government-led deliberative consultation, a technological trial of energy practices, grassroots innovations as well as environmental social movements [20]. These engagement forms may vary in terms of who participates (such as consumers, activists, communities), what they participate in (ranging from energy efficiency measures to the adoption of technologies), and how they participate (including but not limited to deliberative processes, protests, digital engagement) [21]. Wahlund and Palm [22] further argue that forms of citizen participation in the energy transition can be split into three groups: i) consumer forms, such as deliberative polls and consumer choices, ii) direct forms of participation, including prosumerism and organizing social movements and protests, and iii) representative forms, such as municipal ownership and participation in policy processes. By having different forms and scales of citizen engagement, the policies in the energy transition will not only be technically and economically viable, but also socially acceptable and equitable [23].

To better understand citizen engagement, it is essential to connect it to individuals' capabilities to act and make decisions within their specific social, economic, and technical contexts. Engagement is not simply a matter of willingness or motivation, but it also depends on whether individuals have the real freedom and means to participate meaningfully in decisions that affect their energy use and well-being. This includes access to resources, knowledge, time, and institutional support. To explore these underlying conditions, we turn to the Capability Approach (CA) developed by Amartya Sen, which highlights individuals' abilities to pursue the lives they value [24]. Sen [25] emphasizes that the CA recognizes how individual, contextual, and societal factors influence a person's ability to convert resources into meaningful outcomes. Furthermore, Sen [26] expands the evaluative space of well-being beyond economic indicators by acknowledging its multidimensional nature. As an evaluative framework centered on agency and human freedom [27], the CA ensures that personal capabilities and freedoms are not overlooked. CA has been used in the literature to understand the tensions between energy use, climate change mitigation and well-being attainment [28], to consider issues of energy poverty [29], to determine the social acceptability of renewable energy technologies [30], as well as to analyze the development impacts of electrification across developing countries [31].

However, there is limited exploration of the use of CA for planning and designing energy systems to build in justice considerations, as argued by Melin et al. [32] in the introduction to the 'Energy justice and the capability approach' special issue. Also, the literature is limited with cases where capabilities are considered specifically in the heating transition, and how individual heating systems such as boilers and heat pumps and collective heating systems such as district heating systems, influence people's capabilities to make decisions related to energy beyond adopting new technologies or adjusting consumption [33–36]. This limited focus signals a gap in understanding the broader capabilities people have to improve their thermal comfort within their contextual constraints, such as income levels and the feasibility of technology adoption in their households.

Building on both procedural energy justice and the capability approach, we introduce the term 'energy decision-making' to encompass all household decisions related to the energy transition, particularly the heating transition, that extend beyond individual well-being to broader societal impacts, bringing together concerns about fair inclusion in decision-making processes with an emphasis on the actual freedoms individuals have to act. From the perspective of procedural justice, energy decision-making relates to whether citizens can participate meaningfully in energy-related governance, such as through public consultations, voting, or stakeholder processes. However, grounded in the Capability Approach, our understanding goes beyond formal inclusion to focus on the real opportunities people have to make choices and influence outcomes, taking into account individual, social, and structural factors that may enable or constrain action. This includes not only the ability to adopt, operate, or afford specific heating technologies [37], but also to engage in wider civic and collective actions, such as such as prosumer activities, participation in policymaking, and municipal ownership initiatives [22]. In this way, energy decision-making reflects both the procedural and substantive dimensions of justice that enable households to shape the heating transition in meaningful ways.

These forms of engagement reflect the practical capabilities individuals possess to enhance their well-being, which is shaped by the heating systems they utilize. In this paper, well-being is primarily defined by thermal comfort, while related factors such as affordable heating costs, access to renewable heating technologies, and availability of information for example, are considered important capabilities that enable households to achieve and maintain thermal comfort. Although physical and mental health considerations are beyond the scope of this research, we acknowledge the strong connection between thermal comfort and overall health. Our focus centers on understanding the capabilities individuals need to take meaningful actions to improve their well-being and support the broader goals of the energy transition.

This paper highlights that variations in citizen capabilities across different heating systems are inevitable, as physical infrastructure inherently enables or constrains possibilities for action. To promote a just heating transition, we integrate technical realities with justice and citizen engagement considerations, examining how heating infrastructure shapes households' capabilities to make energy decisions with both individual and collective impacts. Effective policies for a just energy transition must address the interplay between technical systems such as heating, and justice dimensions, as these systems influence who has a voice in decision-making, who gains access to resources, and whose needs are prioritized. Furthermore, we explore capabilities and justice-related tensions and trade-offs in areas such as equity, access to renewable energy, operational efficiency, and system usability. Based on these considerations, we pose the following research question.

How do energy justice and citizens' capabilities for energy decision-making differ between individual and collective heating systems, and what are the implications and trade-offs of these systems for justice concerns related with the heating transition?

This study makes a novel contribution to the growing literature on energy justice and energy transition by offering conceptual, empirical, and methodological advancements. Conceptually, it bridges energy justice and the CA to assess justice not only in terms of normative ideals but also in terms of citizens' real freedoms to act, as this integration remains underexplored in the heating transition. Empirically, it provides original insights from interviews across multiple European countries, capturing a diverse range of perspectives on both individual and collective heating systems. This is particularly relevant given the limited comparative evidence on how these system types differently shape citizen capabilities for energy decision-making. Methodologically, this study shows how qualitative analysis can be used to explore the links between justice, agency, and energy systems, offering a way to connect abstract principles with practical realities and lived experiences in sustainability transitions.

This paper is structured as follows. In Section 2, a literature review is provided, laying out the energy justice arguments and their integration with the CA, along with the forms of citizen engagement and participation in the energy transition. Section 3 outlines the methodology behind this research, while Sections 4 and 5 present the results and discussion respectively, before the Conclusion.

2. Literature review

2.1. Energy justice and the energy transition

Developing effective policies to support a just energy transition requires a thorough understanding of the requirements and constraints of different technical systems. However, technical systems, including heating systems, profoundly shape households' capabilities for energy decision-making, influencing what actions they can take to improve their circumstances. This impact extends to energy justice by determining who has a voice in decision-making processes, who gains access to resources, and whose needs and identities are acknowledged — core tenets of the energy justice framework.

Energy justice extends the concept of environmental justice to the energy sector, emphasizing equitable access to energy technologies and inclusive decision-making, particularly for marginalized groups [38]. Heffron and McCauley [39] outline two primary definitions of energy justice, with the first encompassing three dimensions: distributional justice, focused on fair access to and distribution of energy services and harms [40,41]; procedural justice, which ensures transparent and inclusive decision-making processes [42]; and recognitional justice, which emphasizes the acknowledgment and representation of marginalized communities [43].

Although valuable, the three-dimensional approach is often applied in isolation, risking a fragmented understanding that overlooks the deep interconnections between these dimensions and limits the development of comprehensive, long-term strategies [44]. Additionally, this approach "does not specify who is responsible for defining justice concerns, potentially contributing to a top-down approach to energy justice that does not explicitly include the values of people on the ground" ([30], p. 1). By addressing energy dilemmas in isolation from broader issues, it fails to fully consider the challenges faced by those adversely affected by energy systems [45]. As a result, this can lead to policies disconnected from lived experiences that fail to tackle the root causes of injustices within the energy system.

In contrast to the limitations of the three-dimensional framework, the second definition of energy justice proposed by Heffron and McCauley [39] offers a more integrative and operationalized approach for analyzing energy systems. This framework, developed by Sovacool and Dworkin [40], shifts the focus toward actionable principles that emphasize key issues such as resource availability, governance structures, and affordability, as detailed in Table 1. Unlike the three-dimensional approach, which often isolates justice dimensions, this framework provides a way that links justice concerns directly to the operational and systemic aspects of energy systems.

Table 1
Energy justice decision-making framework by Sovacool and Dworkin [40].

Energy justice principle	Explanation
Availability	People deserve sufficient energy resources of high quality
Affordability	All people, including the poor, should pay no more than 10 % of their income for energy services
Due process	Countries should respect due process and human rights in their production and use of energy
Good governance	All people should have access to high quality information about energy and the environment and fair, transparent, and accountable forms of energy decision-making
Sustainability	Energy resources should not be depleted too quickly
Intragenerational equity	All people have a right to fairly access energy services
Intergenerational equity	Future generations have a right to enjoy a good life undisturbed by the damage our energy systems inflict on the world today
Responsibility	All nations have a responsibility to protect the natural environment and minimize energy-related environmental threats

The energy justice principles outlined above serve as normative evaluative ends, as they define the conditions a just energy system should fulfill, including the provision of access, affordability, and participation. However, realizing these principles depends on whether individuals and households possess the actual capabilities to act within their specific socio-technical and institutional contexts. For example, having the ability to choose a sustainable and affordable technology while participating meaningfully in decision-making reflects a household's capability to enhance its well-being. This integration of energy justice with the Capability Approach, as argued by Melin et al. [32], enables a more grounded analysis of justice tensions by linking systemic ideals with people's lived realities. By adopting this dual framework, we can better assess how individual and collective heating systems enable or constrain citizens' capabilities to achieve just outcomes.

2.2. The Capability Approach and the energy transition

Building on the energy justice principles outlined above, the Capability Approach provides a people-centered framework to assess whether individuals have the genuine possibility to achieve those justice outcomes. Developed by Amartya Sen, the Capability Approach shifts the focus from resources or outcomes alone to the real freedoms people have to live the lives they value. In the context of energy transitions, this perspective allows us to assess not just the presence of technologies or policies, but whether individuals can actually access, use, and benefit from them in meaningful ways. As a normative and evaluative framework rooted in human development [27], the CA highlights the importance of enabling capabilities, ensuring that people's freedoms are not overlooked in socio-technical transitions such as the heating transition. The CA has been widely applied in studies examining justice and energy issues, particularly in addressing the tensions between energy use, climate change mitigation, and the attainment of well-being. For example, Day et al. [29] applied the CA to consider how energy and well-being are interconnected in the context of energy poverty. More specifically, the authors develop two sets of capabilities, basic and secondary, whose attainment ultimately requires energy. This relationship is shown in Fig. 1.

Derivation of different capabilities is also found in the study by Lee et al. [46], as the authors applied the CA to define three categories of energy capabilities to assess energy poverty relief policies in the US. The authors developed three main categories of capabilities related to biological and physical needs, intellectual and emotional needs, and social and political needs, each having specific energy-related capabilities. For example, the capabilities category related to biological and physical human needs include access to affordable and safe energy services as energy capabilities. Lee et al. [46] found that empowerment-focused

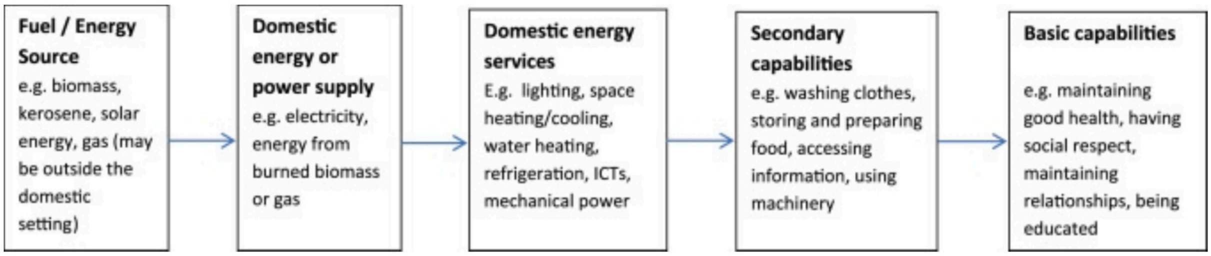

Fig. 1. Relationship between energy, services and outcomes by Day et al. [29].

policies offer a long-term solution compared to the financial aid approach, as the empowerment approach may create lasting improvement across the three categories of capabilities.

Hillerbrand et al. [47] used the CA as a normative energy justice perspective to analyze the impact of digitalization in the energy sector. The authors analyzed two technological developments — smart grids and autonomous driving and focused on the potential impacts on end-users instead across the overall supply chain. The authors assessed the impacts of the two technological developments in the energy sector on the energy capabilities developed by Hillerbrand and Goldammer [48], demonstrating that the CA can be used for identifying energy justice challenges.

Furthermore, the CA has been used to assess the energy justice issues related with access to technologies and infrastructures. For example, Velasco-Herrejon and Bauwens [30] adopted the CA to investigate the social acceptability of renewable energy technologies and understand whether these technologies enhance the lives within the indigenous communities in Southern Mexico. Framing the capabilities of residents in three communities as their understanding of what a good life is, Velasco-Herrejon and Bauwens [30] used the CA to understand what the three dimensions of energy justice mean to people on the ground, gain deeper context-specific understanding of their acceptance of energy technologies, and how such technologies influence their capabilities.

Hunt et al. [49] have used the CA to look at the cost and benefit as well as the achievement of freedoms and capabilities of Indigenous people in a renewable energy transition in North Australia. The findings show that the CA may point out the diverse aspirations of Aboriginal people across renewable energy developments, underscoring the need for Aboriginal decision making to be placed at the center rather than the periphery of the decision-making and development processes of the renewable energy projects [49]. Frigo et al. [50] on the other hand have used the CA as a normative framework when arguing for a human right to access necessary energy services, including electricity and cooking fuel, strengthening the calls for making access to electricity a universal human right, confronting both the contractual rights and the derived human rights positions [51]. Further, Wood and Roelich [28] focused on the tensions between energy use from fossil fuels and climate change mitigation, arguing that these aspects must be viewed by their relationships to achieving well-being, instead of viewing them separately.

Moreover, the studies done by Malakar [52] and Rajagopalan [53] used the CA to understand the impact that solar micro-grids and rural electrification have on residents' well-being in India. For example, Malakar [52] adopted the CA to examine the effect of residents' access to electricity on their secondary capabilities such as irrigation, entertainment and cooking, as well as basic capabilities such as improved health, increased security and strengthened resilience to changing climate, determining that access to electricity has a positive influence across all capabilities of the residents. The study by Rajagopalan [53] show that the CA can be implemented to understand what people value, how they achieve it, and what factors restrict or enhance their valued capabilities, determining that access to solar micro grids has a positive impact across all the well-being aspects and capabilities.

Building on previous studies that adopted the CA, we aim to further explore and better understand the specific capabilities citizens have and the actions they can take once embedded within a particular heating system. Since the type of heating system significantly shapes the scope and nature of citizen engagement, we now turn to examining the technical and operational characteristics of individual and collective heating systems as a foundation for understanding their justice implications.

2.3. Understanding the types of heating systems

2.3.1. Collective heating systems

Collective heating systems are characterized by centralization, enabling economies of scale and enhanced efficiency compared to individual systems. These systems rely on extensive networks for the efficient transport of energy to end users and allow for the integration of diverse heat sources [54]. Their development requires long-term planning that accounts for future energy needs, urban integration, and advanced forecasting [55]. Operationally, they demand continuous management and monitoring to ensure safety and adaptability to fluctuating demands. Financially, these systems involve substantial capital investment and ongoing operational cost management, with ownership typically residing with public utilities or local governments. Expansion feasibility hinges on dynamic heat load demands and associated economic considerations, alongside technical viability. Collective heating systems that are owned and operated by local public authorities, dominate across Europe [56]. These systems include centralized heat supply networks, such as district heating systems, energy communities (including thermal communities), and setups managed by energy service companies that deliver heat to individual or collective housing units. Here, individual households' decisions primarily revolve around their consumption patterns.

District heating systems demonstrate higher efficiency and sustainability scores across economic and technical dimensions compared to individual systems, as analyzed by Balode et al. [57]. Their cost-effectiveness and environmental benefits are particularly pronounced in populated areas with minimal retrofit requirements [58]. However, sustainability outcomes depend on factors like the availability and cost of heat inputs, spatial distribution, and system design [59]. District heating's potential for global adoption as a climate mitigation tool is well-recognized, though significant efforts in planning and implementation are required [60].

A specific organizational form within the broader category of collective heating systems is the thermal energy community. These initiatives are typically citizen-led and may involve community ownership and/or operation of a shared heating infrastructure, such as small-scale district heating networks. What distinguishes them is not necessarily the technology used, but the governance model, which is based on democratic control, local engagement, and collective decision-making. These citizen-led initiatives, though underexplored, include high levels of citizen coordination and engagement, emphasizing aspects such as leadership, different stakeholder roles, and financial responsibilities [61,62], as well as different decision-making mechanisms. Despite their potential to increase renewable energy production and the use of local resources while enabling local ownership and improving social acceptance of energy infrastructures, these thermal communities currently occupy only a minor share of the heating market compared to more common operator-controlled collective heating systems.

While natural gas and electricity networks may be considered as collective heating systems, key distinctions exclude them from this category. District heating systems and thermal communities often involve municipalities, public entities, and community managers, emphasizing renewable energy integration, local resource use, and community governance. These systems align with energy efficiency and decarbonization policies due to their adaptability to renewable sources like biomass, geothermal, and solar thermal. In contrast, natural gas networks, being fossil fuel-based, do not support decarbonization goals, making district heating systems and thermal communities better suited for low-carbon heating transitions.

2.3.2. Individual heating systems

In contrast, individual heating systems are decentralized solutions operated by households, offering autonomy in selecting, installing, and managing technologies such as natural gas boilers, biomass systems, heat pumps, and electric heaters [63]. While this independence allows customization based on preferences and budget, it requires technical knowledge and financial resources. These systems demand regular maintenance by users and place the financial burden of installation, operation, and upkeep on homeowners [64]. However, widespread reliance on individual systems risks fragmented management and reduced operational efficiency, posing challenges to achieving broader system-wide benefits. Table 2 summarizes the differences between the individual and the collective heating systems, outlining some of the heat sources/technologies that may be used across the different heating systems.

The comparison between the heating systems highlights distinct technical and operational characteristics as well as their implications for system-wide efficiency and decarbonization. However, these systems exist within complex socio-economic and institutional contexts that shape how citizens can interact with and influence them. Challenges such as the landlord-tenant dilemma reveal how financial responsibilities and structural barriers can constrain individuals' ability to participate in heating-related decisions. To fully understand how technical systems impact justice outcomes, it is necessary to examine how they enable, or restrict, citizen engagement. We now turn to this critical dimension, exploring how different forms of participation are shaped by the capabilities afforded within individual and collective heating systems.

2.4. Understanding citizen engagement and participation in heating systems

An underexplored aspect of the energy justice discourse is the integration of procedural and representational justice dimensions, particularly through the lens of the capabilities approach, as emphasized in the interdisciplinary discussions and outlined in the introduction to the special issue ‘Energy Justice and the Capability Approach’ by Melin et al. [32]. For the heat transition, as a subset of the energy transition, citizen engagement is crucial in both individual and collective heating systems, though it manifests differently, considering the capabilities for energy-decision making that the technical infrastructures enable or constrain. In individual heating systems for example, engagement is often about personal choice, investment, and maintenance of the heating system, which brings the risk of sustaining or exacerbating energy poverty, considering that the cost of new heating systems may disproportionately affect low-income households [65]. In contrast, citizen engagement in operator-controlled collective systems such as district heating is rather passive [66], mostly reduced to consumption [67], but it can take the form of public consultations, advocacy and voting. This involvement is more about influencing policies and decisions at a communal or municipal level, reflecting a broader form of engagement. A different model is offered by community initiatives such as thermal energy communities, which enable more direct citizen involvement through collective ownership [68], shared visions and organizational responsibilities [69], and participatory decision-making processes [70], as presented in Section 2.3.

However, the capability of citizens to act and advance their well-being depends on the heating systems they are part of. Institutional arrangements, such as ownership, management, and operational structures, play a significant role in either limiting or fostering citizen engagement. For instance, lack of transparency and the absence of inclusive decision-making procedures can create a poor participatory environment which may act as a barrier to engagement [71,72]. Additionally, institutional barriers and entrenched interests often resist change to maintain the status quo, further constraining citizen agency [73]. Capabilities for decision-making within heating systems also vary, particularly regarding financial responsibility and investment, which often leads to tensions, as exemplified by the landlord-tenant dilemma [74]. This dilemma highlights structural barriers to decision-making in the built environment, influencing the adoption of new technologies like solar PV [75], the implementation of carbon taxes [76], retrofitting efforts, and energy efficiency measures [77]. Moreover, tenants frequently lack control over key energy decisions, from technology adoption to the energy performance of their homes [78,79], further complicating their ability to participate in the heating transition.

In individual heating systems, citizens typically have full agency over their choices within contextual constraints, such as selecting and operating their heating systems. On the other hand, collective heating systems that are owned and/or controlled by a single operator (a district heating system operated by a municipality or a public institution for example), often limit citizens in their ability to influence management, operation, or the selection of heat sources. While citizens in district heating systems face restricted decision-making capabilities, those outside these systems often miss out on the equitable distribution of the local energy resources used by the system. For example, municipal waste incineration can produce hot water distributed through district heating systems, benefiting only their users and excluding others from access to this shared resource.

Understanding citizens' capabilities across different heating systems is crucial to identifying the barriers and enabling factors these systems impose on citizen engagement and on the decarbonization process. Such insights can illuminate pathways toward a more just heat transition, ensuring that all citizens are empowered and may attain more capabilities to engage and contribute to as well as benefit from the energy transition.

Table 2
Summary of differences between individual and collective heating systems.

Feature	Individual scale	Collective scale
Heat source/technology	Biomass, heating oil, heat pump, natural gas, electricity	Natural gas, municipal waste, waste heat, geothermal and lake-source heat, biomass, heating oil, heat pump
Control and operation	Decentralized	Centralized
Responsibility for management and maintenance of the system	Individual	Central body (e.g. district heating operator)
Financial risk borne by	Individual	Shared

3. Methodology

3.1. Data collection

Recalling that this study aims to understand how energy justice and capabilities for energy decision-making differ between individual and collective heating systems, and what are the implications and trade-offs of these systems for realizing a just heating transition, our data collection approach was based on interviews. More specifically, we conducted interviews with stakeholders that have knowledge of different types of collective heating systems. From December 2023 until April 2024, we conducted 17 semi-structured interviews across eight European countries, with representatives of operator-controlled thermal communities, former and current representatives of district heating companies and district heating associations, as well as researchers with current or past projects associated with any type of a collective heating system. Our goal was to provide different perspectives across different European countries, thus maximizing the diversity of the collective heating systems and contexts as well as the associated citizens' capabilities for energy decision-making. We contacted representatives with the aim of diversifying the following characteristics: i) the technical composition and operation of the collective heat system (fuel/ heat source, area of system operation, evolution of the system, ownership and operational aspects), ii) the role that citizens play in the current system and their ability to improve their thermal comfort (including decisions about consumption, choice of supplier, joining or leaving the system, drivers and barriers of organized citizen forms for supplying heat), and iii) the future of the collective heating system and the roles that citizens are expected to play. We first contacted all representatives which were already in our research network, and then relied on a snowballing approach to reach more potential participants.

We focused mainly on stakeholders who have knowledge of collective heating systems rather than individual households for several reasons. Firstly, even though these stakeholders primarily operate within the realm of collective heating systems, they possess extensive knowledge of both collective and individual heating systems, as they offered insight related to individual heating systems relevant for their specific context, which was in the interest of this study. Involving these stakeholders allowed us to mitigate potential biases from the personal experiences and preferences of individual households, which may not reflect broader systemic issues related with households' energy decision making capabilities and fell outside the scope of this research. Finally, our aim was to contribute to the literature by offering empirical insights into how operators of collective systems perceive the differences between individual and collective decision-making, as much of the existing research focuses on household behaviors. Table 3 below provides a summary of the interviewees' profiles, along with the codes that would be recalled in the discussion section.

The semi-structured interviews were conducted in English, they lasted between 50 and 90 min and were carried out online. The initial interview transcripts were either obtained through the transcription service of Microsoft Teams which produced the transcripts automatically, or by uploading the recordings to Trint [80]. In both cases, the automatically generated transcripts were manually checked for consistency and possible errors by comparing the transcripts with the recordings.

Table 3
Profiles of interviewees.

Code	Country	Affiliation
BE1TCR	Belgium	Thermal community representative
BE2TCR	Belgium	Thermal community representative
BE3TCR	Belgium	Thermal community representative
BE4TCR	Belgium	Thermal community representative
DK1DHA	Denmark	Association of district heating companies
DE1DHA	Germany	Association of district heating companies
GR1RES	Greece	Researcher
IE1DHC	Ireland	District heating company
NL1TCR	Netherlands	Thermal community representative
MK1RES	North Macedonia	Researcher
MK2DHC	North Macedonia	District heating company
CH1DHC	Switzerland	District heating company
CH2RES	Switzerland	Researcher
CH3DHC	Switzerland	District heating company
CH4RES	Switzerland	Researcher
CH5DHC	Switzerland	District heating company
CH6TCR	Switzerland	Thermal community representative

3.2. Data analysis

The interview transcripts were anonymized, reviewed to correct transcription errors and ensure formatting consistency and subsequently coded with MAXQDA by the first author, following the thematic analysis approach [81]. More specifically, two main themes were considered: i) the technical composition and operation of the collective system (with codes related to costs, efficiency and operation issues, decision-making processes for example, all related with the energy justice decision-making framework principles) and ii) the role that citizens play in the current and the roles they can play in the future system as well as their actions to enhance their well-being (codes related with financial capability, decision-making capability, capabilities for collective action, all related with the CA). The coding tree is provided in the Appendix.

In analyzing the data, we used the energy justice decision-making framework developed by Sovacool and Dworkin [40] to identify how different principles of energy justice manifest across individual and collective heating systems. While the original intent of the framework is to guide more just energy decisions, we adopt it here as an analytical lens to examine how each of the eight energy justice principles such as affordability, due process, good governance, and sustainability emerge in different system configurations. The results were categorized under these principles to distinguish how justice-related concerns vary between centralized, collective heating infrastructures and decentralized, individual solutions.

To complement this analysis and better understand the agency and freedoms of households, we integrated the Capability Approach (CA) into our coding process. This allows us to explore the extent to which households are actually able to make decisions that advance their well-being in the context of different heating systems. Specifically, we focused on identifying the capabilities households have for energy decision-making, such as the ability to afford heating technologies, access information, or participate in collective actions. Interviewees were asked about the roles that citizens currently play, the decisions they can make, and the actions they may take to improve their situation. This dual-framework approach helped uncover the interaction between systemic justice conditions and individual capabilities. To illustrate how this combined analytical lens was applied, two quotes and their corresponding energy justice (EJ) and capability approach (CA) codes are provided in Table 4.

3.3. Ethical concerns and potential limitations

The interview guide was shared with the participants before the interview was carried out, together with a consent form that outlined all ethical considerations related to the research. The ethics approval was obtained by the ETH Zurich ethics commission prior to starting the seventeen interviews. The interview transcripts were anonymized and are stored safely on the ETH Zurich internal server. The transcripts are accessible only to the authors and they will be deleted after 10 years.

The limited number of interviews and countries that were part of this study represents the strongest limitation. The interviewees were able to provide input regarding their domain of work, their activities within the companies/organizations they are associated with or that they have knowledge of, as well as the governing policies associated with their field. However, the information we obtained from the limited number of countries prevents us from generalizing the findings across all European countries. Despite the limited number of cases, we are able to reveal important insights regarding operator-owned and controlled heating systems since we analyzed different types of such systems. Considering the same technical, operational and management aspects of such

Table 4
Coding example.

Interviewee code	Quote	EJ code	CA code
BE4TCR	"*This is a system of shared responsibility. The citizens take part not only in using the heat, but also in building and managing the system. That's why it works, it's not just technical, it's social.*"	Responsibility: Collective responsibility for environmental and social performance. Due process: Citizens involved in management and oversight.	Collective agency: Strong example of shared ownership and governance. Decision-making capability: Active participation in shaping the energy system.
IE1DHC	"*We were involved in the local district heating network, which was the first large-scale district heating network in the country, and the first non-profit public utility of its kind here. It's been a significant shift from traditional heating systems, and it's changed how we think about delivering heat fairly and efficiently to all residents.*"	Intragenerational equity: Aims to provide fair access to modern heating. Good governance: Public ownership and non-profit model reflect democratic accountability.	Collective agency: Involvement in co-owned infrastructure. Financial capability: More equitable pricing through non-profit structure.

systems, contextual factors play an important role, as is also the case for having different types of citizen engagement, which we were able to analyze to a limited extent, as we only interviewed stakeholders from eight European countries. Nevertheless, as the goal of this exploratory study was to provide an insight into a diversity of heating systems and their impacts on differences and outcomes, the results offer valuable perspectives on how various contextual factors can influence the effectiveness, equity, and applicability of different types of heating systems across various settings.

While the study focuses on stakeholders associated with collective heating systems, which might introduce a potential bias toward the perspectives and technical aspects specific to these systems, the findings offer valuable insights into the structural, policy, and operational dynamics that can inform broader discussions about heating systems. The stakeholders interviewed also have relevant knowledge of individual heating systems, which helps mitigate this bias to some extent. However, it is important to note that the lived experiences of end-users of individual systems may not be fully represented.

Another potential limitation of this study is that it focuses on either individual or collective heating systems in isolation, rather than considering the combination of both. This may result in overlooking some unique challenges and opportunities related with energy justice and individual capabilities for decision-making related with energy. However, such combined systems were beyond the scope of our work.

4. Results

To present our findings clearly and systematically, we have organized Section 4.1 around the eight energy justice principles proposed by Sovacool and Dworkin [40]. For each principle, we examine how it manifests across individual and collective heating systems, drawing on interview data. To better understand how these justice conditions either enable or constrain energy decision-making capabilities, we integrate the Capability Approach, focusing on the specific capabilities that households possess (or lack) in making energy-related decisions. These capabilities are linked to each justice principle and are summarized in Table 5 at the end of Section 4.1. Section 4.2 further expands on these insights, providing additional relevant findings from the interviews that contribute to the broader analysis.

4.1. Understanding energy justice and energy decision-making capabilities

In assessing the energy justice manifestations across individual and collective heating systems, the results show clear differences across the principles of the energy justice decision-making framework, each associated with specific advantages and challenges. The differences outline the influence that technical systems, and more specifically, heating systems, have on energy justice considerations. The results are presented below according to the principles of the energy justice decision-making framework.

4.1.1. Availability

Availability refers to both the presence of heating infrastructure and technologies and the institutional conditions that determine access. Interview findings show that availability is structured differently in individual and collective systems, shaping household agency.

In individual systems, people may formally choose their heating solution based on financial and contextual factors (DK1DHA; IE1DHC). In practice, this choice is often constrained by infrastructure limitations and technical feasibility, restricting the real range of available options. On the other hand, in collective systems, availability depends on the geographic scope of the network and criteria for expansion. Households are often unable to join if certain techno-economic conditions are not met and, once connected, may not have the option to exit (CH1DHC; IE1DHC). Institutional rules thus limit flexibility and user control.

From a CA perspective, these dynamics affect both the capability to achieve thermal comfort and decision-making capability. In individual systems, practical constraints reduce the ability to act on formal choices. In collective systems, constrained exit and limited user influence restrict autonomy.

4.1.2. Affordability

Affordability in heating refers to the ability to manage both initial investment and ongoing costs. Interview findings reveal that affordability challenges differ significantly between system types.

In individual systems, households bear full responsibility for capital and operating costs, including exposure to price volatility and maintenance (GR1RES; MK2DHC). This can deter low- and middle-income households from adopting cleaner technologies and may result in reliance on outdated systems. In collective systems, while infrastructure development involves high capital investment, these costs are absorbed by operators or public authorities. Operational costs may be lower due to economies of scale. Still, affordability is not guaranteed, as users may face fixed costs and limited control over pricing structures.

From a CA perspective, these patterns shape financial capability of households. Individual systems often restrict this capability due to financial barriers. In collective systems, while risk is shared and certain subsidies are available, upfront costs may be more than what households can afford, as two interviewees pointed out:

> "*Sometimes the problem is not the rentability of renewable systems. We have subsidies, we have laws that push those things, but people don't have enough money on the bank account to finance those installations.*"
> (*CH6TCR*)

> "*We want to make heating more sustainable, which is probably even more important than electricity at the moment, but it is a big challenge because there is not much budget.*"
> (*BE4TCR*)

Table 5
Summary of heating systems according to energy justice principles and key capabilities.

Energy justice principle	Manifestation in individual heating systems	Manifestation in collective heating systems	Key capabilities
Availability (of resources/ technologies)	People can freely choose their heating source/ system within contextual boundaries,[a] depending on their preference, financial situation, and information they have (DK1DHA; IE1DHC)	The availability of the collective heating system is limited to certain areas, and people cannot join the system if techno-economic conditions[b] are not met (CH1DHC; IE1DHC)	Capability to achieve thermal comfort; decision-making capability
Affordability (low cost of energy services, also for the poor)	Individual systems may have high capital expenditure (CAPEX) or operating expenses (OPEX), while the financial risk of implementing the system is fully borne by the individual/ household (GR1RES; MK2DHC)	Capital expenditure (CAPEX) costs are significant in collective systems, however due to economies of scale, these systems may have low operating expenses (OPEX), while the financial risk is borne by the system's operator/owner	Financial capability
Due process (respect due process in production and use of energy)	People have full control over decisions on choice and operation of the heat system, within contextual boundaries (BE1TCR; MK1RES)	People have limited to no individual control over decisions on choice and operation of the system (MK2DHC; DK1DHA; BE4TCR)	Decision-making capability
Good governance (access to energy information, accountability and transparency in decision making)	People require accessible information of the different heating systems to choose according to their preference and financial situation, as well as for efficient use of the system (NL1TCR; CH4RES)	The collective system operator/ owner is responsible for providing access to information and ensuring transparent decision-making processes (BE2TCR; CH2RES; IE1DHC)	Informational capability; capability for collective action
Sustainability (energy resources not depleted quickly)	The decision on the use of the energy resources rests on the households (GR1RES; MK2RES)	Collective systems may use local resources such as municipal waste, or excess heat from different processes (DE1DHA; CH5DHC; DK1DHA)	Capability to achieve thermal comfort
Intragenerational equity (fair access to energy services)	Disparities may arise due to affordability (CH1DHC; MK1RES) and knowledge of technologies (NL1TCR)	Disparities may be reduced by providing equitable access to the system (IE1DHC; MK2DHC)	Financial capability; Informational capability; capability to achieve thermal comfort
Intergenerational equity (concern for future generations from today's energy use)	Individual decision to adopt renewable and highly efficient heat technologies may decrease the environmental impact of energy use (GR1RES; IE1DHC)	Collective systems may rely on renewable and highly efficient heat technologies along with local resources to satisfy the heat demand (DE1DHA; DK1DHA)	Financial capability
Responsibility (to protect the environment and minimize energy-related environmental threats)	Households bear the full responsibility to protect the environment and minimize environmental threats (BE1TCR; CH4RES)	The responsibility rests with the collective heating system operator (DK1DHA; BE2TCR; BE4TCR)	Financial capability; capability for collective action

[a] Contextual boundaries may include but are not limited to a ban on specific heating technologies in certain areas (such as a ban on geothermal technologies in areas with protected ground waters (CH1DHC)) or due to incompatibility of the system with the built environment (individual wood stove in a collective housing unit), to name a few.

[b] The decision to build or extend an existing collective heating system depends on the techno-economic conditions, meaning that available heat sources, heat loads, and favorable financial conditions, among other conditions, must be met.

4.1.3. Due process

Due process refers to the ability to participate in decisions around heating system selection and operation. Interviews reveal a strong contrast in procedural autonomy between system types.

In individual systems, households typically retain control over decisions related to installation, use, and technology (BE1TCR; MK1RES). While shaped by contextual constraints, this reflects a high degree of autonomy. In collective systems, participation is minimal. Once connected, users have little to no influence over pricing, technology, or management decisions (MK2DHC; DK1DHA; BE4TCR), which are generally made by utilities or public bodies.

From a CA view, this affects decision-making capability. Individual systems support it, though unequally. Collective systems often limit it due to centralized governance, reducing households' ability to shape outcomes that affect their well-being.

4.1.4. Good governance

Good governance includes access to clear, trustworthy information and transparent decision-making. Interviewees described contrasting dynamics between system types.

In individual systems, users must independently seek out and interpret information about costs, system options, and implications (NL1TCR; CH4RES). The burden of navigating complex technical and financial material often limits informed decision-making. However, in collective systems, information is expected to be provided by operators, municipalities, or cooperatives (BE2TCR; CH2RES; IE1DHC). While some maintain transparency and user engagement, others lack mechanisms for explaining decisions or future plans.

These differences affect informational as well as capability for collective action. In individual systems, limited access or complexity can undermine autonomy. In collective systems, even if technical decisions are centralized, informational transparency is essential to ensure that users are not excluded from understanding, influencing, and even owing their heating systems, as mentioned by one interviewee:

> "*We want to invest in a sustainable future… and we want, when we develop something, that it is in the hands of the citizens. So the citizens are owners.*"
>
> (*BE4TCR*)

4.1.5. Sustainability

Sustainability concerns the use of resources that support long-term environmental goals. Interviewees highlighted the divergent roles of households and institutions in driving sustainability.

In individual systems, sustainability depends on the household's ability and willingness to adopt efficient or renewable technologies (GR1RES; MK2RES). Environmental outcomes vary widely and often reflect differences in motivation, awareness, or affordability. Sustainability in collective systems is influenced by design and sourcing decisions made at the system level. Many integrate waste heat, renewables, or efficient technologies (DE1DHA; CH5DHC; DK1DHA). However, outcomes depend on planning and policy, with users having limited influence.

From a CA lens, the capability to achieve and maintain thermal comfort is unevenly distributed. Individual systems make this contingent on personal capacity; collective systems offer more consistency but less individual control.

4.1.6. Intragenerational equity

Intragenerational equity addresses fairness in access to energy within the current generation. Interviews reveal both risks and opportunities across systems.

In individual systems, affordability and knowledge gaps limit access to cleaner technologies (CH1DHC; MK1RES; NL1TCR). Households with fewer resources face greater challenges in adopting sustainable solutions. In collective systems, shared infrastructure can help reduce disparities by lowering entry barriers and distributing costs more evenly (IE1DHC; MK2DHC). When inclusively designed, they can help overcome income and knowledge-based inequities.

These findings relate to multiple capabilities: financial, informational, and the capability to achieve thermal comfort, as intragenerational equity is not only about universal service but about ensuring that all households can meaningfully participate in and benefit from the heating transition.

4.1.7. Intergenerational equity

Intergenerational equity focuses on the impact of current energy choices on future generations. Both individual and collective systems can contribute positively or negatively, depending on how sustainability is prioritized.

In individual systems, environmental performance depends on households' capacity to adopt low-carbon technologies (GR1RES; IE1DHC). These decisions are often shaped by affordability, awareness, and access—factors that are unevenly distributed. The use of energy sources and efficiency in collective systems are determined at the system level. Many incorporate renewables or local heat sources to reduce long-term environmental impacts (DE1DHA; DK1DHA). However, these benefits depend on policy and system governance, with limited user influence.

From a CA perspective, intergenerational equity in individual systems is highly contingent on personal resources or on financial capabilities. In collective systems, it is shaped by governance arrangements and planning processes that determine how systems evolve over time, as put forward by one of the interviewees:

> "*In the past, district heating in Switzerland was something very localized… It was based on where locally there was an opportunity to build networks. So typically, if there was a cheap and easily available energy source, like a waste incineration plant, there will be district heating.*"
>
> *CH2RES*

4.1.8. Responsibility

Responsibility concerns who bears the burden of environmental stewardship. Interviews point to contrasting patterns between system types.

In individual systems, households are solely responsible for the environmental impact of their heating choices (BE1TCR; CH4RES). This can place unfair pressure on those with fewer resources or limited information. In collective systems, environmental responsibility is institutionalized. Operators or authorities decide on system design and energy sources (DK1DHA; BE2TCR; BE4TCR). This centralization can promote sustainability but may reduce users' sense of involvement or agency.

Responsibility connects to the financial capability and capability for collective action. In collective systems, this capability is shaped by governance models. Where user engagement is supported, responsibility can be shared more equitably, as shown from the example in Switzerland:

> "*The problem with heating systems is that at the beginning you have very high investment costs you have to make, and the payback is not as good as in PV systems. Also, the communication is more difficult. If you pay 1000 Swiss francs, you have maybe 1/6 of a heating system in a house with one flat, and that is not easy to communicate. You need 60 people to each pay 1000 Swiss francs to make it happen. So we built a platform where everyone can invest, like a cooperative and get the benefit out of it financially. We removed the fossil fuel heating system and replaced it with a renewable one. Now it's working. They have lower energy costs than before, and we have maybe 2% return.*"
>
> (*CH6TCR*)

The findings presented above are summarized in Table 5, which consolidates the key insights related to each energy justice principle, highlighting the differences between individual and collective heating systems. This table also integrates the energy justice decision-making framework and the relevant capabilities from the Capability Approach, offering a clear overview of how these principles manifest across system types and the implications for household agency. The table serves as a synthesis of the results, providing an understanding of the interplay between energy justice and the capabilities that enable or constrain household participation in the heating transition.

4.2. Efficiency concerns

In addition to differences in energy justice and decision-making capabilities, the interviews highlighted technical and coordination challenges associated with the implementation and operation of individual and collective heating systems. These concerns, while not directly tied to justice issues, play a critical role in the broader evaluation of system efficiency and sustainability.

Individual heating systems tend to have lower overall efficiency compared to collective systems. System efficiency encompasses the production, supply, and consumption of energy and is closely tied to the operational practices of the heating system. In decentralized setups, efficiency is influenced by personal preferences, practices, and varying levels of information among users. This can result in inefficient operation and maintenance, as the responsibility for these tasks lies solely with households, leading to a lack of standardized, centralized strategies to enhance system performance (MK2DHC).

In contrast, collective heating systems benefit from centralized operation and maintenance, which contributes to higher system efficiency. For instance, district heating systems are managed by operators who continuously monitor and balance heat production and consumption to optimize system performance. The centralized structure enables coordination by skilled professionals, ensuring consistent maintenance and efficient exploitation of resources. This combination of technical design and professional oversight makes collective systems inherently more efficient than their individual counterparts (MK2DHC).

However, the higher efficiency of collective systems can be undermined if households are permitted to exit the system without constraints. Several interviewees emphasized that the ability of households to leave collective systems, such as district heating networks, poses risks to system efficiency and cost stability, as argued by some of the interviewees:

> "*It only makes sense operationally, economically, financially if you just expand the system and not let anyone opt out… because the efficiency decreases.*"
>
> (*DK1DHA*)

> "*They [citizens] can basically on a yearly basis opt out or opt in into the district heating system… which creates a lot of mess… you either have an overproduction of heat or an underproduction of heat and it's not optimised at all… From a technical point of view, it's not interesting and from a business perspective, it's also not a good way of working.*"
>
> (*BE4TCR*)

In some cases (e.g., DK1DHA, CH1DHC, CH3DHC, IE1DHC), mechanisms are in place to impose conditions or constraints on households seeking to leave the system, safeguarding efficiency and preventing cost increases for remaining users. In other cases (e.g., MK1RES, MK2DHC), no such conditions exist, potentially jeopardizing the system's overall performance.

Ultimately, decisions about remaining in or leaving a collective system, as well as choices regarding heating technologies, are often driven by cost considerations. As noted by interviewees from various contexts (e.g., BE1TCR, BE3TCR, IE1DHC, NL1TCR, MK1RES, MK2DHC, CH2RES, CH4RES, CH6TCR), heating costs are the primary concern for households and the most influential factor shaping their heating-related decisions.

These findings underline the importance of considering both technical efficiency and household energy decision-making capabilities in the evaluation of heating systems, as factors that intersect with, but also extend beyond, traditional justice frameworks. The following discussion reflects on these insights and explores their broader implications for a just and sustainable heat transition.

5. Discussion and implications

It is important to acknowledge that there is no singular, universally 'just' transition pathway. Instead, justice in the heating transition should be understood as context-dependent, shaped by local governance structures, social conditions, and technological arrangements. Our focus is not on the organization of the transition itself, but rather on the implications of heating systems on justice considerations and their ability to meet the diverse needs of communities in a fair and equitable manner. Importantly, the transition is not a static goal but an ongoing process addressing technological, social, and economic dimensions inclusively. Viewing it as a process means embedding the justice principles throughout, adapting to evolving challenges and fostering equitable, sustainable outcomes.

While country-level variation exists, this discussion focuses on the structural and justice-related implications of heating system types (individual vs. collective), rather than national comparisons. This approach reflects the study's design, which prioritized cross-contextual themes over country-specific analysis.

5.1. Capabilities for energy decision-making

5.1.1. Availability, intergenerational equity and sustainability

The results highlight the capability of households to access reliable and environmentally sustainable heating resources through collective heating systems. By utilizing local heat sources, such as municipal waste incineration or waste heat from production processes and IT equipment, collective systems provide opportunities that are typically unavailable to individual households. These sources, which are viable at a larger-than-individual scale, enable households to benefit from the externalities of local activities, including waste heat recovery or municipal waste management, without requiring them to manage or invest in these processes individually.

By incinerating municipal waste to generate heat (or combined heat and power in cogeneration plants), collective systems enhance the capability of households to participate in sustainable energy practices. This approach not only ensures a steady supply of energy but also helps mitigate environmental challenges, such as reducing landfill waste [82]. Thus, households contribute to and benefit from broader sustainability goals without bearing the direct logistical and environmental responsibilities. These capabilities — accessing shared resources, reducing environmental impacts, and contributing to long-term sustainability, are made possible by the centralized and collective nature of these systems.

5.1.2. Affordability and intragenerational equity

In the context of the heating transition, both individual and collective heating systems aim to meet households' thermal comfort needs, but their affordability depends significantly on households' capabilities. The efficiency and operational costs of these systems are influenced by factors such as individual decisions and contextual conditions. Collective heating systems, in particular, benefit from economies of scale, which can reduce costs for households by distributing expenses across a larger user base [54]. However, their cost-effectiveness also relies on factors like the spatial distribution of the region, as highlighted by Yu et al. [59], making geographic and infrastructural considerations critical.

Considering that costs are a decisive factor in heating choices, households' capabilities to manage heating expenses play a critical role. The significant concerns raised about energy poverty related with the rising electricity and gas prices in recent years align with findings from Gordon et al. [83], which highlight the financial pressures driving such shifts. Households' capabilities to adopt specific heating systems depend on their financial capacity to handle both capital expenditures (CAPEX) and operational expenditures (OPEX). For example, renewable energy-based systems like solar thermal or efficient heat pumps have higher CAPEX than wood stoves but generally offer lower OPEX. Without supportive policies, households with limited resources may struggle to adopt these technologies, creating a gap between the needed uptake rates and actual adoption. This financial barrier not only hinders the transition to low-carbon solutions but also risks deepening energy poverty, a growing concern across Europe [7,8].

Collective heating systems can play a vital role in enhancing households' capabilities to avoid and recover from energy poverty. By leveraging economies of scale, these systems can be designed to address the needs of energy-poor households through mechanisms such as subsidized or reduced heating costs, ensuring equitable access to thermal comfort. As energy poverty often overlaps with broader issues of poverty, integrating collective heating systems into social housing developments can provide a dual benefit, addressing both energy and housing needs. The sharp increase in natural gas prices in recent years exemplifies how external shocks can strain households' capabilities to maintain stable heating. In some contexts, governments have intervened in heating provision to protect citizens from energy price volatility, including the nationalization of a private district heating company to shield citizens connected to the system from financial shocks, ensuring stable service and steady costs. This intervention highlighted the potential of collective systems to protect vulnerable households by enhancing affordability and stability. However, such targeted interventions also raise concerns about distributional energy justice. In this case, governmental support was exclusively directed toward households connected to the district heating system, leaving others reliant on individual systems without similar protections. This disparity underscores the importance of designing collective systems and policies that enhance capabilities equitably, ensuring that interventions consider all affected households to avoid exacerbating existing inequalities.

Furthermore, insulation and retrofitting of buildings is crucial for reducing carbon emissions and preventing future carbon lock-ins [19]. However, the high costs of these interventions can limit households' capabilities to invest in energy-efficient upgrades, exacerbating energy poverty for those unable to afford the initial capital expenditures. This issue is further complicated by the split incentives between landlords, who may be reluctant to invest in energy-efficient upgrades, and tenants, who are often responsible for energy bills but lack the authority or resources to make significant changes to the property. These concerns are pointed out through the landlord-tenant dilemma, especially in terms of the adoption of renewable energy technologies [75] and the need for urgent government investments in retrofitting to alleviate energy poverty [84]. That is why countries are providing financial support to individual households that want to switch to and utilize individual heating systems based on renewable energy, considering the higher CAPEX associated with these systems. Such activities align with the literature, as Domenig et al. [85] outline the need for diverse support measures that may span from incentives to adopt new technologies, to subsidies for renovation and retrofitting, considering that energy retrofits play a key role in decarbonizing heat [84]. Supporting mechanisms are also needed across different types of housing tenures, such as the non-profit housing or the social housing sector, considering the slow rollout of energy efficiency and renovation measures [86] despite the tenants being attracted by decreased costs and enhanced comfort [87].

5.1.3. Due process, good governance and responsibility

Households' capabilities to influence decisions and ensure accountability in heating systems vary significantly depending on the ownership and operational structure. In operator-owned and controlled systems, centralized management eliminates coordination challenges commonly found in citizen-owned thermal communities, such as disagreements over technology choice, financing, and system operation. While this enhances operational efficiency, it may limit households' capabilities for democratic participation in decision-making, raising procedural justice concerns. These findings are supported by the study of Knox et al. [88] related to (in)justices of local energy systems, and by Lacey-Barnacle [89] regarding the procedural (in)justice related with non-recognition and exclusion from consultation.

Households connected to collective heating systems also face tradeoffs between individual autonomy and collective responsibility. For instance, households can choose to leave a district heating system without administrative or time constraints in some contexts, but such individual actions can reduce system-wide efficiency and increase costs for remaining users. This raises questions about balancing individual capabilities with collective system performance. By contrast, in other contexts, constraints on exiting collective systems safeguard efficiency. In some collective heating systems, households face structured exit conditions designed to preserve network efficiency, as they must coordinate their exit with the operator, often requiring years of notice or payment of collective mortgages. These constraints highlight a trade-off: while limiting individual flexibility, they ensure the system operates efficiently for all connected users.

Housing type further shapes household decision-making capabilities. In collective housing units, decisions often require majority consensus, but renters face structural barriers to implementing changes, as decisions rest with property owners. This limitation aligns with literature that identifies renters as having diminished capabilities to influence technological choices [78,79]. By contrast, households in individual housing units retain greater autonomy to opt for sustainable alternatives, such as switching to individual heating systems, provided technical and financial conditions allow.

Collective heating operators also attempt to balance efficiency with household autonomy by providing conditional opt-out options. Some systems offer trial periods before long-term commitments, helping households make more informed decisions. However, these systems leverage economies of scale, efficient technologies, and supportive policies to maintain low costs, making it unlikely for households to opt out. These findings are in line with Balode et al. [57], who outline the cost-efficiency of collective heating systems, however it must be emphasized that the context-specific policies play a significant role, including the spatial distribution of the built environment [59].

5.2. Additional capabilities for energy decision-making

The findings illustrate various forms of citizen engagement that directly influence the energy transition, aligning with the findings of Wahlund and Palm [22] and Chilvers et al. [21]. These engagements reflect households' capabilities to participate in and shape energy systems, affecting both immediate operations and long-term strategies. For instance, citizens connected to collective heating systems may enhance their decision-making capabilities by taking an active role in governance. By running for a seat on the board of a local district heating company, citizens can directly influence operational decisions, such as system efficiency and maintenance, as well as strategic decisions, like long-term investment in sustainable technologies. This direct involvement enhances procedural justice by ensuring citizens have a say in shaping systems they rely on. Another form of engagement is citizens' capability to influence energy policy through voting, which can reshape technical systems and expand household options. Citizen participation in policy processes can influence infrastructure decisions, such as phasing out fossil fuel networks. This decision, driven by collective citizen action, may result in a planned decommissioning of natural gas infrastructure, enabling households to transition to more sustainable heating solutions. However, this shift also highlights the need for adequate electricity supply to meet increased demand, underscoring the interconnectedness of technical systems and households' capabilities to adopt sustainable technologies.

The results suggest that in some contexts, citizens with individual heating systems may enhance their capabilities by forming or joining thermal communities, which is also suggested by Radtke et al. [90]. In the quest for decreased heating costs through renewable and low-carbon energy technologies, citizens living in individual housing units may decide to form or join a thermal community, therefore achieve economies of scale in production with highly efficient technologies and decrease their heating costs. Thermal communities might delegate system operation and maintenance to professional energy service companies to ensure efficiency, making the thermal community an operator-controlled one. In certain cases, citizens may involve the energy service company from the initial phase of the project, leaving the financing considerations along with the operation of the system in the hands of the energy service company, which outlines the thermal communities which are not only operator-controlled, but also operator-owned.

5.3. Implications for realizing a just heating transition

To ensure the heating transition supports broader societal goals of inclusivity, environmental sustainability, and justice, it is essential to improve citizens' capabilities across all eight energy justice principles. By framing these principles as actionable capabilities, policy interventions can empower households to make informed decisions, participate equitably, and access sustainable energy solutions.

Availability as a capability can be improved by ensuring that households have access to reliable and sustainable heating options. Collective heating systems, especially those that rely on economies of scale and utilize local resources such as municipal waste incineration or industrial waste heat, have the potential to expand this capability. However, it is important to acknowledge that these systems are complex, capital-intensive infrastructures that require years of planning, coordination, and significant investments. Their deployment is also highly dependent on local heat demand density, technical feasibility, and long-term urban planning. While policies that incentivize the development of collective heating systems and support their integration with renewable technologies can enhance availability, such solutions are not universally applicable or immediately accessible. Therefore, improving availability as a capability requires not only expanding technical options but also addressing planning, governance, and investment challenges that shape when and where such systems can be implemented.

Affordability is central to enabling equitable participation in the transition. Subsidies and cost-sharing mechanisms in collective systems can stabilize heating expenses, reducing the financial burden on households, especially those at risk of energy poverty. Expanding financial support for retrofitting and renewable heating technologies for individual systems, along with targeted interventions for low-income households, ensures all citizens can access affordable solutions. This approach reduces disparities between households relying on collective versus individual systems.

Due process and good governance capabilities must be strengthened to promote inclusive and transparent decision-making. Citizens need greater opportunities to influence the operation and governance of collective systems, such as running for board positions or participating in policy votes. Transparent and inclusive processes ensure that citizens' voices are not only heard but actively shape decisions, fostering procedural justice and a sense of ownership. For example, enabling renters and other marginalized groups to participate meaningfully in governance structures can address long-standing barriers to decision-making.

Sustainability as a capability depends on ensuring households can contribute to and benefit from the transition to low-carbon systems. Collective systems are well-suited for integrating renewable resources and reducing fossil fuel reliance. However, as demonstrated in Switzerland, transitioning from natural gas requires careful planning to secure alternative supplies and address the social acceptance of new technologies. Policymakers must ensure that sustainability goals are met without compromising energy availability or affordability for households.

Intragenerational equity can be advanced by reducing disparities in energy access and costs between different socioeconomic groups. Collective systems must be designed to serve all households equitably, with specific provisions such as subsidized rates or tiered pricing for low-income and vulnerable populations. Policies that support energy retrofits and renewable heating adoption across diverse housing types, including rental properties, can bridge existing gaps and ensure that no group is disproportionately burdened.

Intergenerational equity requires embedding long-term sustainability into current decision-making processes. Investments in durable, low-carbon heating infrastructure ensure that future generations inherit systems that are efficient, equitable, and environmentally sustainable. This capability also requires planning for resilience to climate and energy supply challenges, ensuring that the benefits of today's decisions extend well into the future.

Responsibility as a capability involves empowering households to participate in collective environmental stewardship. By centralizing resource management in collective systems, households can indirectly contribute to sustainability goals, such as waste-to-energy initiatives, without bearing individual logistical burdens. For individual systems, incentives for adopting renewable technologies can enable households to take direct responsibility for reducing their environmental footprint.

To achieve these improvements, policies must prioritize context-specific solutions, tailoring interventions to local social, economic, and geographic conditions. Regulatory frameworks should balance individual autonomy with collective efficiency, ensuring that households have the freedom to make informed choices while protecting the broader system's sustainability. By enhancing citizens' capabilities across all eight energy justice principles, the heating transition can be both inclusive and equitable, fostering a future where all households can actively participate in and benefit from the transition.

6. Conclusion

This paper explores the complexities, differences, and trade-offs between individual and collective heating systems through the lens of energy justice and citizen capabilities for energy decision-making across eight European countries. The findings provide valuable insights into how technical systems shape justice considerations by influencing households' capabilities for energy decision making, highlighting their role in enabling or limiting a just heating transition and the trade-offs inherent in balancing equity, efficiency, and sustainability. Building on previous studies [29,46,47], we identified distinct capabilities for energy decision-making that households possess across different types of heating systems. This work highlights the capabilities that households have to enhance their well-being, which is defined as their thermal comfort. Additionally, we outline the broader implications of these findings for advancing a decarbonized and equitable heating transition.

This exploratory study suggests that collective heating systems, despite limiting individual decision-making capabilities, may present significant advantages in terms of efficiency, environmental impact, and affordability. The centralized management and economies of scale that are inherent in these systems may facilitate the integration of local renewable energy sources, thereby contributing to broader decarbonization goals. Moreover, the potential for collective systems to safeguard vulnerable populations from energy poverty issues strengthens their role in advancing distributive justice.

On the other hand, the results show that individual heating systems may enable greater autonomy and control to households, allowing them to adapt the energy solutions to their personal preferences and financial situations. However, this decentralization can lead to fragmented and uncoordinated efforts with possible inefficient operation and management of the heating systems, which can lower the overall system efficiency and challenge the pace of the heating transition. From the financial point of view, the increased cost of sustainable heating technologies can exacerbate existing inequalities, which can particularly burden low-income households.

Key implications for realizing a transition that supports broader societal goals related to inclusivity, environmental sustainability and justice include the need for supportive policies and interventions that address energy poverty and affordability of the costly renewable energy technologies, the expansion of collective systems together with the regulation of citizen participation to maintain system efficiency. Also, the promotion of good governance through transparent and inclusive decision-making processes along with the prioritization of renewable energy and low-carbon heating technologies coupled with insulation and retrofitting activities must be prioritized, with a focus on integrating local renewable energy sources and reducing reliance on fossil fuels.

CRediT authorship contribution statement

Vanja Djinlev: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **BinBin J. Pearce:** Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

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Appendix A

Coding tree

Energy justice principles codes

Availability.

- Access to heating infrastructure
- Technical reliability and security of supply
- Diversity and integration of renewable and local heat sources

Affordability.

- Heating costs
- Risk of energy poverty
- Upfront (CAPEX) and operational (OPEX) costs
- Financial incentives and support programs

Due process.

- Citizen access to legal protection mechanisms
- Participation in regulated decision-making
- Transparent communication of energy decisions
- Right to consent or object

Good governance.

- Access to high-quality and understandable information
- Clarity in pricing, billing, and technical choices
- Local consultation, public information and citizen participation mechanisms

Sustainability.

- Use of renewable, low emission and waste heat sources
- Circularity and resource efficiency
- Long-term environmental/decarbonization goals and alignment with climate plans

Intragenerational equity.

- Fair access to heating across communities, regions, age or income groups
- Differences between owners and tenants
- Rights and inclusion of marginalized or vulnerable groups

Intergenerational equity.

- Environmental planning for long-term sustainability
- Avoiding system and carbon lock-ins

Responsibility.

- Active steps to reduce environmental impact
- Shared responsibility between institutions and citizens
- Alignment with international, national, or local climate targets

Capability approach codes

Capability to achieve thermal comfort.

- Adequacy of heating under all seasonal/weather conditions
- Heating system performance and reliability

➔ Linked EJ codes: availability; intragenerational equity

Financial capability.

- Ability to afford heating systems and ongoing costs
- Access to financial support and subsidies
- Exposure to risk from price volatility or system changes

➔ Linked EJ codes: affordability; intragenerational equity.

Informational capability.

- Access to clear, trustworthy, and complete information
- Understanding rights, technologies, and financial implications
- Ability to compare heating options and make informed decisions

➔ Linked EJ codes: good governance; due process; intragenerational equity

Decision-making capability.

- Freedom to choose a heating system or supplier
- Ability to disconnect or adopt alternatives
- Barriers in rental or multi-occupant dwellings

➔ Linked EJ codes: due process; availability

Capability for collective action.

- Ability to form or join a thermal energy community
- Influence decisions beyond individual consumption
- Shared ownership or governance
- Local engagement in planning and operation

➔ Linked EJ codes: good governance, responsibility, availability

Data availability

Data will be made available on request.

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