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Contextualizing policy mixes – A configurational study on rapid transitions

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ABSTRACT

The policy mixes in sustainability transitions have been recognized as a central component in accelerating decarbonization. Policy mixes are embedded in a broader institutional and structural order involving technologies, infrastructures, markets, practices, and environmental conditions within socio-technical transitions. In this paper, we examine how various combinations of demand-pull policy mixes, and infrastructural, environmental, and market configurations result in either rapid or slow transitions. We draw on European heat pump diffusion as a novel innovation featuring very different diffusion levels within the continent. The analysis draws on a country-level data set of 20 European countries, and a configurational analysis using the fuzzy-set Qualitative Comparative Analysis (fsQCA) method. The policy mix measures for configurational analysis are constructed using data on sector specific policy instruments, taking in economic policies, regulatory policies, and mandatory and voluntary soft and systemic instruments. We complement the model with environmental conditions, infrastructure data on gas and heating networks, and market conditions. Three key findings emerged. First, we contextualize policy mixes to reveal how various configurations can lead to either rapid or slow transitions. Second, we contribute to the research on energy transitions by demonstrating the importance of infrastructural arrangements. Third, we make a methodological contribution by exemplifying how the two-step comparative case study method can separate slowly changing remote conditions and more rapidly evolving proximate conditions in studies on sustainability transitions. The results emphasize system-level environment and climate policy approaches that improve the cost competitiveness of clean technologies.

1. Introduction

Government entities, corporations, and community organizations are actively exploring methods and strategies for rapid transitions to tackle the challenges posed by climate change (Newell et al., 2022). A combination of policies has been acknowledged as a pivotal mechanism to expedite these transformative shifts (Edmondson et al., 2019; Rogge and Reichardt, 2016; Rogge and Schleich, 2018). Policy mixes form bundles of instruments to support innovation, and are equally crucial in demand-pull to enhance technology diffusion. Policies do not operate in isolation but function configurationally, interacting with different instruments to support and create synergies, or at times unintended counterproductive effects (Howlett and Del Rio, 2015). Policy mixes are always embedded within broader institutional and structural orders with technologies, infrastructures, institutionalized social practices, mental models, and geographical and environmental factors. Thus, there is a need to extend the scope of the research on policy mixes beyond policy instruments and their combinations, to consider the implementation context (Mavrot et al., 2019). The context-related conditions are often interlinked and organized in a manner that supports the efficient operation of existing socio-technical regimes. The existing regimes may create an unfavorable or even hostile environment for new solutions, slowing their diffusion for the broader utility (Fligstein and McAdam, 2011; Greenwood et al., 2011; Hinings et al., 2018).

The context can be understood as configurational and socio-material. The impact and effectiveness of policy mixes depends on various other contextual conditions with which they interact. The earlier literature on policy mixes has emphasized the role of institutions (Kivimaa and Rogge, 2022) shaped by the material world and its structures (Foxon, 2013; van der Steen et al., 2008). This paper positions demand-pull policy mixes within the broader context of institutional conditions by asking: How various combinations of demand-pull policy mixes, and infrastructural, environmental, and market configurations result in either rapid or slow transitions?

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As a significant body of earlier policy mix research has focused on conceptual and analytical aspects, the studies predominately draw on the analysis of a single case or small-N, which has led to insufficient theorization (Howlett and Del Rio, 2015; Kanger et al., 2020). In lieu of inductive studies, a stream of literature has emerged focusing on the effectiveness of policy mixes as a dependent variable. The studies focus on a single demand-pull instrument or instruments at an aggregated level (Pitelis et al., 2020), and concentrate on the early phases of technology development by measuring patenting activity (Dechezleprêtre and Glachant, 2014; Peters et al., 2012) rather than technology deployment. How policy mixes enacted in different contexts can foster rapid transitions remains underexplored. Cross-country studies here can offer valuable insights into the diversity of approaches and elaborate contextual factors that shape the relative effectiveness of different policy configurations in achieving sustainability goals.

Our study aims to bridge the gap by adopting a configurational perspective, and employing fuzzy-set qualitative comparative analysis (fsQCA) to conduct a medium-sized comparative case study of 20 European countries. FsQCA is a set-theoretic method that can reveal complex causal relationships involving outcomes resulting from several possible conditions. Our empirical context is energy transition, and specifically space heating transformation. Drawing on our results, we contribute to the policy mix research and the transitions literature by theorizing on the role of infrastructures and institutional complexity in rapid transitions.

The remainder of the paper is structured as follows. The next section reviews the policy mix literature within sustainability transitions research, focusing on the acceleration phase of the transitions. We elaborate on contingencies of policy mix effectiveness related to other contextual factors and our research context. The third section elaborates on the fsQCA method of the study, the data set, and outlines analytical steps. Thereafter, Section 4 introduces the results of the analysis. The final section discusses the results, outlines the paper's theoretical contributions, highlights the study's policy implications and limitations, and drafts avenues for future research.

2. Theoretical background

2.1. Rapid transitions

Sustainability transitions are described as long-term processes of systemic change within socio-technical systems, such as food, energy, and transportation, aiming to reorient them toward a sustainable configuration (Geels, 2024, 2002). These transitions involve fundamental transformations that require dynamic interaction among technologies, institutions, actors, sub-systems, regulations, markets, societal norms, and the structural frameworks underpinning these systems (Geels, 2004; Köhler et al., 2019; Schot and Geels, 2008). The multidimensional nature of these processes and interactions makes transitions inherently complex and nonlinear process, often taking decades to unfold (Geels, 2024; Rotmans et al., 2001).

Although transitions are widely recognized as being slow and gradual,[1] spanning at least one generation, significant variations have been observed across different communities, regions, nations, and continents (Rotmans et al., 2001). Transition scholars generally agree that transitions can be speeded (Roberts and Geels, 2018). Rapid transition needs to occur on a system level and global scale to drive a coordinated and transformative change in response to urgent challenges.

As transitions advance, they move through distinct phases that characterize different interactions, processes, and features (Kanger and Schot, 2016; Kivimaa et al., 2019). There is an implied understanding that transitions can be categorized into three or four consecutive phases, each reflecting a distinct stage of the transition process (Kanger and Schot, 2016; Rotmans et al., 2001). Rotmans et al. (2001) outline four phases: predevelopment, take-off, breakthrough or acceleration, and stabilization. For rapid transitions, the acceleration phase plays a pivotal role. During this phase, nascent innovations have already matured to a level that enables rapid diffusion and widespread breakthroughs across societies.

The research has shown that the acceleration phase is characterized by visible structural changes resulting from the accumulation of socio-cultural, economic, ecological, and institutional shifts that interact with each other (Markard, 2018). This phase is also marked by diffusion, and embedding processes that start to exert increasing pressure on the existing regime, making destabilization processes visible with the regime's stability increasingly challenged (Koretsky et al., 2022). An essential feature of the acceleration phase is the integration of complementary technologies and solutions, which enhances the diffusion of core innovations. Further, the phase requires sectoral integration across and between adjacent sectors, which is essential to advancing the transition, with digitalization playing a key role (Andersen et al., 2021; Mäkitie et al., 2023).

The acceleration phase of sustainability transitions also drives significant organizational changes. Much of the recent research has focused on reshaping the role of incumbent actors, the emergence of new players, and reconfiguration of existing organizational structures (Geels et al., 2016; Kump, 2023). Alongside these organizational changes, the role of different actors and stakeholders is evolving. Citizens, in particular, are becoming more engaged through their active participation, for example, through prosumption activities (Juntunen, 2014a). The role of intermediaries has also received increasing interest among transition scholars, as they facilitate system building efforts, cross-system configurations, and multisystem interactions (Bergek, 2020; Kivimaa, 2014).

Rapid system-level transformation requires positive visions of the future, new types of actor coalitions, rapid technological advancements, and significant policy changes (Skjølsvold and Coenen, 2021) across various scales, including national, sectoral, organizational, and individual. Due to the complexity, this poses challenges for policymakers who seek more rapid change. Particular emphasis has therefore been placed on relevant regulations and policies to accelerate these processes (Fan et al., 2022; Foxon and Pearson, 2008). As part of this effort, transitions have been analysed from the political process perspective. In the acceleration phase of the transitions, it is important for policymakers to monitor progress, identify and eliminate bottlenecks, and stimulate further developments (Markard et al., 2020). Political processes are inherently contentious, as different individuals and groups present alternative visions of transitions, potentially leading to the emergence of winners and losers. We see resistance from incumbents who seek to protect their vested interests, while new entrants and grassroots organizations advocate for their own agendas (Ford and Newell, 2021). In broader terms, these discussions concern the politics of sustainable development (e.g., Meadowcroft, 2009; Scrase and Smith, 2009), and studies of power and politics in transitions (e.g., Avelino and Rotmans, 2009; Hoffman, 2013). Along with the political process perspective, which has a central interest in governance, power, and agency aspects, the notion of policy mixes has emerged as an instrument to help in overcoming the complexity of the required changes, facilitating progress, and accelerating the pace of transitions (Flanagan et al., 2011; Kern et al., 2019; Kivimaa and Kern, 2016). Therefore, in the following, we explore the policy mix literature and its role in accelerating transitions.

2.2. Use of policy mixes to accelerate transitions

Since early work by Kern and Howlett (2009), the past two decades have witnessed increased attention on the role policy mixes play in promoting environmental innovation and sustainability transitions (Rogge and Song, 2023). While the definitions, scope, and

[1] The slow pace has also been challenged, and some research points out that sustainability transitions can occur more quickly (Sovacool, 2016; Sovacool and Geels, 2016).

conceptualizations of policy mixes vary, the core idea remains that policy mixes comprise a combination of several policy instruments (Lehmann, 2012; Nauwelaers, 2009; Rogge, 2018, p. 35). Yet, wider conceptualizations are common. These include goals and means (Kern and Howlett, 2009) or policy processes (policy-making and policy implementation), elements (policy strategies and instruments), and characteristics (consistency, coherence, credibility, comprehensiveness) (Rogge and Reichardt, 2016). For our comparative research design, we, however, focus on the narrower conceptualization and in this study consider only a mix of instruments.

The early works in the policy mixes research focused on examining the interaction between different policy instruments and their optimal combination (Del Río González, 2007). More recently, research has started to explore how policy mixes can simultaneously address the dual needs of the transition process by accelerating niche innovations while destabilizing existing regimes (Kivimaa and Kern, 2016; Turnheim, 2022). These studies particularly underscore the importance of combining 'creation' policies that support emerging technologies with 'destabilization' policies aimed at phasing out unsustainable practices (Kivimaa and Kern, 2016). Destabilizing policies (e.g., environmental policies) can essentially influence competitiveness between incumbent and emerging solutions and shape market dynamics (Scordato et al., 2018). To stimulate the development and scaling of emerging technologies, both demand-pull and technology-push instruments have been used (Costantini et al., 2017; Nuñez-Jimenez et al., 2022).

Technology-push and demand-pull instruments are typically used together (Döme et al., 2025; Hötte, 2023; Nuñez-Jimenez et al., 2022). Technology-push instruments focus on stimulating the development of innovations, often through R&D grants and tax incentives. They are instrumental when the maturity of technological solutions is subpar for mass market uptake, which hinders transitions from occurring. In contrast, the focus of demand-pull instruments is to support the scale-up of the innovations by expanding market demand for new technologies (Del Río et al., 2010). Demand-pull instruments of the policy mix become increasingly important in the acceleration phase of transitions (Costantini et al., 2017, 2015; Hoppmann et al., 2014). Practical examples of these include regulations, mandatory and voluntary soft and systemic instruments, and economic instruments that alter the competitive landscape of solutions (Rogge and Reichardt, 2016).

The research has shown that the effectiveness of technology-push versus demand-pull policies depends on the policy goals and the relative weight given to existing and future performance, and the future time horizon (Nuñez-Jimenez et al., 2022). A careful systemic design is essential, as combining multiple instruments may not always yield better results than single policies (Wang et al., 2022). A systemic policy design features multiple objectives to reach beyond several policy domains and touch innovations, business, markets, and consumption, while also addressing changes in infrastructures, social practices, and market arrangements (Kern and Howlett, 2009; Schot and Steinmueller, 2018). As the effectiveness of different policies varies across technologies, earlier studies have highlighted tailored approaches (Pitelis et al., 2020). Legacy matters, as new policies always operate together with the extant, so it is essential to establish a productive combination of both to deliver an impactful policy mix (Kern et al., 2019) and to avoid inequities and promote just outcomes (Torné and Trutnevyte, 2026). The existing literature stresses the need to design, evaluate, and implement appropriate policy mixes to shape the directionality of socio-technical systems, while avoiding transformation and system failures. Recent research also shows that the effectiveness of the demand-pull policy mixes depends not only on their design but is also influenced by the incumbent heterogeneity, as firm level characteristics may inhibit responsiveness (Luetkehaus, 2025).

Such nuances in the policy mix literature points to a broader question on generalizability. To this end, there is a limited consensus on which combination of policy instruments is likely to be most effective (Geels et al., 2018, p. 25; Meckling et al., 2017). This is because the research on policy mixes in sustainability transitions has often drawn on a single country study (Capano et al., 2020; Magro et al., 2014), the comparison of two or three countries (Hansen et al., 2019; Kern et al., 2017; Kivimaa and Kern, 2016; Pakizer et al., 2023), or small-N studies (Samant et al., 2020). Given a wider set of countries, the empirical data have often been used for conceptual development (Flanagan et al., 2011; Warren, 2019), to study technology-push policies (Guerzoni and Raiteri, 2015), for instrument type balance (Schmidt and Sewerin, 2019), or aimed to explain technology development through patenting activity (Dechezleprêtre and Glachant, 2014; Peters et al., 2012; Pitelis et al., 2020). Moreover, the generalizability of results has often been impacted by the limited geographical scope of these studies (Schmidt and Sewerin, 2019). The literature has also been criticized for the ambiguity in policy outcomes, which raises the question of data comparability (Köhler et al., 2019). More parsimonious empirical approaches are called for to facilitate larger-N, comparative analyses of policy mixes to reveal the impact and links between policy mixes to the sustainability transition outcomes (Schmidt and Sewerin, 2019). Since the recent literature on policy mixes has emphasized the importance of the surrounding institutions (Kivimaa and Rogge, 2022), we expand the perspective and contextualize policy mixes, with a specific focus on explaining rapid transitions.

2.3. Contextualizing policy mixes

To contextualize policy mixes, we draw on institutional theory in which the stability of social structure is a central tenet of the theorization. The stability is grounded in invisible institutionalized practices, with shared beliefs, norms, routines, mindsets, shared identities, and missions (Lammers and Garcia, 2014; Phillips, 1994). Much of the sustainability transitions literature has drawn on foundational principles of institutional theory (Turnheim and Geels, 2013), and considers a dominant regime an institutionalized core of a socio-technical system (Jehling et al., 2019). In order for change to take place, it is necessary to deinstitutionalize existing socio-technical configurations, and institutionalize new, more sustainable configurations (Fuenfschilling, 2019).

Markets act as an institutional force that influences actors in transition (Boon et al., 2022). New technological solutions must demonstrate competitiveness and economic viability against incumbent solutions to attain widespread diffusion. Economic instruments impact the competitive positions of regime technologies, and those emerging from niches to challenge the regime (Kern et al., 2019; Rogge and Reichardt, 2016). Still, the final cost structure in a region or country results from complex dynamics that extend beyond policy scope.

Materiality and especially large-scale infrastructures are weakly addressed in the mainstream institutional theories within organization studies (Greenwood et al., 2017). To incorporate infrastructures into an institutional perspective, we lean toward earlier works on sustainability transitions (Bolton and Foxon, 2011; van der Steen et al., 2008). In line with the works of Foxon (2013); Foxon et al. (2010)), and van der Steen et al. (2008), we consider infrastructures inseparable from supporting institutions and institutional order. Infrastructures are embedded in complex sociotechnical, political and cultural systems. Institutions are partly shaped by these material objects, and current infrastructure and technologies maintain stability in the socio-technical regime, creating self-reinforcing mechanisms and lock-ins (Unruh, 2000). On the other hand, institutional practices legitimize and are also able to delegitimize infrastructure (Krisch and Suitner, 2020), creating feedback loops in which institutions and infrastructures mutually reinforce or undermine one another. Infrastructures also mediate how consumers use, store, and dispose of resources, such as energy. Households act as nodes within infrastructures involved in generating, distributing, and storing energy (Otnes, 1988; van Vliet et al., 2005, p. 5). Materiality in the form of technologies and contextual factors, such as existing infrastructures (Barrera et al., 2022; Wu et al., 2022), impacts the pace of transition.

There are some limitations in how systemic perspectives examine the role of infrastructure. The literature emphasizes either the emergence of

infrastructure (Hughes, 1993), systemic change under which infrastructures and their evolution are embedded (Geels, 2002), or infrastructure as a necessary enabler for the transitions (Andersen, 2014). For example, energy infrastructures can be considered both restraints and facilitators of everyday life and domestic consumption (Otnes, 1988). This dual role of infrastructures, where their absence or presence can moderate transition processes, is much less examined. Existing infrastructures and infrastructural arrangements with institutional order can accelerate the transition, but they may also act as a barrier and central stabilizing component in the existing socio-technical regime.

In sum, policy mixes tend to create positive change in a socio-material world where complexity arises from incompatibility between structures and institutional factors of transitions. A more nuanced examination of the interplay of various factors could help us understand and theorize when an infrastructure can become an enabler or barrier to change.

2.4. Empirical context of the study - Energy transition and the role of heat pumps

Governments worldwide have implemented various incentives and support mechanisms to (Foxon, 2013; Foxon et al., 2010) encourage the adoption of clean energy solutions and support transition pathways. The practical demand-pull policy instruments in the energy transition have been tax credits, subsidies, and feed-in tariffs. Also, various other mechanisms have been used, including regulations, and soft and systemic instruments. These instruments have helped reduce the cost of clean energy technologies and make them more accessible to a broader range of households and communities. They are critical policy intervention points in accelerating the niches and destabilizing the regime (Kanger et al., 2020).

The energy transition and decentralized energy technology diffusion is surrounded by a multiplicity of institutions with conflicting operating principles and logics (Ocasio et al., 2017). Distributed, decentralized operating logic differentiates essentially from the traditional field logic, which is based on large physical infrastructures facilitating the generation and distribution of energy. These conditions create an interconnected web featuring complexity, as different conditions can support or hinder transitions.

Infrastructures, such as distribution networks, in the energy transition can be seen as a critical enabler (Ghorashi and Maranlou, 2021). They require expansion and investment to reach normative goals (Bridge et al., 2018), but can also act as a legacy structure and potentially stranded asset (Caldecott et al., 2021). In other words, the role of infrastructures is complex and situated. The legacy energy infrastructures in developed countries deliver heat or power between nodes of generation and consumption. In examining how new decentralized energy innovations diffuse in the household sector, we need to recognize infrastructures and networks that are centrally connected to the incumbent regime's production and heat delivery mechanisms. The destabilization of a regime may require disruption of infrastructural elements at various levels in a socio-technical configuration, involving how business aspects and models are configured to operate infrastructures.

Heat pumps are a low-carbon heating technology with the potential to deliver large-scale reductions in carbon emissions from heating buildings. The technology is highly mature, with more than 177 million heat pumps having been installed globally by 2020 (International Energy Association (IEA), 2021). However, only 10 % of global building heating demand is met by heat pumps (IEA, 2024), highlighting their potential to accelerate the transition toward sustainable heating. To this end, the supply of heat pumps is concentrated in a few countries. In Europe, Germany has several major players in the field, with two of the seven largest producers being German. Other European countries are not globally significant in this respect (Verified Market Research, 2023), but the technology is available for both households and industries. It is widely believed that the existing utilisation is far lower than the potential. The diffusion level in many markets is lagging, and heat pumps are far from a primary choice, as they are part of an emerging niche challenging the regime.

Heat pumps use the source energy to transfer heat from a cold to a warm space, which enables cooling and heating of the spaces. The conventional electricity-powered heat pump typically generates around three to six times more heating output than direct electricity heating. A year-round average Co-efficiency of Performance (COP) of three to four is common for household applications (Gibb et al., 2023). The degree of efficiency is also much higher than in gas-powered systems (Pawela and Jaszczur, 2022). Some specific models utilize natural gas as the energy source, but their market success has been modest.

Various EU legislative initiatives including REPowerEU have encouraged EU countries to establish subsidy programs for heat pumps. In 2023, several countries, including Austria, Croatia, France, Germany, and Spain, launched grant schemes to support heat pump installations. To date, heat pumps have been most widely installed in countries with colder climates (EHPA, 2023; Rosenow et al., 2022).

The role of heat pumps in energy transition has been widely researched. As a decentralized micro-generation technology, much attention has been paid to citizens as adopters of heat pump products and technologies in households. These studies include perspectives ranging from domestication and user practices (Juntunen, 2014b; Parrish et al., 2021; Van Beek et al., 2024), to user innovations (Hyysalo et al., 2013a; Hyysalo, 2021; Martiskainen et al., 2021) and communities (Hyysalo et al., 2018, 2013b; Juntunen, 2014a), and behavioral diffusion studies (Bjørnstad, 2012a). The extant research acknowledges the importance of policies (Bjørnstad, 2012b; Peñasco, 2024), but policy mixes have rarely been explicitly examined. An exception is the study by Cilinskis et al. (2017), based on data from Latvia, which found radical emissions reduction could be achieved by applying a policy mix involving a wide range of policy instruments, including carbon taxes, subsidies, and funding for energy efficient renovation.

In general, heat pumps seem to have proliferated best in a context that features favorable economic conditions combined with a supportive, holistic policy mix. Technology-push instruments can steepen the diffusion curve. To build a supportive policy mix for rapid uptake, sector specific financial instruments such as grants, tax reductions, and loans, as well as regulatory instruments, including building regulations and appliance standards are needed (Rosenow et al., 2022). Furthermore, soft and systemic instruments, which build consumer confidence, improve knowledge creation, and foster skills development are essential, along with the creation of a supportive intermediary environment, such as heat pump associations and citizen knowledge-sharing via digital forums (Hyysalo et al., 2018). Non-sector specific instruments can include destabilizing instruments (Leipprand and Flachsland, 2018; Turnheim and Geels, 2013), such as carbon taxes and supportive energy pricing policies, which are used to phase out fossil fuel heating and speed diffusion of clean heating technologies (Rosenow et al., 2022). Factors influencing a rapid energy transition and high diffusion levels of heat pumps are rather well-known, but how these factors interplay, reinforce or act as substitutes for each other, has not been systemically examined.

3. Data and methods

3.1. Methodological approach

Our point of departure in selecting a methodological approach was the realization that impactful policy mixes are context dependent, and that a “right” policy mix does not exist as national objectives and constraints differ (Howlett and Rayner, 2013; IEA, 2017). Consequently, we have adopted a configurational approach to studying case countries and small-scale energy technology diffusion, using the qualitative comparative analysis (QCA) method. The method has its roots in political

science (Marx et al., 2014). QCA as the methodological approach is particularly well-suited in this context, since it has a long history of investigating the effects of various policies (Borozan, 2022; Capano et al., 2020; Ma et al., 2021), and has proven its suitability for examining the effectiveness of policy mixes (Pakizer, 2020). The method has specific advantages in contexts where causal complexity is present. In other words, different configurations of policy mix conditions in a different context can also lead to different diffusion outcomes. For example, the heterogeneity of European countries produces a wide range of policies concerning climate change (Steen and Weaver, 2017), environmental factors, and different types of infrastructural arrangement and business operating environment. On the other hand, several successful configurations of the abovementioned conditions may produce positive outcomes, and it is essential to identify the configurations that work (Heiberg et al., 2022). In QCA terms, this type of feature of causal complexity is termed equifinality (Fiss, 2007; Rihoux and Ragin, 2008).

Moreover, infrastructural and institutional conditions do not operate in isolation, but are interdependent and feature conjunctural causation (Misangyi et al., 2017). A research approach that can reveal this interdependency can provide important details about the joint effects of policies and other conditions.

3.2. Sample and procedure

In QCA studies, the case selection and sampling strategy do not rely on random sampling or other mechanistic procedures. The process is iterative, aiming to define an area of comparability and heterogeneity in the case outcomes (Rihoux and Ragin, 2008, p. 20).

Our data concern heat pump diffusion, infrastructural, environmental and market conditions. First, we defined the domain of investigation to establish boundaries within which the case countries would be selected. Rihoux and Ragin (2008, p.20) guide toward the selection of cases which are sufficiently parallel to each other and can be compared along the specified dimensions. In other words, we drew an explicit hypothesis that the selected cases are sufficiently alike to permit comparison. Thus, we focus on developed countries with similar liberal market dynamics.

A second consideration in case selection concerns the matter of diversity within the selected case country set. We aimed for a maximum heterogeneity among the selected cases within the defined boundaries. Those cases differ in their policy, regulatory, infrastructural, market, and environmental context, which allows us to employ a comparative case approach in this paper. Regarding the outcome, both rapid and slow transitions case countries are included in the analysis to offer a comprehensive perspective on outcomes.

We started with the EU-27 countries list, choosing a subset of 22 countries with available heat pump diffusion data. In the final round, data points were missing for two countries, so they were removed from the list, bringing the total case number to 20.

To study rapid transitions, heat pumps provide a solid empirical case, since they are widely recognized as a clean technological solution in the energy transition (Rosenow et al., 2022). The heat pump is one of the rare energy technologies that has demonstrated rapid diffusion in the market. In less than two decades, the technology has penetrated from close to zero installations to over 90 % penetration of the total accessible housing stock (e.g., in Norway and Finland) (EHPA, 2022).

3.3. Configurational model and data sources

In developing our configurational model, we consider the literature on sustainability transitions and frameworks explicitly addressing institutional conditions, including materiality and infrastructures. The relevant frameworks serve different purposes, such as innovation system (van der Steen et al., 2008), conditions influencing transition pathways (Foxon et al., 2010), and depicting layered analytical frameworks for institutional analysis (Bolton and Foxon, 2011). Our configurational model draws on Foxon's (2013) three-layered framework, comprising regulation, policy, and markets; and, otherwise, energy infrastructures. These institutional conditions are measurable at the country level, and we exclude organizational, individual level conditions from our analysis (e.g., actor strategies, values, behaviours), which can have a large variation inside a case country. Our decision sharpens the analytical focus, positions the level of analysis at the country level, and reduces analytical complexity by controlling the number of examined conditions.

We build on prior research that uses proxies such as energy intensity improvements, renewable energy shares (Liu et al., 2022), and technology diffusion (Min et al., 2023) to measure the outcomes of rapid transitions. In addition to technological diffusion, our model incorporates several other key features of rapid transitions as conditions in the QCA model.

3.3.1. The outcome measure

Our outcome variable is rapid transition, measured by heat pump diffusion (Table 1). The heat pump technology represents a commonly used element of decarbonizing heating systems and provides robust, comparable data across countries, enabling country comparison and theorization. We draw on heat pump diffusion data provided by the European Heat Pump Association (EHPA), and operationalize diffusion by examining the market share of heat pumps in space heating, considering the current heat pump stock and total housing stock. In the measurement, we cover all the major heat pump types, including Air-to-air Heat Pumps (AAHP), Air-to-water Heat Pumps (AWHP), Exhaust Air Heat Pumps (EXHP), Ground Source Heat Pumps (GSHP), and Water Source Heat Pumps (WSHP). We base our analysis on 2019 numbers. The diffusion of heat pumps was greatly impacted by the 2020 coronavirus outbreak, which slowed development in all the markets. Economic stimulus, the Russian invasion of Ukraine, and the consequent energy crisis in 2022 increased sales drastically. We see that excluding the impacts of these extreme events increases the robustness of the results.

3.4. Conditions

We distinguish between remote and proximate conditions based on their rate of change. Some of the influencing conditions can be considered fixed or at least their change is very slow. These include natural environment-related conditions, such as geography or climate. Further, some human-made constructs require inherently extensive networked scope and are slow to implement. Large-scale technological systems, such as infrastructures, can then be categorized as remote conditions influencing technology diffusion together with proximate, more dynamic conditions that may change more rapidly. Examples of proximate conditions include policy mixes or market related conditions. Furthermore, organizational- and individual-level conditions can be understood as proximate conditions but are beyond the scope of our country-level study.

The main focus of our research lies on slowly changing environmental and infrastructural conditions, and proximate policy mix and market conditions. Thus, we build a two-layered configurational model and employ two-step QCA in our analysis (Haesebrouck, 2019; Schneider, 2018; Schneider and Wagemann, 2006), allowing us to include more conditions than traditional QCA. In our analysis, we build a configurational model comprising three remote conditions (Energy-consuming weather conditions, Gas network coverage, District heating network coverage), and four proximate conditions (three policy mix conditions and one market-related condition). The data set, measures, and operationalizations are introduced below (Table 2).

3.4.1. Remote environmental condition

Our model is divided into remote and proximate conditions. First, we measure energy-consuming weather conditions. The natural

Table 1
Overview of outcome, its operationalization and data set.

Outcome	Operationalization	Data set	Min.	Mean	Max.
High heat pump diffusion	Heat pump market share calculated by total installed heat pump stock divided by accessible housing stock.	European Heat Pump Association (EHPA) data set on country-level diffusion of heat pumps in Europe, based on the most recent annual figs from 2019 (EHPA, 2022).	0	0.33	0.97

Table 2
Overview of conditions, their operationalization, and data set.

Conditions		Operationalization	Data set	Min.	Mean	Max.
Condition 1: Remote, Environmental	High energy-consuming weather conditions (ENV)	We measured the total number of heating and cooling degree days per year by country in 2019.	Eurostat. Cooling and heating degree days by country (Eurostat, 2024b).	1276	3027	5510
Condition 2: Remote, Infrastructural	Wide gas network coverage (GAS)	Share of households using natural gas as the main heating source, of total households, in 2019.	European Heat Pump Association (EHPA) data set (EHPA, 2022).	0	32.85	85.50
Condition 3: Remote, Infrastructural	Wide district heating network coverage (DIST)	Share of households using district heating as the main heating source, of total households, in 2019.	European Heat Pump Association (EHPA) data set (EHPA, 2022).	0	16.47	57.60
Condition 4: Proximate, Sector specific policy mix pillar	Strong mix of economic demand-pull instruments (ECO)	We used household sector policy data targeting space heating end-use energy, and included economic demand-pull measure types (financial, fiscal) at country level. We assigned 3 points for high-impact policy, 2 points for medium-impact policy, and 1 point for low-impact policy, and calculated the total (sum) policy impact of all measures. We included policies set in 2019 or earlier.	Odyssee-Mure database (Odyssee-Mure, 2025).	0	3	11
Condition 5: Proximate, Sector specific policy mix pillar	Strong mix of regulation demand-pull instruments (REGU)	We used a household sector policy database targeting space heating end-use energy, and included regulation demand-pull measure types (mandatory information, mandatory standards) at country level. We assigned 3 points for high-impact policy, 2 points for medium-impact policy, and 1 point for low-impact policy, and calculated the total (sum) policy impact of all measures. We included policies set in 2019 or earlier.	Odyssee-Mure database (Odyssee-Mure, 2025).	0	3.6	13
Condition 6: Proximate, Sector specific policy mix pillar	Strong mix of soft and systemic demand-pull instruments (SOFT)	We used a household sector policy database targeting space heating end-use energy, and included soft and systemic demand-pull measure types (information and training on financial aspects, other information and training types, mandatory information, and market-based instruments) at country level. We assigned 3 points for high-impact policy, 2 points for medium-impact policy, and 1 point for low-impact policy, and calculated the total (sum) policy impact of all measures. We included policies set in 2019 or earlier.	Odyssee-Mure database (Odyssee-Mure, 2025).	0	2	7
Condition 7: Proximate, Market conditions	Low energy market price ratio (ERATIO)	We measured the energy market price ratio, and compared the electricity price at €/kWh to the main competing source price (gas or district heating). For the calculation, we used the average price for households from 2017 to 2019.	Eurostat. Electricity and gas prices for household consumers (Eurostat, 2025).	1.1	2.5	4.23

environment may mediate diffusion outcomes, as technology may prove viable or economically competitive in certain environmental conditions earlier than in others. This should be considered in the analysis. Several studies have underscored the influence of weather conditions on household energy consumption (Beccali et al., 2008; Haas et al., 1988, p. 8). The heating and cooling degree days (HDD and CDD) measure is commonly used to calculate the impact of outdoor temperatures on a building's energy use, or on countries' energy demand for heating (Bhattacharjee and Reichard, 2011; Isaac and Van Vuuren, 2009). This measure improves the comparability of different countries with different weather conditions and energy usage patterns, which is also reflected in the economic viability of household energy systems. The measure provides pan-European information relevant to indoor heating and cooling demand—each degree deviation from the balance point results in either heating or cooling of the building. The measure quantifies how far the outdoor temperature is from a given indoor comfort temperature. The comfort temperature thresholds in this application are 15.5 °C in winter and 22.0 °C in summer.

3.4.2. Remote infrastructural conditions

Energy infrastructures are large material constructs that do not inherently define the source of heat or power transmitted through them. However, the fossil fuel-based economy has configured these infrastructures to deliver fossil fuel-based energy products to consumers. This also applies to our empirical setting, in which we look deeper at heat distribution, and socio-technical change in heat generation and distribution. To date, gas networks have remained carriers of fossil fuel-based products. The potential exists for decarbonization of the natural gas network through green hydrogen injection (Romeo et al., 2022), though that is not in commercial use. Similarly, district heating networks have traditionally been powered by coal and natural gas; however, a change to cleaner sources is underway, and the carbon emissions of district heating are being reduced using waste heat, bioenergy, and larger-scale heat pumps.

3.4.3. District heating network coverage and gas network coverage

Central and southern European countries have traditionally relied on extensive gas networks, and district heating has remained relatively uncommon. In contrast, Northern and Eastern European countries

primarily rely on district heating networks for household heating. We measure the country-level ratio of the primary heating source for district heating and natural gas,[2] and include these two infrastructural conditions in the remote conditions set in our model.

3.4.4. Proximate policy mix conditions – Sector specific policy mix pillars

We measure three distinct sector specific policy mix pillars using data that include economic incentives, regulatory policies, and soft and systemic policies related to residential space heating areas. The economic policy mix pillar measures the impact of the policy mix formed by subsidies and other financial instruments, and uses fiscal instruments such as tax breaks to encourage heating technology diffusion. The regulatory policy mix pillar measures the impact of several instruments, including mandatory standards and regulations related to space heating and hot water provision. The soft and systemic policy mix pillar takes into account information and training related to financial aspects, mandatory information provision, and market-based instruments, and measures the impact of the mix. We base our measure on 130 active household space heating-associated policies in the case countries in 2019 (Figs. 1 and 2). The Mure database has been widely used to study energy transition and energy efficiency policies (Bertoldi and Mosconi, 2020; Bigano et al., 2011; Filippini et al., 2014; Kern et al., 2017). The database delivers an impact classification on three levels (low, medium, high) and has frequently been used to evaluate policy efficiency (Ó Broin et al., 2015). We use the Mure impact classification in all the above measurements.

3.4.5. Proximate market conditions

The physical energy infrastructures are linked to socially constructed markets, which mediate the competitive position between solutions. The economic viability of the diffusing technology is particularly relevant. The Energy Price Ratio can be used when comparing the prices of diffusing technology with the alternative options (Aditya et al., 2020) or most widely used incumbent solutions. The extant literature has recognized the low economic viability of heat pump solutions in many European countries, which can hinder diffusion. Only Nordic countries Denmark, Finland, and Sweden, and also France and Serbia, have an energy price ratio that could make a heat pump solution[3] competitive with a solution where heat is produced by a gas boiler (Jovet et al., 2022). We measure energy market conditions by the energy price ratio, and consider the country's dominant solution. This means the electricity price (kWh) is compared, depending on the country, to that of gas or district heating. The energy price ratio in the case countries is visualised in Fig. 3.

The energy market conditions in a specific country are a result of market-based factors related to specific fuel sources and the employed energy market policy mix. The extant literature has shown that carbon pricing and the attribution of levies and taxes have a significant impact on the energy market ratio (Rosenow et al., 2022). For instance, destabilization of the existing regime (Turnheim and Geels, 2013) by increasing taxes on fossil fuels or removing taxes and levies on electricity can further improve the diffusion of heat pumps. As our policy mix pillars measure sector-specific policy instruments, for the energy market conditions we measure the energy market price ratio which is able to grasp impact of a system level policy mix, which can heavily influence the diffusion.

3.5. Analysis

In our analysis, we followed best practice in qualitative comparative analysis as laid out by Greckhamer et al. (2018).

3.5.1. Calibration of data

Fuzzy set analysis delivers a method to define whether a case belongs to a particular set. In our calibration, the qualitative anchors transform the original interval-scaled values into a fuzzy value scale ranging from 0 to 1.

We calibrated the cases into sets based on theoretical and contextual knowledge (Greckhamer et al., 2018). We used fuzzy set calibration for the outcome and all conditions. The calibration was performed using the direct method (Rihoux and Ragin, 2008, p. 85). We used prior theoretical knowledge, case knowledge, and visible value breaks to define the threshold anchor points. The calibration table with entries is presented in Appendix A.

After the calibration, we proceeded to a QCA two-step approach. For the necessity analysis and sufficiency analysis in the second phase, we used the QCA[4] (Dusa, 2018) and SetMethods[5] (Oana et al., 2020) package for R.[6] We followed best QCA practice (Rubinson et al., 2019; Schneider and Wagemann, 2010).

The first step, necessity analysis of remote conditions consisted of two phases. In the first phase, we tested whether any condition in our model was by itself necessary for generating the outcome.[7] In the second phase of the necessity analysis, we tested possible disjuncts of several conditions forming necessary conditions. This involved running a subset/superset function with high consistency, coverage, and relevance of necessity thresholds (Schneider, 2018). The resulting disjunctions were taken into account in the second step, when performing Enhanced Standard Analysis (ESA).

For step two, the sufficiency analysis (Fig. 4), we applied ESA (Schneider and Wagemann, 2013) to determine which conditions are sufficient for high diffusion. The sufficiency analysis must consider the limited diversity of the sample. In other words, the set of case countries is not a result from an exhaustive sampling, and there can be empirically unobserved cases that lead to a positive outcome. We performed the counterfactual analysis (Schneider and Wagemann, 2012, p. 169) by making theoretically informed directional assumptions[8] to distinguish between easy and difficult counterfactuals (Ragin and Sonnett, 2005). In doing so, we are able recognize each solution's core and peripheral causal conditions. ESA enabled us to deal with empirically unobserved cases, in order to ensure the outcome coding in the truth table (Appendix B) did not contradict prior findings of necessity or sufficiency (Schneider and Wagemann, 2012, pp. 198–211). Thus, in analysing outcomes, we excluded such logical remainders, which were found to be necessary disjunctions in step one.

In analysing the positive outcome, we set the frequency cut-off to 1, and used a consistency cut-off of 0.89 and PRI cut-off of 0.6 for the positive outcome, and 0.97 and 0.6 for the negative outcome, respectively. We reached consistency scores that can be considered very high (Ragin, 2008, p. 52). The score for the positive solution was 0.96, and for

[2] We adopted a longitudinal view of district heating network coverage. In all the major markets, district heat network coverage has constantly spread until 2019. https://www.iea.org/data-and-statistics/charts/total-operating-district-heat-pipelines-in-europe-2005-2019

[3] This calculation is made assuming a high COP of 5.5.

[4] QCA version 3.17

[5] SetMethods version 3.0

[6] R version 4.2.2

[7] It should be noted that a condition can be either present or absent.

[8] Based on the earlier literature and our findings in the step-one analysis, we made directional assumptions that limited gas network coverage is associated with rapid transition. Based on theoretical assumptions, we also assumed that strong policy mixes regarding economic values, regulations, and a low energy price ratio are associated with a high level of heat pump diffusion. For the negative outcome, we employed the following directional expectations: wide gas network coverage, low energy-consuming weather conditions, absence of impactful policy mixes in all three measurements, and a high energy market price ratio.

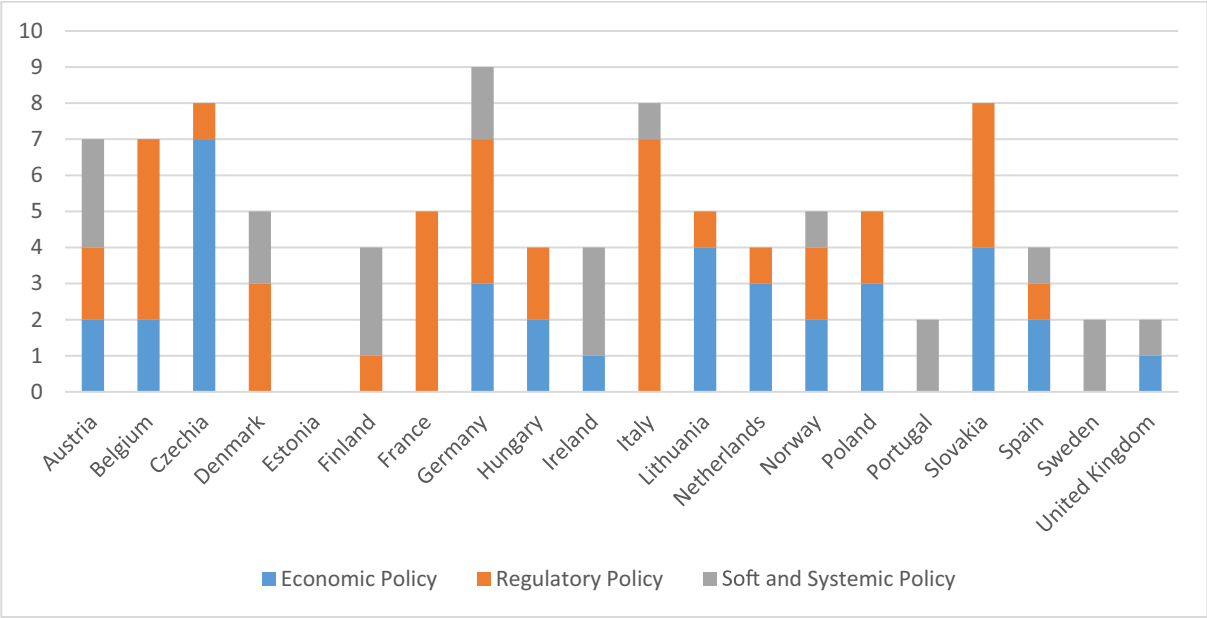

Fig. 1. Number of active space heating-related policy instruments by country in 2019.

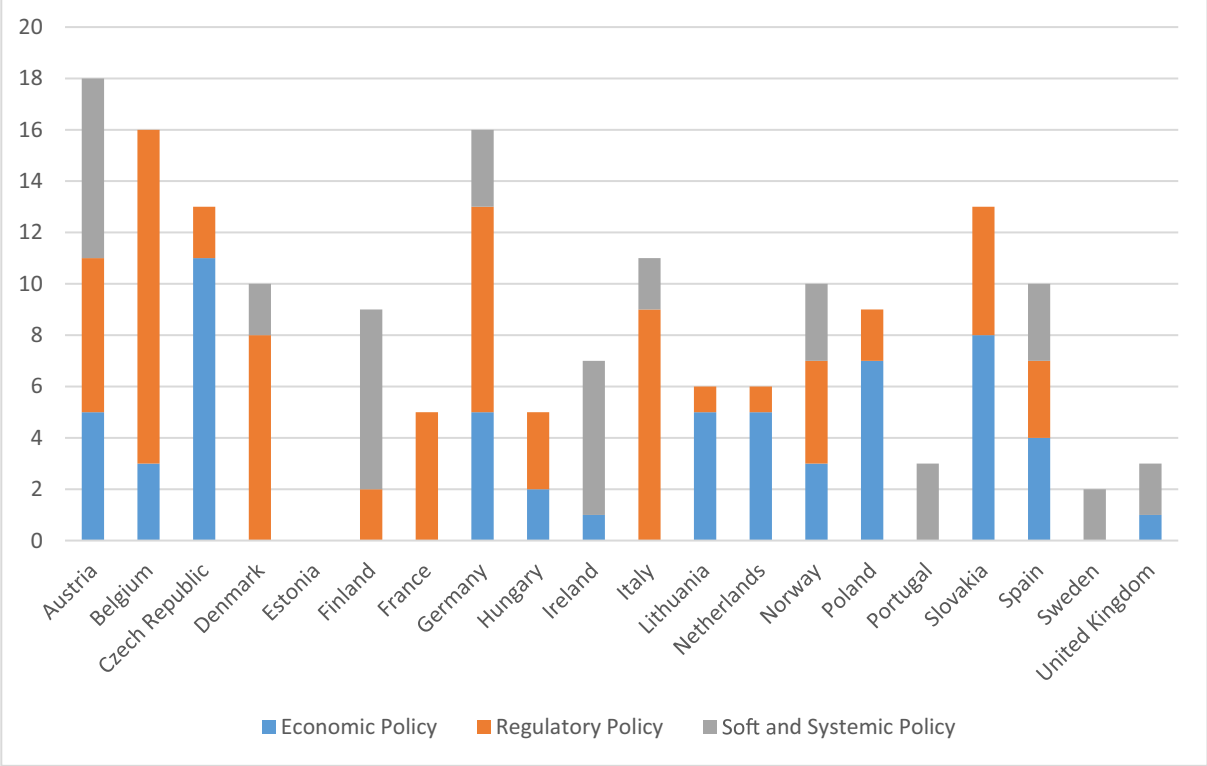

Fig. 2. Impact of active space heating-related policy instruments by country in 2019.

the negative solution 0.99. The solution coverage was 0.75 for the positive outcome and 0.72 for the negative. These values indicate that our configurational model captures the complex causality of the underlying outcome of systemic change well.

We used the intermediate solution for the results (Ragin and Fiss, 2008). Furthermore, we used a parsimonious solution to distinguish between so-called core and peripheral conditions in the result sets. Core conditions would remain in the solution term regardless of the simplifying assumptions made in the analysis, and for them, the evidence indicates a strong association with the outcome. Peripheral causal conditions instead consider what could be plausible, showing weaker empirical evidence for a causal relationship with the outcome. We used grey literature and extant academic literature to interpret our configurational results from QCA. The findings of our analysis are discussed in the following section.

Robustness checks were integral to our analysis. We used the Oana and Schneider (2021) to assess the stability of the resulting configurations. This recent protocol is quickly becoming the standard for the

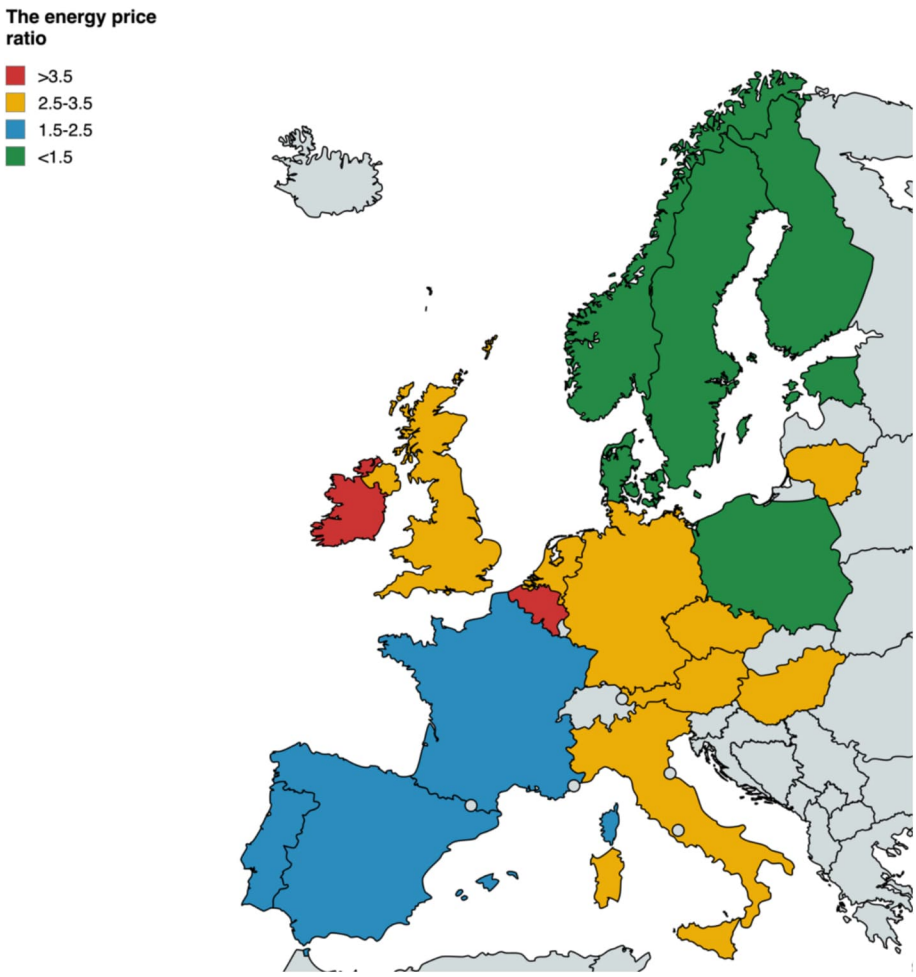

Fig. 3. Energy market price ratio across countries.

assessment of the robustness of QCA results. In this process, we determined the sensitivity ranges for calibration and frequency cut-off. For calibration, we used the rob.calibrange function from SetMethods to find the upper and lower bounds within which the solution remains stable. We found that the parsimonious solution remained consistent, and the interpretation of the solutions persisted, even with relatively significant changes in the crossover points of the conditions.

Next, we conducted checks to identify similar ranges for the consistency threshold value and frequency cut-off value using rob.inclrange and rob.ncutrange, respectively (Greckhamer et al., 2018). The negative solution was found to be more robust to changes in the consistency threshold than the positive outcome. However, both results showed only minor changes when the consistency threshold value was moderately altered. The solutions were more sensitive to changes in the frequency cut-off value, which is to be expected for a dataset with 20 cases where many truth table rows are represented by a single case. For both the positive and negative outcomes, we achieved the highest possible rank of 1, indicating the best possible subset relationship between the Test Set (TS) and the Intermediate Solution (IS), according to the relevant case types. The robustness check report can be found in Appendix C.

4. Results

In the following, we present configurations that result in either rapid or slow transitions. For each, we discuss relevant configurations and their impact on the countries in question. This helps us understand how policy mixes perform under different contexts.

4.1. Necessary conditions which result in either rapid or slow transitions

We analysed both positive and negative outcomes for the necessity. Among the remote conditions, we found limited gas network coverage as a single necessary condition for the positive outcome, while no disjuncts formed the necessary conditions.

We found three disjunctions of conditions when analysing the necessary conditions for the negative outcome. First, wide gas network infrastructure and wide district heating network coverage formed a disjunction, a necessary condition for the negative outcome. Second, narrow district heating coverage with wide gas network coverage also created a disjunction of conditions, leading to a negative outcome. The third disjunction was formed by wide gas network coverage and high energy-consuming weather conditions.

4.2. Explaining rapid transitions

Our analysis of positive outcome reveals three configurations that result in rapid transitions (Fig. 5, Table 3).

With regard to remote conditions, the configurations associated with rapid transitions can be grouped into two, based on the infrastructural conditions. In the first group, configurations RT1a and RT1b are based on *Countries with weak existing infrastructural arrangements*. The second group consists of RT2, based on *District heating dominated countries* with limited gas network coverage. It is noteworthy that sector specific policy pillars do not depict coherent structures, and the pillars should not be looked at separately from energy market conditions. The energy market condition, economic demand-pull instruments, touch on the economic

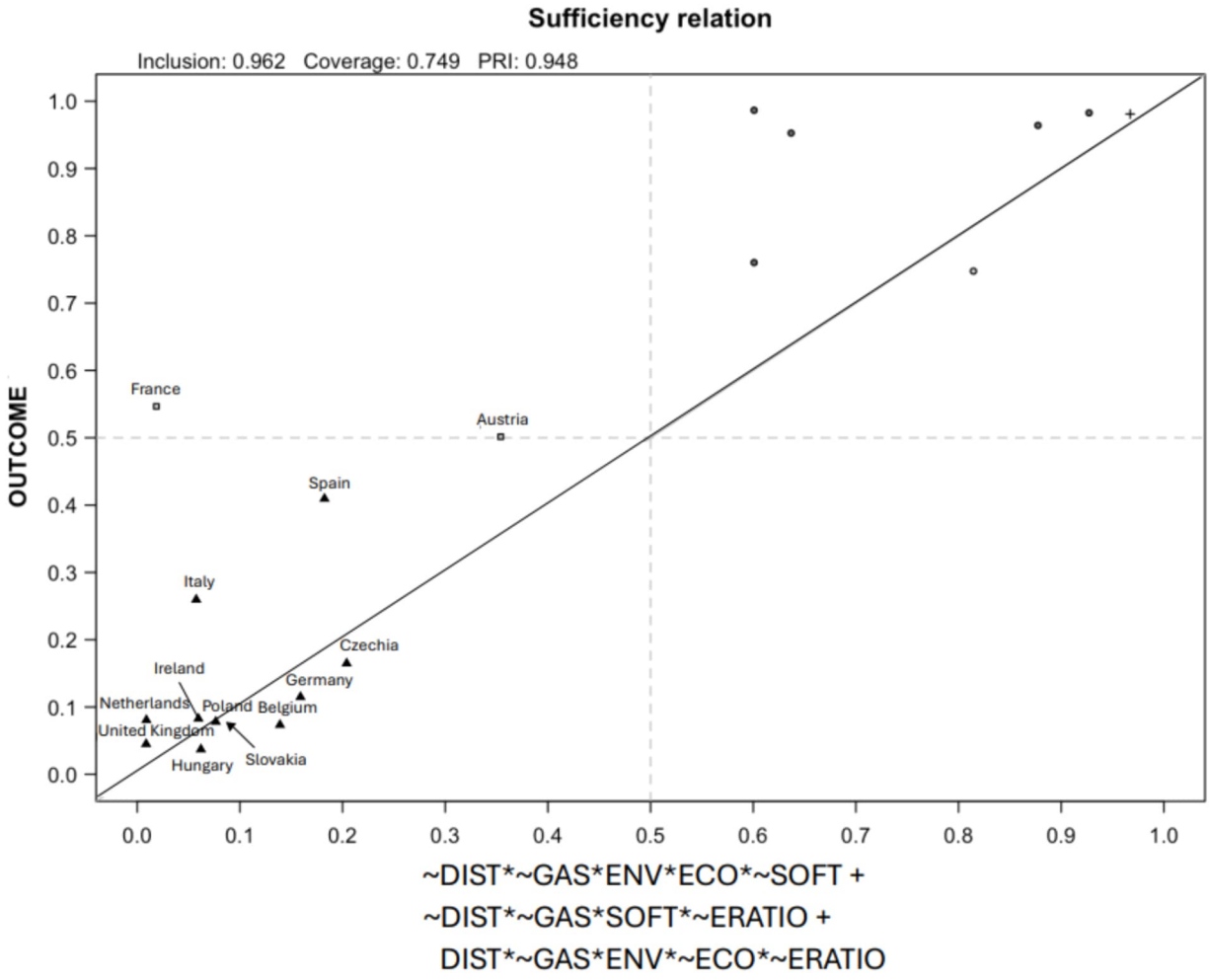

Fig. 4. The sufficiency relation for a rapid transition.

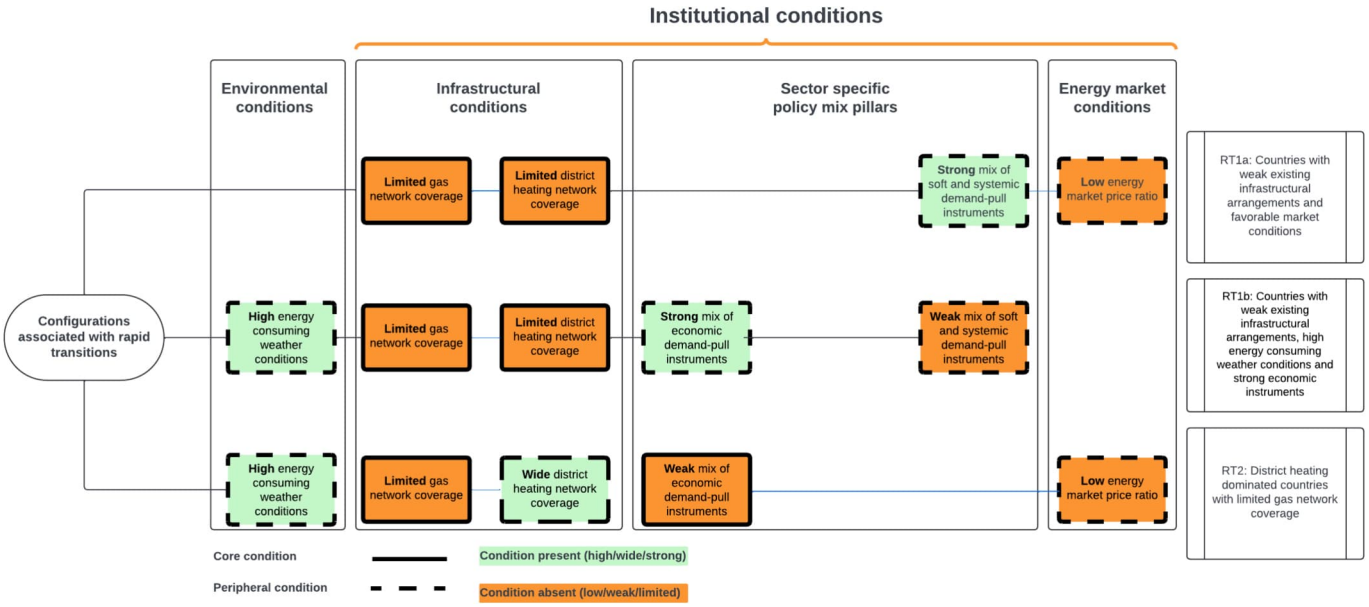

Fig. 5. Configurations leading to rapid transitions.

Table 3
Configuration names, strong cases under configurations and key quality indicators of the QCA analysis.

Outcome	Configurations associated with rapid transitions			Configurations associated with slow transitions			
Configuration name	RT1a: Countries with weak existing infrastructural arrangements and favorable market conditions	RT1b: Countries with weak existing infrastructural arrangements, high energy consuming weather conditions and strong economic instruments	RT2: District heating dominated countries with limited gas network coverage	ST1a: Gas network dominated countries with unfavorable energy market conditions	ST1b: Gas network dominated countries with soft and systemic instruments	ST2: Countries with wide infrastructures and unfavorable energy market conditions	ST3: District heating dominated country with strong economic instruments and favorable energy market conditions
Strong cases under the configuration	Portugal, Norway	Lithuania	Estonia, Sweden, Finland, Denmark	United Kingdom, Hungary, Italy, Netherlands, Belgium, Germany	Ireland, Spain	Czechia, Slovakia	Poland
Consistency	0.983	0.883	1	0.999	1	0.986	1
PRI	0.965	0.778	1	0.998	1	0.977	1
Unique coverage	0.148	0.129	0.371	0.359	0.038	0.047	0.049
Solution consistency	0.96			1.00			
Solution coverage	0.74			0.73			

viability of a technology against alternative solutions. Our results make it clear that a weakness in energy market conditions must be compensated for in the sector specific economic policy mix pillar. But even a weak sector specific economic policy pillar can lead to a positive outcome, if generic energy market conditions are favorable.

The necessary condition is visible in all the configurations leading to the rapid transitions. All the configurations are based on a limited gas network coverage. RT1a and RT2 are formed with a low energy price ratio. This condition is not deemed necessary in the necessity analysis. However, we have some indications that a low energy price ratio is essential to achieving high diffusion levels and rapid transitions. We will return to this point when discussing the negative outcome. In the following, we provide a more detailed interpretation of the configurations leading to rapid transitions.

Countries with weak existing infrastructural arrangements. Overall, RT1a can be characterized by weak existing infrastructural arrangements with favorable market conditions. In this configuration, the energy market price ratio is low and does not establish a barrier to transition. Also, RT1a features a strong policy mix from the soft and systemic instruments but is ambivalent on the economic or regulation instruments of the policy mix. Portugal is one of the case countries under RT1a. The Portuguese market has undergone a rapid diffusion of air-to-air heat pumps, and air to water heat pumps are also gaining in popularity. The country features favorable infrastructural arrangements, and its soft and systemic sector specific policy mix pillar is relatively strong, with an energy labelling system for products (CLASSE+), and energy labelling of heating products and systems. During the monitored period, the electricity price level was below the EU-27 average (Eurostat, 2025). In addition to favorable demand-pull instruments, Portugal has a strong heat pump R&D and manufacturing base, which potentially creates technology-push elements to support the diffusion. The Bosch group has been operational in Aveiro, Portugal since 1977 and has expanded its operations multiple times to meet the increasing demand of heat pumps (Bosch, 2021).

Similarly, RT1b is based on weak existing infrastructural arrangements, but also features high energy-consuming weather conditions as an environmental condition, and strong economic and weak soft and systemic demand-pull instruments. Notably, this configuration is based on one empirical case, Lithuania, which has a relatively cold climate and high heating needs. The country has 42 % more heating degree days than the EU average, and heat pumps are rarely used for cooling. Lithuania's electricity-gas price ratio is favorable for heat-pumps, which has supported the energy transition. In addition to contextual factors examined in the study, the main factor hindering the heat pump installations during the monitored period was the high cost of heat pump units compared to local income levels (Nordic Energy Research, 2021).

Configuration RT2 is characterized by *District heating dominated countries with limited gas network coverage*. They have worked for years to liberalize the energy market, and do not employ a strong policy mix of economic demand-pull instruments. The case countries Sweden, Finland, Denmark, and Estonia have enjoyed low electricity prices, and electricity has remained competitive against popular district heating solutions. Heat pump diffusion in Finland exemplifies this configuration. The country has moved through various phases during the last half-century of heat pump diffusion (Hyysalo and Juntunen, 2024, 2021; Martiskainen et al., 2021). The low energy market price ratio has been crucial to the diffusion. In addition to the favorable price ratio between district heating and electricity, the electricity price is among the lowest in the EU, and the average household income is high, which supports diffusion. The annual average temperature (6 °C in the south of Finland) is cold, contributing to heating bills. With regard to cultural facets, extensive communication in forums has crucially supported the diffusion by providing essential information on selecting suitable products, the use and maintenance of the equipment, and solving problems (Hyysalo et al., 2018, 2013b, 2013a).

4.3. Explaining slow transitions

Our analysis of the configurations that result in slow transitions reveals four distinct configurations of low heat pump diffusion in the monitored period (Fig. 6). The outlook for sector specific policy mixes is characterized as ambivalent. Wide gas network coverage is present in three out of four configurations. Problems arising from a high energy market price ratio are widely visible, and we shall examine these next, along with the other features of the configurations leading to the negative outcome.

Gas network dominated countries form ST1a and ST1b configurations. ST1a features a high energy market price ratio, whereas the ST1b configuration features strong soft and systemic demand-pull instruments, and remains ambivalent regarding the other sector specific policy mix pillars and the high energy market price ratio. Due to mild weather conditions in the case countries under these configurations, ST1a and ST1b have low energy consuming weather conditions. Although ST1b comprises strong policy mix pillars of soft and systemic demand-pull instruments, this condition is unable to balance out other unfavorable conditions. One of the case countries in ST1a is the UK,

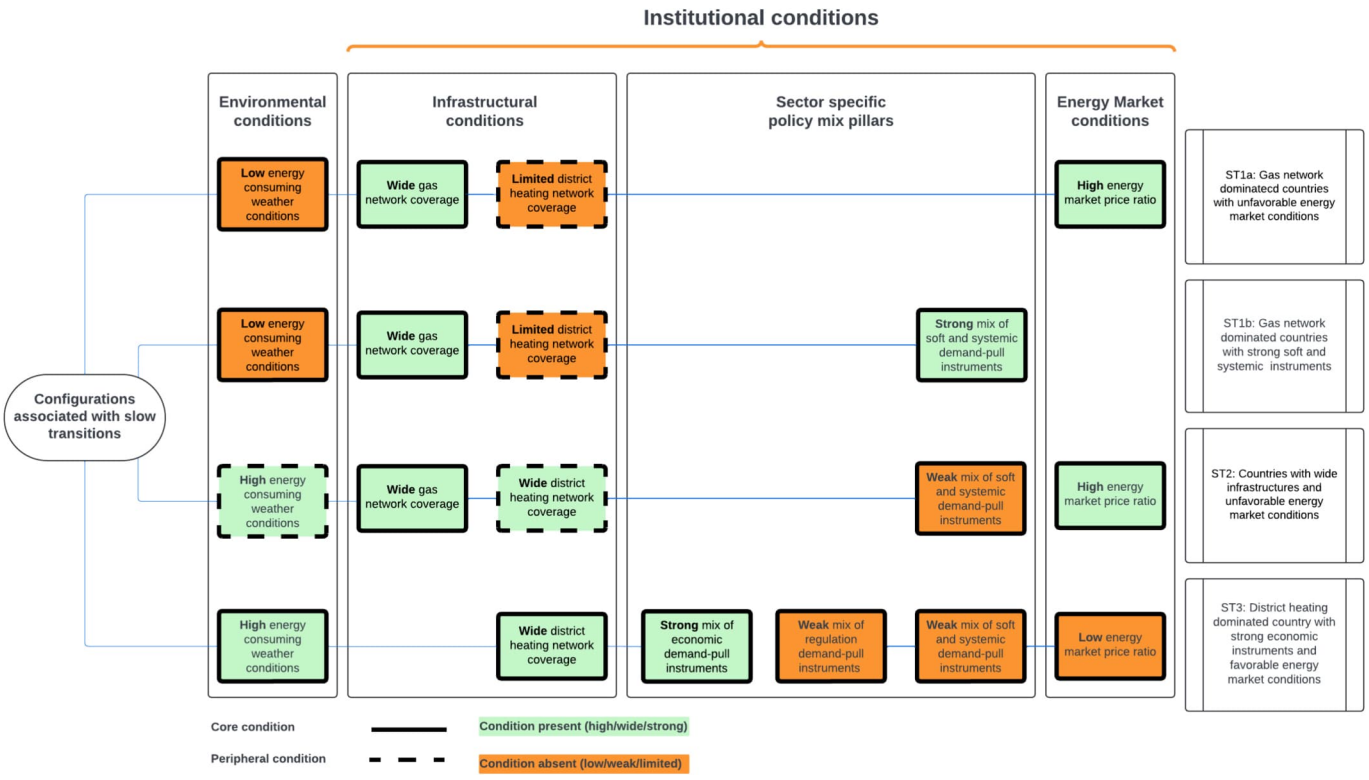

Fig. 6. Configurations leading to slow transitions.

where the 1970s oil crisis initiated interest in heat pumps. However, take-up was slow due to the lack of awareness of the solution (Martiskainen et al., 2021). Government funded technology trials were implemented between 2008 and 2013, and yielded surprisingly negative results (Energy Saving Trust, 2013). Policy support in the UK for heat pumps has been volatile and relatively weak throughout the monitored period. Also, building emission targets have varied over the past two decades. For instance, the zero carbon homes objective, set in 2006, was scrapped in 2015. With regard to the policy changes, a Low Carbon Building Programme (LCBP) was launched in 2006, and Green Deal (GD) in 2013 to encourage households to undertake energy renovations. In 2014, the LCBP was replaced by the Renewable Heat Incentive (RHI), which provided seven-year payments for renewable heating systems. The GD was closed in 2015 (Martiskainen et al., 2021).

Spain is one of the case countries under ST1b. Wide gas network coverage slowed heat pump diffusion even in Spain, where the electricity price ratio to gas was low (see Appendix B, Spain ERATIO). Housing energy needs are relatively low in Spain, as it has 44 % fewer heating degree days and 146 % more cooling degree days than the EU average (European Commission, 2024). Spain also has several heat pump manufacturing facilities, which may have a positive technology-push component supporting the diffusion of the technology. As a cultural context, people in Spain often perceive renewables as requiring more maintenance than traditional energy technologies, which can act as a barrier to diffusion (Peñaloza et al., 2022).

ST2 can be characterized as *Countries with wide infrastructures and unfavorable energy market* conditions. The configuration is ambivalent with regard to the use of a strong mix of economic and regulatory demand-pull instruments. Czechia, falls under configuration ST2. Whereas the ST2 configuration is ambivalent regarding economic demand-pull instruments, Czechia has implemented an impactful mix of economic instruments. Green Savings Programmes have provided the financial support for energy renovations and renewable heat generators, including heat pumps and biomass boilers (Karásek and Pavlica, 2016). ST2 and case Czechia exemplify the importance of the energy market price ratio. Although subsidy programs for renewable new heating technologies do exist, the incentives are not high enough to show impact when generic energy policies reinforce the dominance of regime technologies and fossil fuels.

Finally, Poland forms the ST3 configuration. ST3 displays *a District heating dominated country with strong economic instruments and favorable energy market conditions*. Energy use is high due to weather conditions. ST3 is an outlier among slow transition configurations from an infrastructural arrangements' perspective. Compared to RT2, it has a stronger mix of economic instruments, but the case is still associated with slow transitions. The explanation is likely related to the heating mix in Poland, where households remain heavily reliant on coal (47 % of households used coal as a heating source in 2019) (Rafał, 2019). There have been significant developments in heat pump diffusion, with an increase from 2.8 % to 6.9 % between 2014 and 2019. However, the increase in gas heating popularity has been about two times higher (Dwarokowska and Smogowy, 2024). Another potential factor hindering diffusion is Poland's relatively low purchasing power per capita (PPS) compared with other EU countries. While PPS has increased over the years, the figure was still at 26 % below the EU average in 2019 (Eurostat, 2024a).

5. Discussion and conclusion

This paper demonstrates how demand-pull policy mixes and infrastructural, environmental, and market configurations result in either rapid or slow transitions. It contributes to the innovation studies focused on accelerating the diffusion of mature technologies and policy studies by providing a broader, contextualized perspective on understanding policy mixes. In the following, we reflect on our findings, connect them to the theoretical background presented at the beginning of the paper, and discuss how policymakers can utilize the insights provided by the study.

5.1. Contextualized policy mixes for rapid transitions

Our findings highlight two key insights for understanding policy mixes in transitions: a) different configurations can lead to either rapid or slow transitions, and b) infrastructures play a central role in enabling or constraining transitions.

First, we demonstrate that strong demand-pull policy mixes are not systematically employed in cases leading to rapid transitions. It is therefore not easy to identify straightforward "winning recipes" of demand-pull policy mixes for rapid transitions. In line with the earlier literature (Markard, 2018; Mavrot et al., 2019), our results reveal that rapid transitions are an outcome of equifinal transition pathways. That is, rapid transition does not occur due to a single type of configuration; various configurations can lead to a positive outcome. This underscores that the transition dynamics should not be understood as linear or uniform processes, but contingent and varied across national contexts and conditions.

Earlier contributions have rarely examined demand-pull instruments at the sub-pillar level. The study by Costantini et al. (2015) found demand-pull policies benefiting mature technologies at the aggregated level. However, their analysis focused on technology development, measured through patents, rather than examining the diffusion of the technology. Pakizer's (2020) study on water systems revealed that none of the policy mix pillars were necessary for a successful operational outcome. Our study differs from previous work by focusing explicitly on rapid transitions and examining the transition trajectory from the pre-development to the acceleration phase of transitions. Aligning with Pakizer (2020), our test of necessary conditions reveals that none of the sector-specific policy mix pillars constitutes a necessary condition. Sectoral economic instruments, and systemic and soft instruments, are sufficient conditions when configured in a specific manner with other infrastructural, market and environmental conditions. Regulatory-based pillar, though present in some of the case countries that have undergone rapid transitions, are surprisingly not consistently associated with rapid transitions.

With regard to the contextuality, the result of the configurations leading to positive outcomes reveals that it is difficult to substitute unsupportive market conditions with impactful sector-specific policy mixes. Here, we lean toward a constructivist understanding of markets. They are, at least partially, shaped by governments, which constitute them by establishing property rights, rules, structures, and specific policies (Sovacool and Geels, 2016). National climate and energy policies set the scene for transitions. It may be possible to temporarily boost the diffusion of technologies through sector-specific policy mixes, particularly with strong incentives such as financial subsidies. Our results support earlier studies and claims for the need for systemic policy design (Kern and Howlett, 2009; Schot and Steinmueller, 2018). In other words, climate and energy policy is essential, which centrally shapes the markets and levels the playing field between incumbent solutions and novel emerging innovations.

Turning to the second point, our research emphasizes the significance of materiality, and specifically the role of infrastructures, for the explanation of socio-technical transitions (Fuenfschilling and Truffer, 2016). We take a step to operationalize infrastructurally sensitive mode of inquiry (Foxon, 2013; Foxon et al., 2010; van der Steen et al., 2008) to examine policy mixes for rapid transitions. Our results provide a tangible depiction of how infrastructures simultaneously contribute to both stability and change in socio-technical systems. To this end, configurational analysis reveals conjunctural causation (Misangyi et al., 2017) in how infrastructural and market conditions interact and can create unfavorable conditions for transitions (cf. Fligstein and McAdam, 2011; Greenwood et al., 2011; Hinings et al., 2018).

Specifically, in relation to energy transition, we found that limited gas network coverage constitutes a necessary condition for the positive outcome in heat pump diffusion. The analysis of the negative outcome supports this finding, revealing that although other conditions do not display symmetry, a consistent pattern emerges when looking into infrastructural arrangements of configurations leading to positive and negative outcomes. More interestingly, configurations that featured wide gas network infrastructures together with high energy market price ratios (ST1a and ST2) achieved significant, unique coverage in the analysis of the negative outcome. In other words, heat pump diffusion progressed slowly in countries with extensive gas networks, and relatively cheap gas prices compared with electricity. In contrast to gas network impacts, comprehensive district heating network coverage does not constrain rapid transition. In many markets, this condition is paired with a low energy market price ratio.

Taken together, these insights emphasize the importance of contextualizing policy mixes. Rapid transitions are not explained by policy mixes alone but result from the interplay of policy instruments, market conditions and infrastructural arrangements. The equifinality of the configurations exhibits that there is no single pathway to success, while the significant influence of infrastructures demonstrates why policy mixes should be embedded in broader systematic approaches that explicitly account for material conditions. By underscoring the centrality of infrastructure in shaping transition dynamics in rapid transitions, our findings point to the need for policy mixes that are systematic, contextually grounded and attuned to the material foundations of socio-technological transitions. Building on this, Section 5.3 elaborates on the key implications for policymakers and policy design.

5.2. Use of configurational methods for policy mix analysis

We apply an established configurational method widely used in political science, management science, and innovation studies, to the research stream of policy mixes in sustainability transitions research. We demonstrate that a medium-N comparative case study can have significant benefits in revealing the causal complexity underlying a phenomenon. When the number of cases is extended and examination opened to include various conditions, including contextual arrangements, we can interpret transition in a novel way. Furthermore, we demonstrate how the two-step QCA research design (Haesebrouck, 2019; Schneider, 2018; Schneider and Wagemann, 2006) can add value by distinguishing more rapidly evolving proximate conditions from those that are relatively stable over time, temporarily and spatially remote from the outcome, or even outside the influence of present actors. The two-step QCA proves to be relevant when separating different analytical levels in the transition studies (e.g. MLP levels, innovation system and organization level). We believe a configurational view of the results is particularly useful to policy makers who operate with policy tools but in a context with existing infrastructures, cultures, norms, and values, that is, in an environment featuring high institutional complexity. The limitations and further research section gives several examples of how the configurational analysis could be used in a more comprehensive way in the future with larger data sets.

5.3. Implications for policy makers

Our study makes important contributions to the policy mix literature and yields tangible implications for policymaking. We adopt an infrastructurally sensitive approach, which holds promise to be particularly relevant in policy design.

Our results underscore the importance of existing infrastructure and the necessity of addressing infrastructural lock-ins through destabilizing policies (Klitkou et al., 2015). The previous research highlights technological repurposing of infrastructures, such as converting gas networks to hydrogen (Kigle et al., 2025) or upgrading electricity networks to smart grids (Hiteva and Watson, 2019). We find these avenues relatively slow, as they assume maturation of technological innovations within the process. Also, repurposing may risk reinforcing incumbent power structures and creating new path dependencies, which cumulatively decelerate integration of disruptive alternatives. Drawing on

broad perspectives on destabilization (cf. Kivimaa and Kern, 2016; Turnheim, 2022), we argue that changes in regime rules represent a particularly promising pathway for enabling rapid transitions. Regime rule changes can occur through two main avenues: control policies aimed at reducing the environmental impacts of the existing regime, or structural reforms in overarching regulation that do not directly target environmental impacts (Kivimaa and Kern, 2016). Regarding the first avenue, our recommendation is the use of destabilizing instruments, such as carbon taxes and fossil fuel phase-out plans, to overcome infrastructural lock-ins and support the emergence of new socio-technical configurations (Bachus and Vanswijgenhoven, 2018; Rosenow et al., 2022). For the second, liberalization efforts to enhance market dynamics hold significant policy impact potential for accelerating transition.

In addition, we encourage policymakers to prioritize system-level policy design over isolated sectoral (Markard et al., 2020) or standalone (Torné and Trutnevyte, 2026) instruments to enable rapid transitions. While sector-specific economic, regulatory, and soft/systemic demand-pull instruments can support diffusion, our analysis shows they are not sufficient on their own. Rapid transitions can even take place when strong sector-specific demand-pull policy instruments are not systematically employed. This contrasts with Nuñez-Jimenez et al. (2022), which underscores the importance of a strong demand-pull policy mix in achieving accelerated technology diffusion.

This leads us to heat pump-specific policy implications. Electricity is part of the European Emissions Trading System (ETS), which currently raises electricity prices (Bai and Okullo, 2023; Kara et al., 2008), directly affecting the economic viability of heat pumps. However, other heating and cooling systems (e.g., district heating and cooling) currently fall outside the scope of ETS. While ETS2, coming into effect in 2027, will expand coverage to include emissions from building heating, it still excludes emissions from wood-based fuels, peat, and waste fuels, as well as direct fuel consumption in the municipal housing sector. There is an urgent need to resolve the policy discrepancy between electricity and these other energy carriers.

5.4. Limitations and future research

Our study is not without its limitations. Our outcome measurement is based on the idea of capturing the speed of change to make rapid transitions comparable across countries. However, rapid transition encompasses not only technology diffusion but also a wide range of change processes within a socio-technical system. Instead of attempting to capture change over time at the level of conditions, we chose to measure the extent and impact to reflect how the effects are cumulatively constructed over time. Incorporating both impact and change measurements would have led to an increased number of conditions, which was not methodologically feasible. Future studies should aim to address this limitation. Furthermore, regarding equifinality, we are able to grasp equifinal pathways to rapid transitions involving technological diffusion. However, rapid transition of heating systems can also result in equifinal outcomes where technological change does not play a central role. Using the QCA method, this would require multiple operationalizations of outcome and separate analyses. Future research may therefore also explore approaches to examine equifinal outcomes beyond technology driven pathways.

The data set of 20 cases presents two main limitations. First, the strength of the empirical evidence underpinning configurations varies, and can also be based on a single case (configurations RT1b and ST3). A larger data set would have allowed us to increase the frequency cut-off in the QCA analysis. Second, the use of QCA as our method limited the comprehensiveness of our model. Policy mix interactions within a specific policy mix pillar impact the strength of the total effectiveness of the mix (Rogge, 2018). We summarized the impact of instruments but could not conduct a configurational analysis of the instrument level categories. For example, within the soft and systemic policy mix pillar there are instrument categories such as mandatory information, or information and training. Neither could we conduct a more nuanced breakdown of the market conditions that links to many policies on taxes or levies on fuels. Thus, future studies should seek ways to include the effect of instrument interactions within policy mix pillars. Furthermore, future research should consider how to separate climate and energy policy instruments from single aggregated market conditions, which in our study was also reflected in broader energy and climate policy instruments within countries.

With a higher number of cases, a measurement of income level is a potentially relevant condition. The capital needs of heat pump investments closely follow global market prices, but income levels and purchasing power may vary greatly, influencing households' opportunities to invest in clean technologies. In addition, when examining niche innovations in the early phases of transitions, the inclusion of technology-push instruments becomes essential. Our measurements are based on national level data. However, in many countries, regional level regulation and subsidies are applied which may impact the overall diffusion of clean technologies. Future studies should in a suitable manner address this limitation and incorporate regional level data into the analysis.

Other data-related limitations stem from the use of Mure ratings for policies, our examined temporal scale, and sectoral and geographical focus. Mure ratings may be based on individual judgements, and a systematic comparable evaluation of the impact on energy saving outcomes may vary. We purposefully limited our temporal scale to the end of 2019. Future studies could examine how extreme events in recent years impacted the rate of transitions, investigate other sectors and innovation types, and expand the study beyond the European context.

Our final limitation relates to the use of Foxon's (2013); Foxon et al.'s (2010)) conceptualization of transition pathways, and the omission of the middle layer of the framework, including strategies, values, and behaviours, from our examination. We encourage researchers in future studies to expand the focus on contextualization and delve deeper into organizations, actors, institutionalized practices, norms, and beliefs, together with the institutional conditions that were included in this study. In the examination of institutionalized stability and emerging socio-technical change, the role of actors, their interactions in maintaining and creating shared understandings of the purposes of the regime, relationships within sectors, and the rules governing legitimate actions in the sector, are an essential part of institutional conditions. However, these are beyond the scope of our current focus and the capabilities of the selected methodological approach and dataset.

CRediT authorship contribution statement

Jouni K. Juntunen: Writing – original draft, Visualization, Supervision, Software, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Shah Rukh Shakeel:** Writing – original draft, Writing – review & editing, Formal analysis, Conceptualization, Project administration, Validation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jouni Juntunen reports financial support was provided by Research Council of Finland. Shah Rukh Shakeel reports financial support was provided by Research Council of Finland. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendices.

Appendix A
Calibration table.

Outcome and conditions	Threshold Non-membership	Crossover Point	Threshold Full Membership
OUTCOME: Rapid transitions (high level of heat pump diffusion by 2019)	0.05	0.278	0.75
Environmental conditions			
High energy-consuming weather conditions (ENV)	2000	2900	4000
Infrastructural conditions			
Wide gas network coverage (GAS)	5	30	60
Wide district heating network coverage (DIST)	10	20	42
Sector specific policy mix pillars			
Strong mix of economic demand-pull instruments (ECO)	0.9	3.5	5.1
Strong mix of regulation demand-pull instruments (REGU)	0.9	2.5	9.1
Strong mix of soft and systemic demand-pull instruments (SOFT)	1.9	2.5	6.1
Energy market conditions			
High energy market price ratio (ERATIO)	1.5	2.5	3.6

Appendix B
Truth table.

DIST	GAS	ENV	ECO	REGU	SOFT	ERATIO	OUT	n	incl	PRI	cases
0	0	0	0	0	1	0	1	1	1	1	Portugal
0	0	1	0	1	1	0	1	1	1	1	Norway
1	0	1	0	0	0	0	1	2	1	1	Estonia, Sweden
1	0	1	0	0	1	0	1	1	1	1	Finland
1	0	1	0	1	0	0	1	1	1	1	Denmark
0	0	1	1	0	0	1	1	1	0.9	0.775	Lithuania
0	1	0	0	1	0	0	0	1	0.781	0.194	France
0	1	0	1	1	1	0	0	1	0.775	0	Spain
0	1	1	1	1	1	1	0	2	0.629	0.049	Austria, Germany
0	1	0	0	0	1	1	0	1	0.518	0	Ireland
0	1	0	0	1	0	1	0	3	0.466	0	Belgium, Hungary, Italy
0	1	0	1	0	0	1	0	1	0.466	0	The Netherlands
1	0	1	1	0	0	0	0	1	0.463	0.002	Poland
0	1	0	0	0	0	1	0	1	0.43	0.0062	United Kingdom
1	1	1	1	0	0	1	0	1	0.427	0.002	Czechia
1	1	1	1	1	0	1	0	1	0.391	0.002	Slovakia

Appendix C
Robustness check report.

Sensitivity Ranges									
	Exclusion			Crossover			Inclusion		
Calibration anchors	Lower bound	Threshold	Upper bound	Lower bound	Threshold	Upper bound	Lower bound	Threshold	Upper bound
GAS	NA	5.00	NA	1.00	30.00	NA	NA	60.00	NA
DIST	NA	10.00	NA	5.00	20.00	55.00	NA	42.00	NA
ENV	NA	2000.00	NA	1300.00	2900.00	5500.00	NA	4000.00	NA
ECO	NA	0.90	NA	0.50	2.50	10.50	NA	5.10	NA
REGU	NA	0.90	NA	0.50	2.50	12.50	NA	9.10	NA
SOFT	NA	1.90	NA	0.50	2.50	6.50	NA	6.10	NA
ERATIO	NA	1.50	NA	1.20	2.50	4.20	NA	3.60	NA

Robustness parameters (for the positive outcome)								
Fit oriented	RF_{cons}:	0.954	RF_{COV}:	0.608	RF_{sc_minTS}:	0.58	RF_{SC_maxTS}:	0.809
Case oriented	RCRtyp:	1.00	RCR_{dev}:	0	RCC_Rank:	1		

Robustness parameters (for the negative outcome)								
Fit oriented	RF_{cons}:	1.00	RF_{COV}:	0.775	RF_{sc_minTS}:	0.679	RF_{SC_maxTS}:	0.682
Case oriented	RCRtyp:	0.00	RCR_{dev}:	0	RCC_Rank:	2		

(*continued on next page*)

Appendix C (*continued*)

Worst performing model (for positive outcome)	
Model:	DIST
Worst performing model (for negative outcome)	
Model:	~DIST

Data availability

Data will be made available on request.

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