


Interweaving systems, embedding practices: Multi-system practice constellations in just sustainability transitions

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ABSTRACT

Urgent climate action and sustainability transitions remain insufficient, with escalating climate change impacts on human and environmental health disproportionately affecting vulnerable populations. Dominant frameworks in transition research often sideline the lived experiences and adaptive practices of these non-elite actors. This paper argues for a shift in perspective by introducing multi-system practice constellations as interconnected bundles of everyday practices that occur across provisioning systems, including mobility, housing, and food. Through a synthesis of systems thinking and praxeological approaches, we explore how social practices interact with ecological, technological, and institutional dynamics in co-evolving, uneven ways. Drawing on persona-based vignettes from an exploratory study in Austria, we examine how vulnerable population groups perform practices including cycling, heating, and food shopping, revealing four recurring interaction modes: contesting, adjusting, reconfiguring, and converging. These constellations expose how transitions are already being negotiated in daily life, not as innovations *per se*, but as precarious improvisations shaped by structural constraints and fragile agency. We conclude that understanding transitions through the lens of multi-system practice constellations offers a more equitable and grounded pathway toward just sustainability transitions that accounts for who is left out, what is taken for granted, and where systemic change is most urgently needed.

1. Introduction

Scholarship on sustainability transitions and transformations (Hölscher et al., 2018; Fisher et al. 2022) highlights the urgency and complexity of climate change and its effect on ecological degradation (Steffen et al. 2018), health injustices (Limaye 2021), and spatial inequalities (Garvey et al. 2022; Zahnnow et al. 2025). Despite global and local targets, current climate action remains insufficient, resulting in inequitable outcomes (IPCC 2022). Climate change presents a triple dilemma: affluent communities emit more, vulnerable groups suffer most, and climate policies often impose disproportionate burdens on them (Gough 2017). Disadvantaged communities face unequal access to green space (Tzoulas et al. 2007), exposure to urban heat island effects (Singh et al. 2020), and poor air quality (Richards et al. 2023), despite contributing far less to emissions (Muñoz et al. 2020). Low-income families, children, older adults, and those with chronic illnesses are especially vulnerable to climate-health risks (CDC 2015; Iyer et al. 2021). We define vulnerability as ‘the propensity or predisposition to be adversely affected’, characterised by ‘susceptibility to harm and lack of capacity to cope and

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adapt' (IPCC 2019, 5). For vulnerable groups, the traditional definition of health as complete physical, social, and mental wellbeing (WHO 1948; Horton et al. 2014) has been criticised as unrealistic. Instead, scholars propose a dynamic perspective, viewing health as adaptive capacity amid social, physical, environmental and emotional challenges (Huber et al. 2011). Within this framework, inclusive climate action can yield significant health co-benefits, particularly when designed to promote health equity (Bell et al. 2019).

Strengthening climate-friendly, health-promoting practices supports human and planetary wellbeing, reduces healthcare burdens, offers socio-economic benefits, and improves quality of life (Sauerborn et al. 2022). Aligning climate and health policies with social equity and biophysical planetary boundaries can generate synergies that benefit both disadvantaged and privileged groups alike (Steffen and Stafford Smith 2013; APCC 2023). Central to this are provisioning systems, understood as social-ecological-technological systems that convert resources into human-satisfying needs through intertwined ecological, technological, institutional, and social components that our daily life depends on (Fanning et al. 2020; Schaffartzik et al. 2021). These systems, including those related to food, mobility and housing, shape daily life and mediate climate-health risks, especially for the most vulnerable.

Transformative change, defined as a systemic shift accelerating the development of processes and practices for change (Gallopín 2006), requires coordinated action across multiple levels and scales (Andersen et al. 2023; APCC 2023). While transition studies frameworks have advanced our understanding of regime shifts (Geels 2002; Berkhout et al. 2004), innovation (Smith et al. 2005), and diffusion (Rogers 2003), they largely focus on structural change within single socio-technical systems. Recent calls to integrate multi-system interactions reflect growing awareness of systemic interdependence (Andersen et al. 2023) yet often sideline ecological and social concerns (Parris et al. 2022).

Although longstanding social theory emphasises that transformative change requires both structure and agency (Giddens 1979), a key limitation of structural perspectives is their neglect of everyday practices, situated experiences, and agency of those most impacted by socio-ecological crises (Hanke et al. 2021; Cairney et al. 2023). This imbalance can obscure how individuals and communities actively navigate, resist, or reshape systems in practice (Shove and Walker 2010; Faller 2016; Keller et al. 2022). In response, actor-centred scholarship highlights the strategies, resources, and capacities of individuals and collectives to better capture transitions on the ground (Sørensen et al. 2018; Löhr 2020; Labanca et al. 2020). Yet, within multi-system interaction discourse, these perspectives often privilege institutional and elite actors, marginalising the lived experiences, adaptive strategies, and systemic entanglements of vulnerable populations.

Praxeological approaches to sustainability transitions offer a complementary lens by focusing on how change emerges through routinised, everyday social practices (Sotarauta and Grillitsch 2023). By examining how meanings, materials, and competences co-evolve, these approaches show how practices both stabilise existing systems and enable transformation (Hui et al. 2017; Novy et al. 2023). However, most practice-based research has focused on single systems, limiting its capacity to address how practices are shaped by intersecting systems and how those intersections are often governed, constrained, or enabled by broader institutional structures and powerful actors that determine whose practices matter in transition pathways (Wesselink et al. 2020). This is especially true for the climate-health nexus, where multi-system and cross-sectoral approaches remain limited. While existing studies connect environmental and health concerns, including physical inactivity and obesity (Cecchini et al. 2010) and sector-specific analyses (cf. Biermann and Rau 2020 on food), they often overlook how such outcomes are shaped through intersecting social practices embedded across multiple systems. Moreover, while climate-friendly practices have been widely studied, particularly in relation to privileged actors, there remains a critical gap in understanding how these practices emerge, adapt, or falter among vulnerable populations in high-income countries as groups who are frequently exposed to transition risks, but often underrepresented in transition narratives (Anantharaman 2018).

The disconnect between systemic and practice-based perspectives reflects a research gap in understanding how non-elite actors engage with and shape interdependent provisioning systems through everyday life. Bridging this divide is essential for advancing just sustainability transitions (Avelino et al. 2024) that recognise both structural change and the situated agency of those navigating multiple, intersecting climate-health risks. To address this, we propose multi-system practice constellations as interconnected, co-evolving bundles of practices composed of shared materials, meanings, and competences, that span social-ecological-technological provisioning systems and stabilise through routine coordination and spatial-temporal organisation (Schatzki 2002; Shove et al. 2012; Hui et al. 2017). Such constellations are considered sustainable when they contribute to socially negotiated transformations that uphold ecological integrity, social equity, and long-term viability, treating sustainability not as a fixed condition, but as a contested socio-political process shaped by values, priorities, and spatial imaginaries (Swyngedouw 2007). We explore how these constellations are (or are not) performed by population groups vulnerable to climate-health risks, and how these performances mediate broader system dynamics. We demonstrate how practices transgress system boundaries and generate feedbacks often overlooked in siloed regime approaches, illustrating this with three examples:

- Cycling intersects bodily experiences (e.g., pedalling, signalling, steering), infrastructure (i.e., streets, bicycles) and financial resources (material) (Liu et al. 2021), knowledge of traffic rules and cycling skills (competence) (Larsen 2017), and transport norms (meaning) (Dunlap et al. 2021; Rérat 2019; Sovacool and Griffiths 2020). It links mobility patterns with ecological impacts (e.g., air quality, energy demand, land use) that are often treated as externalities, but are embedded in both infrastructure and embodied practice (McPhearson et al. 2016; Grimm et al. 2017).
- Heating is shaped by building conditions and heating technologies (material) (Groves et al. 2017), living standards and care norms (meaning) (Bärnthaler and Dengler 2023; Smetschka et al. 2023), and knowledge about efficient and healthy temperature regulation (competence) (Groves et al. 2017). Rather than focusing solely on technological or institutional innovations, understanding heating practices requires recognising how poor insulation, for example, exacerbates both fuel poverty and GHG emissions,

revealing feedbacks among energy flows, health outcomes, and climate vulnerabilities (Chester and Allenby 2020; Markolf et al. 2018).

- Food shopping includes bodily experiences of accessing food and retail spaces (material) (Parekh and Svenfelt 2022), dietary habits and norms (meanings) (Biermann and Rau 2020), and food and nutrition literacy (competence) (Egg et al. 2020). It connects individual consumption to economic and technological processes (e.g., retail, logistics) and ecological impacts (e.g., agricultural land use, biodiversity, waste), showing how everyday practices interact with broader feedbacks, reshaping access, prices, and nutrition (McPhearson et al. 2016).

These three practices are embedded in key provisioning systems of mobility, housing and food, requiring fundamental transformation for climate-health equity (Calafati et al. 2021; Bohnenberger 2023; Novy et al. 2023). While each practice is connected to others in its respective system (e.g., cycling intersects with driving, walking, or public transport), they provide distinct entry points and analytically coherent units from which to ‘focus on specific performances and on the ways in which these are linked through time and space’ (Shove et al. 2012, 22). Analysing concrete, observable practices, such as cycling (or its absence), food shopping routines, or domestic heating, allows us to trace how materials, meanings, and competences co-evolve within situated, everyday performances. Examining them as multi-system practice constellations offers a more integrative and just understanding of sustainability transitions, connecting structure and agency, systems and subjects, across the interdependent domains of everyday life. We pose two research questions: What systemic constraints and enabling conditions shape multi-system practice constellations performed by those vulnerable to climate-health risks? How do these constellations reproduce or transform relationships between individuals and the socio-ecological-technological systems they rely on?

We illustrate this through an exploratory study of vulnerable groups in Austria. We begin by outlining system-level and praxeological approaches to sustainability transitions, before conceptualising multi-system practice constellations to better capture the complex dynamics of how transitions unfold in practice. Next, we describe our empirical exploratory study and methodological approach, followed by an analysis of how the performance of practice constellations unfolds across systems. Finally, we discuss the implications of our findings for just transition strategies, reflecting on practice constellations and promising intervention points for policy and practice.

2. Conceptualising multi-system practice constellations

Recent work on interconnected systems and governance complexities (Schwanen 2018; Leck et al. 2015) highlights the need to move beyond siloed analyses and engage with how transformation unfolds across ecological, technological, and social domains. To do this, we synthesise systemic and praxeological approaches through the lens of social-ecological-technological systems.

2.1. Theories of multi-system interactions

Two traditions underpin systemic thinking: Nexus thinking (NT), and Multi-System Interactions (MSI). Both examine interdependencies across domains of provision, but they differ in conceptual origins and assumptions about how systems evolve.

NT emerged to address the water-energy-food interdependencies in sustainable development and resource management. Initially developed to reduce cross-sectoral trade-offs and identify synergies in resource use (Hoff 2011; Leck et al., 2015), NT has broadened from a resource-management tool into a more systemic perspective on socio-ecological systems (Zara et al. 2022), examining resource circulations and actor-networks (Schwanen 2018; Walker 2020), issues of scale (Williams et al. 2019), vulnerability (Browne et al. 2017), and infrastructural coordination across urban, rural, and household contexts (Monstadt and Courtard 2019; Browne et al. 2017; Rohrer and Köhler 2019). NT’s contribution lies in highlighting systemic interdependency while bringing ecological processes and resource flows to the centre of governance concerns. Yet, critics emphasise that NT often remains managerial in orientation and insufficiently theorises the technological and embodied practices that underpin system dynamics (Leck et al. 2015; Krafl et al. 2019).

MSI by contrast, rooted in systems theory and sustainability transitions research, explores how previously distinct socio-technical systems providing key societal functions such as energy, housing, or transport (Konrad et al., 2008) become strategically coupled during periods of change (Andersen and Geels 2023; Käsböhrer et al. 2024). Conceptualised as relatively bounded but dynamically evolving configuration, such systems interact through shared technologies, actor constellations, institutional alignments, or value-chain interdependencies (Rosenbloom 2020). MSI analysis has integrated modelling and transition approaches to capture cross-system dynamics in low-carbon pathways (Papachristos 2014), thereby showing how systems interact through multiple forms of coupling. Advancing such a perspective requires examining existing functional and structural couplings (Konrad et al. 2008), identifying emerging sites of interaction that may reshape system boundaries (Rosenbloom 2019), and analysing how evolving patterns of interaction shape sustainability transitions (Raven and Verbong 2007). Within these processes, key actors, or ‘system entanglers’ play a critical role by building or dismantling institutional bridges between systems (e.g., companies developing integrated hydrogen ecosystems across electricity and mobility sectors) (Löhr and Chlebna 2023; Käsböhrer et al. 2024), though such interactions often involve tensions and unintended consequences (Andersen et al. 2023). MSI is therefore especially relevant for climate mitigation, where deep decarbonisation of production and consumption systems requires interlinking multiple domains rather than isolated regime transformations (Löhr and Chlebna 2023). Reflecting this growing complexity, MSI scholarship is rapidly consolidating conceptually and empirically, drawing together diverse approaches to resource flows, couplings, and interdependencies from various transition perspectives (Andersen and Markard 2024).

While NT and MSI advance systemic thinking, both tend to treat systems as relatively stable, bounded regimes coordinated through

strategic actors (Bakhuis et al. 2024). This can unintentionally reproduce a dynamic-static opposition: MSI and NT depict change as occurring between otherwise stable systems, obscuring how systems themselves are constantly reproduced through ecological feedbacks, biophysical limits, and the material and embodied practices (Cairns and Krzywoszynska 2016; Shove and Walker 2010). This risks reinforcing technocentric and anthropocentric sustainability narratives by focusing on infrastructure and strategic actors while treating ecological processes and lived practices as background conditions rather than constitutive system elements. These limitations make a framework crucial that more fully integrates an equity-orientated perspective within social, technological, and ecological dynamics.

2.2. Dynamic boundaries of interconnected systems

To address these limitations, we draw on the Social-Ecological-Technological Systems (SETS) framework, which conceptualises systems as co-evolving configurations of infrastructure, environmental processes, and social practices. SETS emerged from urban resilience, social-ecological systems research and environmental governance scholarship (Berkes and Folke 1998) and has gained increasing methodological coherence in recent years, particularly in urban studies where it has been employed to examine interconnected infrastructures, environmental pressures, and social inequalities (Andersson et al. 2024). SETS emphasise cross-scale interdependencies and the permeability of systems through resource exchange, functional overlaps, and trade-offs or synergies (McPhearson et al. 2016; Bakhuis et al. 2024; Chester et al. 2023). This perspective expands both NT and MSI by foregrounding ecological embeddedness of infrastructures and the practical enactment of system relations in everyday life.

SETS conceptualises systems as evolving configurations of elements (e.g., actors, materials, practices, institutions), functions (e.g., providing shelter, mobility, food access), and dynamics (e.g., flows, shocks, feedbacks), with boundaries that are analytically necessary, but fluid and context dependent, including material (e.g., infrastructure), institutional (e.g., sectoral policies), ecological (e.g., resource flows), or social boundaries (e.g., inequalities of access) (Andersson et al. 2024). In this way, SETS assigns equal analytical weight to social, ecological, and technological domains, avoiding the implicit hierarchy that can arise when 'socio-' operates as an umbrella term. Moreover, SETS is increasingly used in empirical studies of urban sustainability (McPhearson et al. 2022), resilience thinking (Ahlborg et al. 2019), climate adaptation (Kim et al. 2021), or household- and community-level research (Pineda-Pinto et al. 2021), providing a coherent logic for analysing practice-infrastructure-ecology relations. Unlike socio-technical systems in transition studies assuming system stability and clear boundaries (Geels 2011; Smith et al. 2005), SETS foregrounds fluidity, feedback, and ecological embeddedness, critical for analysing how social practices traverse and transform system configurations at the intersection of multiple systems (Krueger et al. 2022).

In aligning with SETS, we therefore locate transitions within multi-domain transformations rather than within isolated socio-technical regimes. SETS allows us to analyse how transition processes emerge, are inhibited or facilitated through the interplay of ecological constraints and infrastructural affordances.

2.3. Praxeological approaches to systemic change

While systemic frameworks map the macro-architecture of transitions, praxeological approaches (PA) reveal how they unfold in ordinary actions. Social practice theories¹ conceptualise social life not as a series of isolated behaviours, but as patterns of activity composed of interconnected elements: materials (i.e., necessary artefacts like objects, tools, and infrastructure), meanings (i.e., mental activities, emotions, and social reasoning), and competences (i.e., understanding and skills needed to perform a practice) (Shove et al. 2012; Rabadjeva and Butzin 2020). Together, these elements form a 'practice-as-entity', while 'practice-as-performance' refers to variations in performing the practice (Parekh and Svenfelt 2022). Practices persist through cycles of performance and reproduction, influenced by both individual agency and structural conditions (Reckwitz 2002; Landau-Donnelly et al. 2024; Svennevik 2022) within and across systems (Hui et al. 2017).

Transitions, from this view, involve shifts in the composition, circulation, and legitimacy of these practices, what is done, by whom, and under what conditions (Shove and Walter 2007). For example, cycling combines material components (a bike and public infrastructure), embodied competence (cycling skills and traffic awareness), and shared meanings (health, autonomy, cycling as self-determination), all shaped by and shaping provisioning systems, linked to for instance transport policies, air pollution, and cycling infrastructure as social, ecological and technological components interacting with and mediated through daily practices. This perspective is crucial for understanding sustainability transitions as complex sets of interconnected practices in peoples' everyday lives (Standal and Westskog 2022).

Vulnerable groups often experience intersecting system pressures differently and may adapt or innovate in ways that conventional frameworks overlook. Sustainability transitions in housing, food, and mobility are rarely shaped by a single system alone. Rather, they emerge at the intersection of infrastructure, policies, environmental conditions, and cultural practices (Jones 2012). Embedding practices in system analysis allows us to identify how technologies, social norms, and ecological conditions enable or constrain

¹ There is a plethora of PA stemming from different schools of thought (e.g., on power and social structure see Foucault 1975, on micro-level interactions see Garfinkel 1967 or Heidegger 1927, on practices as enacted by actor networks see Latour 2005), developing into distinct theories of practices (e.g., Bourdieu 1977, or Giddens 1984). While we recognise the significance of these contributions to critical inquiry, our approach aligns with Schatzki (2002), Reckwitz (2002), and Shove et al. (2012), focusing on social practices as routinised behaviour as the primary unit of analysis, rather than solely individuals or structures.

everyday routines, and how these routines, far from isolated, are interlinked in complex, multi-system constellations. It is precisely within these interdependencies across systems that some of the most complex and promising opportunities for transformation arise.

3. A framework for multi-system practice constellations

We conceptualise multi-system practice constellations through an integrated lens combining systemic and praxeological approaches. Systemic frameworks reveal large-scale tensions, trade-offs, and synergies across sectors, while praxeological perspectives illuminate embodied routines of negotiating, coping, and contravening. We define practice constellations as interconnected configurations of social practices that co-evolve with multiple systems across ecological, technological, and social domains. These bundles of practices, composed of materials, meanings, and competences, are embedded in shared infrastructures, overlapping functions, and interdependent demands. Drawing on the SETS framework, we highlight both practice dynamics (i.e., embodied, competence-driven routines shaped by material arrangements) and system dynamics (i.e., ecological flows, technological structures, institutional logics). These are not parallel but mutually constitutive layers, where systems shape the conditions under which practices emerge and evolve, while practices, in turn, stabilise, subvert, or reconfigure systems.

Integrating insights from NT (Williams et al. 2019), MSI (Raven and Verbong 2007), and PA (Cherunya et al. 2020), we identify four cross-dimensional interaction modes, operating vertically (between systems and practice) and horizontally (across systems or practices) (Fig. 1). These interactions reflect both embeddedness (i.e., how practices are structured by system dynamics) and feedback (i.e., how practices reshape those dynamics), often simultaneously:

- (1) **Contesting refers to struggles or conflicts over resources, power, or control within and across systems and practices.** These *tensions* emerge from interdependent resource pressures creating structural stresses and competition for scarce resources (NT); *competition* between regimes or technologies for dominance of resources and market control (MSI); and *contravening*, where individuals bypass systems or norms, often exacerbating tensions as they compete for access to resources (PA). These contestations reveal how institutional asymmetries, unequal access and overlapping logics across social-ecological-technological systems generate bottlenecks for practitioners.
- (2) **Adjusting captures reactive, low-agency responses to systemic constraints.** Systems absorb pressures through *trade-offs* when changes in one sector carry implications for another sector (NT), or *symbiosis*, where regimes become interlinked, creating either mutual benefits or challenges (MSI), while practices are adjusted through *navigating* strategies, where individuals shift between practices out of necessity to find alternative solutions in response to insufficient system support (PA). Practice constellations absorb shocks by redistributing burden across domains in response to unintended consequences originating elsewhere. These silent adjustments reflect how cross-system pressures manifest at the level of everyday life, particularly for

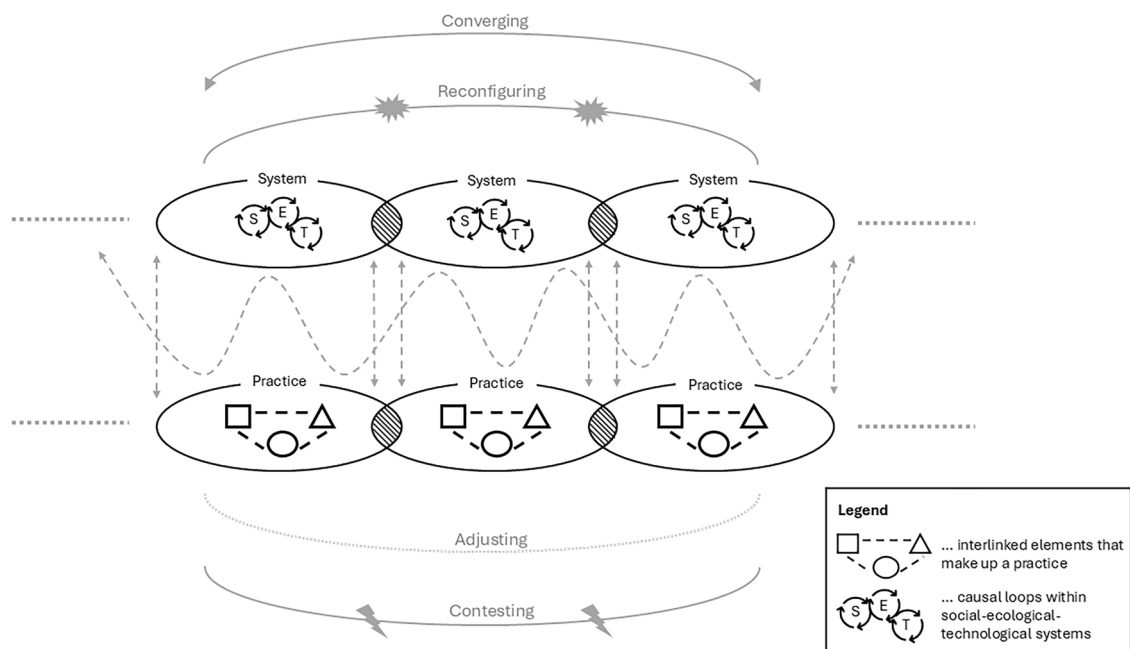


Fig. 1. Visualisation of Multi-System Practice Constellations: The bottom layer of the figure represents practices, composed of materials, meanings, and competences. The top layer illustrates systems and their dynamics, visualised through causal loops that contribute to their internal stability. Neither systems nor practices operate independently – they interact directly and through cross-level dynamics. For example, food shopping practices are linked to mobility practices through the location and set-up of food provisioning, which, in turn, depends on mobility infrastructure; Source: Illustration by the authors based on Williams et al. (2019), Raven and Verbong (2007), Cherunya et al. (2020).

vulnerable groups, while infrastructural and environmental drivers of these adjustments shape spatial and technological vulnerabilities. Adjustments thus mark systemic failures absorbed by embedded, limited capacity responses through practices that expose the distributed cost of misalignment.

- (3) **Reconfiguring reflects intentional, deliberate, and capacity-driven interventions to reshape system-practice relations.** It involves actively reconfiguring resources, practice, or strategies to manage vulnerabilities, often creatively, though not always successfully. This includes *maladaptation*, where poorly managed solutions in one sector inadvertently increase risks and necessitate restructured responses to manage vulnerabilities in other areas (NT), or managing *spill-over effects*, where rules, knowledge or routines are transferred from one regime to another (MSI), whereas on practice level, people *cope* inventively, responding creatively to challenges, often in ways that go against norms and may have negative consequences (PA). Unlike adjusting, reconfiguring implies greater agency and deliberation, albeit often messy or incomplete, and situated in place-specific, technologically and ecologically embedded contexts that play out through interdependent practice constellations. Changes in one routine can set off shifts across others, resulting in either innovation or destabilisation. Reconfiguring thus reflects a form of *resilience* through creatively managing systemic limitations while coping with uncertainty and complexity.
- (4) **Converging describes moments of alignment of interests and the mutual reinforcement of systems or practices.** This includes system *synergies*, where adaptations impact multiple sectors, enhancing efficiency and sustainability across them (NT); *integration*, where regimes merge into unified systems with shared functionality (MSI); and *negotiating*, where individuals leverage social cooperation to generate synergies on smaller scale (PA). Systemic convergence occurs when institutional arrangements, infrastructures, and policies reinforce shared transition goals. Practice-level convergence emerges when routines mutually reinforce shared values or outcomes. However, convergence is not static, but a fragile equilibrium across social, ecological, and technological dimensions and can be strategic or emergent, arising through policy coordination or everyday collaboration. Converging captures the co-evolution of systems and practices, producing mutually reinforcing outcomes – both enabling and constraining – through cooperative alignment among actors, infrastructure and practices.

This framework avoids flattening the ontological distinction between systems and practices, while illustrating their interdependence. It enables a dual-layered analysis, where systems enable or constrain practice, while practices can modify or stabilise systems. This allows to pinpoint not just interactions, but where interventions can occur – through system redesign (e.g., infrastructure, policy), practice reconfiguration (e.g., material access, competence building, value shifts), or interface management (e.g., facilitating alignments across system-practice boundaries).

Table 1
Multi-system interactions from systemic and praxeological approaches.

	Systemic Approaches	Praxeological Approaches
Contesting	<i>Tensions</i> arise when interdependencies between resource systems create structural pressures and <i>competition</i> , either through scarcity-driven conflicts over shared resources (e.g., water, energy, food) or through rival regimes and technologies vying for dominance in fulfilling similar functions and securing market share. For example, electrification of transport can increase competition between mobility, housing, and industrial systems, creating tensions over grid capacity and investment priorities.	<i>Contravening</i> involves individuals breaking rules or bypassing systems to exploit opportunities, mirroring system-level competition by forcing access to resources in ways that clash with established norms. For instance, people may rely on informal lift-sharing, cycle or walk along unsafe roads, use unregistered heating devices contravening inaccessible or inadequate formal systems.
Adjusting	<i>Trade-offs</i> occur when changes in one sector carry negative implications for another sector, while <i>symbiosis</i> occurs when regimes become interlinked through mutual dependencies, resulting in mutual benefits or challenges, both signalling passive interactions. For example, decentralisation of energy production can reduce emissions but increase housing costs, trading-off equality for efficiency or create symbiotic relations between local energy production and consumption.	<i>Navigating</i> describes individuals finding alternative solutions when primary options are insufficient, requiring them to move between systems or practices to mitigate negative impacts. For example, people may combine multiple transport modes, alter shopping routines, or reschedule daily activities navigating limited infrastructure or services.
Reconfiguring	<i>Maladaptations</i> are adaptations to a particular problem when it inadvertently increases vulnerability to that problem, worsening overall outcomes, whereas <i>spill-over effects</i> occur when innovations or policies in one regime unintentionally impact another, transferring practices, rules, or outcomes across sectors, thus both implying active strategies. For example, maldadapting to congestion by expanding road infrastructure can increase car dependence and emissions, while transport policies promoting electrification may spill over into housing by increasing electricity demand and grid pressure.	<i>Coping</i> refers to creative but often hidden individual responses to difficult situations, managing vulnerabilities in private ways that might go against societal norms. This can include rationing heating, delaying bill payments, reducing food intake by skipping meals or relying on informal support networks to cope with daily life under constrained conditions.
Converging	<i>Synergies</i> emerge when adaptations in one sector impact multiple systems, potentially enhancing efficiency and sustainability through interdependencies, while <i>integration</i> involves merging separate regimes into a unified system to create synergies that impact organisational and technological performance. For instance, coordinated urban planning that integrates transport, housing, and energy systems can synergistically reduce emissions and improve health. <i>Williams et al. (2018), Raven & Verbong (2007)</i>	<i>Negotiating</i> is the process by which individuals leverage social relations to find mutually reinforcing solutions, creating synergies on a smaller, more personal scale through collaboration and cooperation. For example, neighbouring parents negotiate shared childcare and shopping arrangements that combine mobility, food access. <i>Cherunya et al. (2020)</i>

4. Methodology: analysing heating, cycling and food shopping practices through personas

This study follows a two-step, exploratory, actor-centred research design aimed at identifying barriers and enablers for climate-friendly, health-promoting practices among vulnerable groups in Austria. First, we conducted a narrative literature review (Pautasso 2019), not as an empirical data collection method, but as part of our theoretical groundwork for developing an analytical framework. Drawing on NT, MSI, and PA scholarship, the review served to develop an initial set of conceptual codes that capture different modes of multi-system interactions. These codes, which were synthesised into the four interaction modes (see Table 1), constitute our analytical contribution and served as sensitising concepts rather than empirical findings. Guided by an abductive approach (Timmermans and Tavory 2012), we iteratively refined this coding framework in dialogue with climate-health scholarship to identify themes relevant to barriers and enablers of sustainable practices among vulnerable populations.

In a second step, we conducted a full-day co-production workshop (Brandsen et al. 2018; Osborne et al. 2016) with ten representatives from eight Austrian organisations serving vulnerable groups, including women, children, youth, and individuals experiencing poverty, homelessness, crisis, or addiction (see Appendix). Participants were selected to reflect socio-demographic, economic, and spatial diversity among populations identified as vulnerable to climate-health risks through the literature review. The workshop served to validate and deepen insights from the literature review, and to co-construct detailed accounts of everyday practices in the domains of mobility, housing, and food as essential to basic needs and tightly interwoven with climate, health, and equity concerns. Discussions were structured using the Three-Horizon approach (Haas et al. 2022; Sharpe et al. 2016), guiding participants through three phases: 1) identifying current unsustainable patterns, 2) envisioning desirable futures for climate-health equity, and 3) determining transformative shifts required to bridge the two. To ground discussions in lived realities, we applied the persona method (Pruitt and Adlin 2006). Personas as fictional yet evidence-based profiles were developed in advance using Austrian demographic and socio-economic data (Gesundheit Österreich (n.d.); Statistik Austria 2022a), and refined with participants during the workshop to reflect structural complexity, avoiding anecdotal or deficit-based framings (Lepzien and Lewerenz 2022).

Participants worked in three subgroups, each engaging with one persona across all three domains. Discussions were supported by researcher facilitation, participant self-documentation via flipcharts, researcher notes, and real-time graphic recordings. A final plenary session allowed for cross-group feedback and collaborative refinement of persona narratives.

The three personas developed and iteratively refined through the workshop are:

1. Lori, a 7-year-old girl living with her parents, two siblings and grandparents in a remote rural community in Lower Austria;
2. Leyla, a 37-year-old single mother from Afghanistan with a 7-year-old son, living in low-income housing on the outskirts of Linz, Upper Austria; and
3. Toni, a 72-year-old man with chronic illness living in urban social housing in Vienna (see Fig. 2).

This workshop thus provided empirical material through which we validated, elaborated, and operationalised our conceptual codes. Workshop materials, including notes, flipcharts, and visual recordings, were coded using the same abductive framework developed in the literature review. To attribute each practice vignette to one of the four interaction modes (contesting, adjusting, reconfiguring, and converging), we followed the two-step abductive coding process. In the first phase of coding, we inductively identified the primary systemic dynamics at play shaping each persona’s storyline (e.g., infrastructural exclusion, trade-offs, adaptive reorganisation, or alignment across domains). These dynamics were not pre-defined codes but emerged through abductive engagement

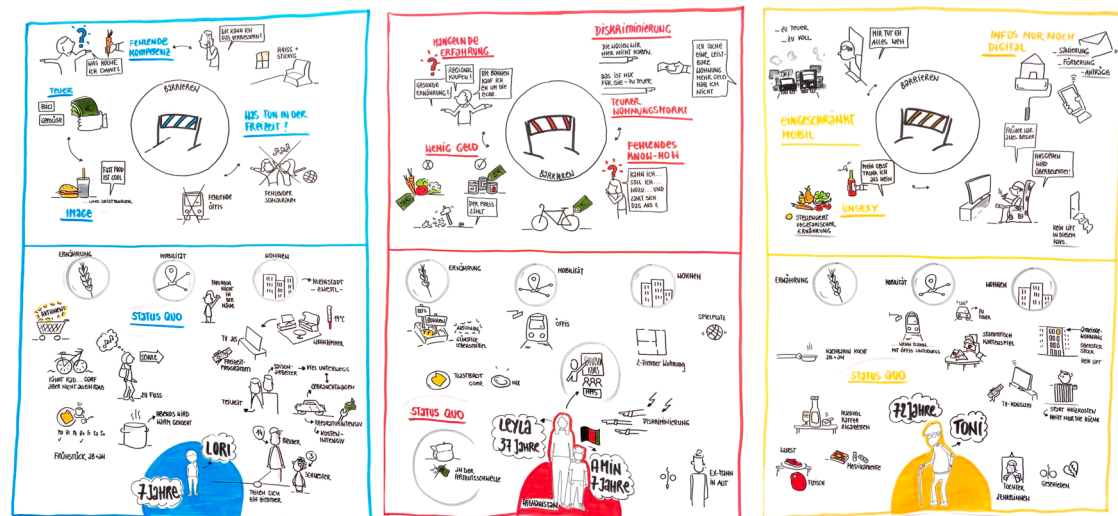


Fig. 2. Three Personas as fictional characters representing vulnerable population groups; illustration by Hoffmann (2022).

with the workshop material, guided by sensitising concepts from the literature. They allowed us to articulate how participants experienced system constraints and possibilities in practice. In a second step, these empirically identified dynamics were synthesised using the conceptual distinctions outlined in [Section 3 \(Table 1\)](#) to code each example according to its dominant interaction mode. Whereas the first phase captured the situated systemic pressures described by participants, the second step applied our analytically derived framework to interpret these pressures in terms of broader multi-system interaction patterns.

To avoid arbitrariness, we applied the same coding criteria to each vignette, using guiding questions of whether the practice expressed direct conflict of systemic friction (contesting), the practice is reactive, low-agency workaround to constraints (adjusting), the actor actively reshapes routines or resource flows to manage conditions (reconfiguring), or the practice produces function alignment across systems or practices (converging). Ambiguities were discussed in research team meetings, and several examples were initially assigned multiple modes. In such cases, we selected the dominant mode based on empirical emphasis and narrative salience. Our goal was not to fix rigid categories, but to illustrate the dynamic interplay of agency and system conditions as they appear in lived contexts. Persona narratives and assigned interaction dynamics were further refined in follow-up exchanges with participants, resulting in vignettes representing everyday challenges and opportunities. Though limited in number, these vignettes are analytically robust, grounded in empirical engagement, and shaped through iterative abductive reasoning in response to emergent themes.

The persona-based vignettes serve as entry points to understand how climate-health practices unfold within and across Austria's provisioning systems. Before turning to these vignettes, we provide a contextual overview of the country's mobility, housing, and food systems to highlight the structural conditions that shape, and often constrain, sustainable practices ([APCC 2023](#)). This system-level framing grounds the subsequent analysis of practice constellations in the social, ecological, and technological configurations that condition everyday life, particularly for vulnerable groups.

5. Examining multi-system practice constellations for climate-health of vulnerable households

5.1. The mobility, housing and food systems in Austria

Despite high GDP per capita, Austria ranks only moderately in climate mitigation and adaptation ([The Climate Change Performance Index 2023](#)). CO₂-attributable deaths exceed the EU average, and although particular matter 2.5-related deaths remain slightly below ([EEA 2023](#)), air pollution continues to pose significant health risks. Climate-oriented investments, including the nationwide coordinated 'Klimaticket' for public transport, railway expansion, renewable energy policies, and CO₂ pricing, signal progress, but persistent inequalities shape who benefits. Health disparities are stark: over 80 % of the highest income quintile report good health, compared to under 60 % in the lowest quintile, and chronic conditions are twice as common among those with lower formal education. Behavioural risk factors, including poor diet and adolescent obesity, account for 40 % of all deaths ([OECD and WHO 2021](#)). Meanwhile, 16.9 % of the population faces urban poverty and social exclusion, with single-parent households, single retirees, and large families most affected ([Lienbacher et al. 2021](#)).

Austria's mobility system remains heavily reliant on private motorised transport, especially in rural areas. This dependency carries social and ecological costs: in 2021, transport emissions contributed to 3240 premature deaths ([Statista 2025](#)). Reducing transport-related GHG emissions could yield both climate and public health benefits, from reduced air pollution and extreme heat ([Khomenko et al. 2020](#)) to noise mitigation currently linked to 1.6 lost healthy life years ([WHO 2018](#)) and increased physical activity through active travel ([Wolkinger et al. 2018](#)). Yet, mobility investments remain uneven. While the Klimaticket has improved affordability and integration in and across urban areas, its costs and limited rural coverage still disadvantage low-income groups. Public transit is robust in larger cities, but rural regions suffer from low service density. Although cycling is gaining popularity in cities, it remains culturally coded as recreational rather than utilitarian, especially for commuting and shopping ([Rérat 2019](#)). Infrastructure gaps, social norms, and policy narratives reinforce unequal access to low-carbon mobility, especially for women and migrants facing cultural and logistical constraints ([Prati 2018](#); [Mohammadi 2019](#)).

Housing also represents a key intersection of climate, health, and inequity. The sector accounts for 8.2 % of Austria's GHG emissions ([Umweltbundesamt 2021](#)), with inefficient thermal performance in both private and public housing undermining climate goals. Around half of Austrians live in owner-occupied dwellings, while the other half rent, with social housing mostly concentrated in cities. Low-income households are overrepresented in rental and public housing ([Litschauer et al. 2021](#)), many of which suffer from damp, mould, and poor insulation ([Amann and Mundt 2019](#)). Although Austria has a strong tradition of public housing, deregulation, limited retrofitting, and stalled new social housing provision have contributed to a shortage of affordable, climate-resilient homes. Efforts to retrofit existing housing are often obstructed by fragmented ownership, high costs, and regulatory inertia ([Holzmann and Schmid 2018](#)). Fossil-based heating systems remain widespread, from gas in cities to wood-burning stoves in rural and alpine regions, exacerbating PM exposure and compounding cardiovascular and respiratory risks ([Glojek et al. 2022](#)).

Austria's food system further reflects systemic misalignments between ecological targets and lived realities across production, distribution, and consumption. Processing and retail industries shape food availability and quality, with 91 % of the market controlled by a few supermarket chains, limiting regional variety ([Penker et al. 2023](#)). While meat consumption has declined slightly, nearly half of Austrian men still eat meat daily ([Statistik Austria 2022b](#)), exceeding both health and environmental thresholds ([Willett et al. 2019](#); [Moshhammer et al. 2016](#)). This affects various domains: ecologically, production of animal-based food is a major driver of emissions and land degradation, while plant-based diets could reduce premature mortality by 30 % ([Willett et al. 2019](#)). Socially, these dietary patterns reflect class- and gender-based norms ([Biermann and Rau 2020](#)). Technologically, despite Austria's leadership in organic farming, with 26.1 % of agricultural land under organic cultivation, climate benefits are inconsistent, depending on crop type and practice ([Penker et al. 2023](#)). Efforts to shift food systems face resistance from entrenched economic interests, political fragmentation,

and consumer norms. Retail giants exert significant influence over production, processing, and consumer choices, pushing for low-cost mass-produced food, and the political system has largely ignored dietary adjustments in emission reduction policies (Voigt et al. 2024). Agricultural policies, shaped by national and international regulations and global trade agreements, remain poorly aligned with climate and health objectives, favouring industrial, resource-intensive models to retain economic competitiveness (Penker et al. 2023).

Although mobility, housing, and food systems have received climate policy attention, they remain fragmented and unequally accessible. Their functioning is shaped by complex social, ecological, and technological entanglements, negotiated not just through institutions and infrastructure, but through everyday practices. Austria's transition dynamics are marked by tensions across these systems, constrained by inequality and governance fragmentation. While the challenges within each system are distinct, it is in the lived realities of vulnerable population groups that their interdependencies become most visible, as the next section explores.

5.2. Examining multi-system practice constellations of vulnerable households

Austria's mobility, housing, and food systems present distinct climate and health challenges, yet they are experienced not in isolation, but through the interwoven routines of everyday life. To examine how these systemic dynamics play out for vulnerable groups, we turn to three persona-based vignettes. We label our personas as Case 1, Case 2, and Case 3 and explore how the practices of cycling, heating, and food shopping practices interconnect with others within and beyond their respective systems. Using a multi-scalar approach, we consider the family house, neighbourhood, and city levels as reference points, situating practices within their spatial and temporal contexts. The following three vignettes serve as exploratory narratives, developed to illustrate the conceptual contribution of this paper rather than as empirical in-depth case studies in a narrow sense. They portray how everyday routines are co-shaped by overlapping system dynamics in mobility, housing, and food, and how structurally vulnerable groups navigate these through contesting, adjusting, reconfiguring, and converging dynamics. Rather than assigning these interaction modes to individual actions, we apply a dual lens, attending to both structural positioning and embodied agency throughout each narrative.

Case 1: Lori's story of growing up in a rural village

Lori, 7, lives in a small rural Austrian village with her parents, 14-year-old brother, 3-year-old sister, and grandparents in an inherited farmhouse that has been in the family for generations. The house is materially vulnerable, poorly insulated, heated by a wood stove, requiring manual labour and exposing the family to indoor air pollution (Brooks et al. 2016). This reflects systemic disinvestment in rural housing, where degraded ecological and technological infrastructures compound energy precarity (*contesting*).

Access to education requires an 8 km commute, starting with a 2 km walk to the nearest bus stop with limited service that runs twice daily on weekdays and no viable carpooling options available in her village. Cycling for Lori and her brother is too dangerous due to a lack of safe infrastructure, reflecting ongoing policy conflicts over Austria's car-centric transport policy (Mattioli et al. 2020), reinforced by media (Theine and Regen 2023) and planning narratives framing cycling as leisure rather than a commuting option (R  rat 2019) (*contesting*). Lori's grandparents once cycled to work locally, but car use has since increased, driven by increase in commuter lengths in Austria by 21 % since 1995 (Follmer et al. 2016; Herry et al. 2012), and growing demands of paid and unpaid care work (Ravensbergen et al. 2020), reflecting structural shifts with downstream effects on daily practice (*adjusting*). Lori's walk to the bus offers physical exercise and moments of family time, revealing an improvised benefit embedded in a structural deficiency (*converging*). In winter, snow and poor lighting make this journey hazardous, requiring temporal and behavioural adjustments to minimise risk as a reactive trade-off with environmental-technological vulnerabilities (*adjusting*). Mobility practices within the family reflect tactical coordination. Lori's mother cycles 40 min to work during summer when the family's only car is needed by her father, a seasonal construction worker. These shifts indicate deliberate seasonal reorganisation across mobility and care systems to manage limited resources as a capacity-driven restructuring of mobility and labour routines (*reconfiguring*). Her grandparents, despite health limitations, assist with caregiving and household tasks, providing intergenerational support for fragile routines, often absorbing structural deficits (*adjusting*).

Heating is rationed to one or two rooms, with comfort managed through layering clothes, taking hot showers or baths, or dietary compromises to cope with poor insulation common in many rural homes (Aigner et al. 2023; Lampl et al. 2024). Despite Austria's high-quality housing stock, three-quarters of buildings constructed between 1945 and 1960 are often occupied by low-income households, requiring major refurbishments (Amann and Mund 2019; Hagauer et al. 2016; Sch  ber et al. 2021). Energy decisions thus are not shaped by preference, but by constrained technological systems and ecological pressures, revealing cross-sectoral trade-offs between health, warmth, and nutrition (*adjusting*). Over time, the family has developed routines to strategically manage energy and nutritional needs, such as aligning cooking and heating schedules or using evening baths as warming practices (*reconfiguring*).

Food provisioning is tightly interwoven with care, time, and transport infrastructures. Even in agricultural regions, access to fresh produce is restricted by market concentration, long commuting hours, and inconsistent transport access. Despite Austria's high store density (Lebensmittelhandel 2022), a few dominant retailers control food supply, limiting local product availability and visibility (Regiodata 2020; Parekh and Svenfelt 2022). In summer, Lori's mother buys lightweight dried goods by bike. In winter, canned food is stockpiled when the car is available, illustrating deliberate seasonal adaptation to infrastructural constraints (*reconfiguring*). Attempts at gardening failed due to recent flooding and regular time scarcity, exposing the fragility and low-tech resilience in the face of ecological volatility (*adjusting*). Social supermarkets, supporting low-income households, are inaccessible to 72 % of rural residents (Lienbacher et al. 2021) and criticised for short-term charity approaches rather than fostering long-term food security (Bruckner et al. 2021). Food poverty, defined as hunger and limited access to socially acceptable food, is prevalent in Austria (Miller 2019; Lampl et al.

2024) and has worsened due to inflation, geopolitical conflicts, and cheap convenience food marketing (Gundersen et al. 2021; Plank et al. 2021). Dinner routines, shaped by cost, availability, and time constraints rather than nutrition or ecological value (Fenninger et al. 2021), typically consist of pasta, eggs, toast, reflecting how systemic food provisioning structures embed precarity at the household level (*contesting*). However, small tactical alignments emerge through running errands, shopping, and childcare that are often bundled into single trips to save time and reduce transport needs, producing everyday efficiencies across systems (*converging*). These routines, while functional, remain energy-intensive and dependent on unpaid labour as forms of tactical resilience compensating for systemic neglect.

Case 2: Leyla and Amin's everyday life in a single parent suburban household

Leyla, 37, lives with her 7-year-old son, Amin, in an apartment block in southern Linz, Austria. The building, a relic of mid-century housing, sits within a heavily trafficked industrial neighbourhood, where low air quality and limited green space intersect with degraded housing and energy systems. Together, these ecological, technological, and social pressures co-produce layered vulnerabilities for residents like Leyla (Boardman 2010; Brunner et al. 2012) (*contesting*).

As recent refugees from Afghanistan, Leyla and Amin navigate dual systemic demands of formal integration requirements imposed by the state, and the informal yet vital support embedded in their Afghan community. This community is not just social capital, but practical infrastructure for helping with translation, administrative paperwork, and everyday logistics as strategic mobilisation of social networks to restructure institutional constraints (*reconfiguring*). Leyla's daily routines reflect constraints across multiple systems. She walks Amin to school before commuting via tram to her job as a supermarket cashier. Although cycling would reduce travel costs, a lack of cycling infrastructure, gendered caregiving expectations (Prati 2018), higher risk-aversion among women (Ravensbergen et al. 2020), and transport norms (Head et al. 2021) render it unviable (*contesting*). Men cycle 2.5 times more often than women (Bruno and Nikolaeva 2020), with additional barriers for women cycling with children or for domestic tasks (Sersli et al. 2020), and migrant women facing legal precarity, limited training opportunities (Markvica et al. 2020), and culturally internalised norms that code public mobility as unsafe or inappropriate (Mohammadi 2019). Leyla is pushed into a slower, inflexible transport mode that reduces her capacity to adapt on short notice (*adjusting*).

Shopping is a time-sensitive and relational task. Leyla prefers ethnic supermarkets that cater to religious and cultural dietary needs but must detour to reach them. For affordability, she relies on friends with cars to make bulk purchases at suburban discount retailers, timing these trips around childcare availability. These coordinated routines demonstrate intentional redesign across provisioning, mobility, and care, enabled not by systemic efficiency but by tactical cooperation (*converging*) and capacity-driven restructuring of routines via informal networks (*reconfiguring*).

Heating at home is managed through sacrifices, where Leyla rations heating in winter to prioritise Amin's nutrition and avoids using cooling appliances in summer to save costs, relying instead on public libraries or shaded corners of the city during heatwaves. These spatial workarounds reflect navigating strategies under constrained agency, embedded in both ecological (urban heat islands) and technological (inefficient heating and cooling systems) conditions (*adjusting*). Shared meals in a nearby parklet, often organised through her community, provide both nutrition and social connection, temporarily offsetting food insecurity and social isolation through informal synergy across food, energy, and social wellbeing (*converging*).

Accessing support through formal channels proves far more difficult. Language barriers and complex subsidy application processes hinder access to energy, housing, and transport support systems (Eisfeld and Seebauer 2022; Brunner et al. 2012). German language classes, a requirement for integration, constrain her time for caregiving and income generation, which she navigates due to policy regimes imposing demands without reciprocal support (*adjusting*). Social inclusion remains also a persistent challenge. Discrimination, dietary constraints, and unfamiliar norms inhibit participation in local networks (Kohlenberger 2021; Said 2019), while alternative housing models, such as co-housing and housing syndicates, often remain socio-culturally and economically inaccessible (Perolini 2015; Jany et al. 2023) (*contesting*). Amin is deeply aware of his mother's struggles, sensing both financial and emotional strain (*adjusting*).

Despite these barriers, Layla makes tactical choices to maintain stability. She delays paying energy bills to preserve immediate food and childcare needs (Brunner et al. 2012), revealing the hidden trade-offs imposed by market-oriented housing and welfare reforms since the 1980s (Kadi et al. 2020; Seebauer et al. 2019). Rather than failures of personal planning, this reflects systemic misalignments between lived practices and institutional design (*adjusting*).

Case 3: Toni's journey navigating chronic illness and isolation in urban housing

Toni, 72, lives alone in a top-floor municipal housing flat in Vienna, accessible only by four flights of stairs. The building, constructed during the city's mid-century public housing expansion, remains unrenovated, relying on outdated gas heating and lacking thermal upgrades, exacerbating energy poverty for low-income tenants (Schwarzbauer et al. 2019; Amann and Mundt 2019). High renovation costs and political inertia leave tenants like Toni with little agency to improve their living conditions (Amann 2019; Global2000 2021). These infrastructure shortfalls expose older, low-income residents to cold, damp, and persistent mould, conditions. Toni manages by heating only his small kitchen and using an electric blanket during winter (Brunner et al. 2012) (*adjusting*). His limited pension, resulting from early retirement due to chronic illness, places him below the poverty line. Since his wife's passing, he has become increasingly isolated. His daughter visits rarely, and access to social services and support structures remain limited, hindered by digital exclusion and the bureaucratic opacity that often affects ageing populations (*contesting*).

Each morning, Toni makes coffee, smokes by the window, and watches television in the kitchen as the only room he usually heats.

The repetitive routines stabilise time but are not restorative, reflecting the constrained agency of older individuals managing daily life under material scarcity (*adjusting*). Though he could apply for energy subsidies, administrative complexity, and digital literacy often prevent access (*contesting*).

On good days, Toni walks ten minutes to the supermarket. Yet Vienna's car-centric design, narrow pavements, insufficient seating, and crowded crossings, make the journey physically and emotionally exhausting (Watson 2012) (*contesting*). He avoids public transport due to overcrowding and has stopped cycling due to perceived declining fitness, further limiting his autonomy.

Once in the store, Toni navigates his dietary needs with cultural and economic systems. His heart condition demands fresh, low-sodium foods, but affordability and familiarity, as well as unhealthy offerings within the neighbourhood often override health priorities. Marketing tactics and limited cooking skills steer him toward processed meats, bread, and convenience items (Schwindenhammer 2016; Schermer 2015). Cultural perceptions of plant-based diets as 'insufficient' or unmanly further limit alternatives (de Schutter et al. 2015) (*contesting*). Occasionally, neighbours share meals with him, reflecting how informal social exchange restructures support across food and care systems, though Toni's reluctance toward unfamiliar food sometimes limits these exchanges (*reconfiguring*).

Toni's only consistent social connection is a monthly tram ride to a local tavern, where he has dinner and plays cards with former colleagues. These brief outings bundle transport, socialisation, and food provision into a single event as a fragile alignment across systems (*converging*). Yet, these moments remain exceptional in an otherwise solitary experience. Most days, he leans on the windowsill, smokes, watches the street below, and prepares simple meals. He rarely cooks from scratch due to limited energy, skills, and motivation, reinforcing a loop of nutritional compromise and emotional stasis (*adjusting*). His routines reflect how structural neglect accumulates in daily life, particularly at the intersection of age, illness, and urban infrastructure.

6. Discussion: multi-system practice interactions in low-income daily lives

We introduced multi-system practice constellations as interconnected, co-evolving bundles of practices composed of shared materials, meanings, and competences, that span across social-ecological-technological provisioning systems. This framework rethinks sustainability transitions as processes not led by elite agency or discrete interventions, but as embodied, negotiated, and often precarious adjustments unfolding through everyday life, especially for those most exposed to climate-health risks. While frameworks like multi-system interactions (MSI) and nexus thinking (NT) have advanced understanding of cross-system interdependencies, they often centre on privileged actors, sectoral infrastructures, or governance structures, overlooking how vulnerable groups navigate and reshape these systems. This absence reproduces systemic injustice and fuels resistance, backlash, and discontent. By integrating praxeological approaches, we capture how fragile, situated agency emerges through entangled dynamics, especially at the intersection of social and ecological crises.

Using persona-based vignettes, we explore how practice constellations unfold across essential provisioning systems of mobility, housing, and food. These domains are both crucial for meeting basic needs and significant drivers of emissions. Across all three vignettes, we observed four recurring interaction modes:

- *Contesting* appears as conflict over resources, power, or systemic legitimacy. Lori's family struggles with Austria's car-centric rural infrastructure, lacking safe cycling paths or viable public transport. Leyla's mobility is constrained by care responsibilities and culturally coded expectations that devalue public mobility for migrant women. Toni, coping with illness, faces a different form of exclusion resulting from mobility limitations, lacking digital literacy and inaccessibility to healthy food that reflect the systemic neglect of ageing populations in urban design. These tensions are symptomatic of deeply rooted policy failures, deregulated markets, and exclusionary infrastructure that reinforce socio-spatial divides.
- *Adjusting* reflects low-agency, reactive strategies to cope with systemic constraints. Lori's family cycles seasonally and shifts food provisioning toward non-perishables in winter. Leyla must balance integration demands with her Afghan community's support networks. Toni rations heating, relying on electric blankets despite health risks. These examples show that adjustments, while necessary, often lead to trade-offs that compromise wellbeing, decarbonisation efforts or dignity. Adjustments absorb systemic failures, masking their long-term costs in private navigating practices.
- *Reconfiguring* involves more strategic, deliberate efforts to reshape practice-system relationships, though rarely under ideal conditions. Leyla reshapes routines by relying on community networks for shared trips and food provisioning. Toni's tavern visits are small acts of agency, reconfiguring isolation through social routines. Lori's family reorganises errands and care responsibilities to better cope with fragmented transport and retail systems. Examples like these show the inventive, fragile ways that practice constellations morph to fill systemic gaps through often resourceful but rarely transformative ways without structural support.
- *Converging* captures tactical alignments across systems and practices. These are moments of emergent synergy, often not by design but necessity. Lori's walk to the bus stop serves as both transport and exercise, while Leyla's shared meals in a neighbourhood parklet address food insecurity and heat mitigation. Toni's shared dinners align food, energy savings, and social integration. These are not scalable solutions, but improvised responses to systemic fragmentation.

Across all vignettes, practices were interdependent, with change in one system or practice triggering ripple effects in others. These constellations reveal that what are often framed as 'unsustainable choices' are in fact constrained adaptations within limited, often invisible, configurations of interlinked systems. Lori's mother's lack of transport affects not only mobility but also food access and time use. Toni's poorly insulated flat exacerbates illness and isolation, undermining both health and energy efficiency. These cascading effects show how cumulative vulnerability forms at the intersection of structural neglect and everyday life.

What emerges from our vignettes is not necessarily scalable innovation, but tactical resilience as the everyday work of making broken systems just functional enough. Although the framework identifies moments of convergence, our findings caution against romanticising and idealising synergy. Most examples of alignment were emergent, precarious, and energy-intensive practices, held together by unpaid labour, or social capital. Leyla's shared meals and Toni's social routines function as micro-breaks, not systemic solutions. These fragile alignments highlight how practice constellations can reinforce or destabilise system dynamics, creating feedback loops that entrench inequality or open up points of intervention.

These insights challenge several assumptions in sustainability transitions research. First, they disrupt the notion of neutral systems. Lori's family lack of cycling is not by choice, but because of unsafe infrastructure and car-centric norms. Leyla's lack of access to healthy food stems not from preference, but from spatial exclusion, cultural erasure, and retail monopoly. Toni's energy poverty is not a knowledge deficit, but the outcome of inaccessible retrofit programmes, gas dependence, and absence of age-sensitive policy. These constraints reflect deeper entanglements between the material, symbolic, and practical elements of everyday life that are inseparable from broader ecological, social, and technological systems. They are thus not individual shortcomings, but structural conditions embedded in systems shaped predominantly by and for urban, middle-class, and digitally literate socio-technical imaginaries.

Second, our findings challenge how systems are traditionally conceptualised in transitions research. Criteria for identifying multi-system dynamics must move beyond sectoral or governance-based boundaries to attend to functional interdependencies, as shared infrastructures, overlapping vulnerabilities, and co-evolving practices that span ecological, technological, and institutional domains. Drawing on the SETS framework, we argue that systems should not be seen as stable or discrete, but as relational configurations marked by feedback loops and uneven exposure to risk. System boundaries, then, are not objective, but rather methodological and political. Decisions about where systems begin and end shape who is included, which dynamics are visible, and which forms of agency are acknowledged. More critical engagement with boundary-setting thus enables recognising its epistemological consequences for just transitions.

Finally, while transitions are often theorised as regime-level shifts, for vulnerable populations they materialise as daily negotiations with frictions, inertia, and structural constraints. Practice constellations show where transition efforts are already and always happening in often mundane actions, not just technically, but socially and politically, yet often remain invisible because they are rarely framed as innovation. These everyday strategies are inherently political and must be treated as such. Actor-centred, cross-system perspectives are essential to uncovering power asymmetries and structural exclusion often embedded in current transition trajectories. We argue that the framework of multi-system practice constellations offers a valuable tool for identifying how transition efforts are negotiated, constrained, or enabled at the level of daily life. It helps surface where friction, exclusion, or opportunity emerge, not just technically, but socially, materially, and politically.

7. Conclusion

We introduce multi-system practice constellations as a conceptual lens for understanding how vulnerable population groups navigate interlinked sustainability transitions across housing, mobility, and food systems. By integrating insights from multi-system interactions (MSI), nexus thinking (NT), and praxeological approaches (PA), we demonstrated that everyday practices are not isolated or marginal, but embedded within co-evolving systems, shaped by structural constraints and embodied agency, contributing to developing tools and methods that make visible situated dimensions of current and desirable transformations in interconnected systems (Labanca et al. 2020). Building on persona-based vignettes, we traced how groups particularly vulnerable to climate-health risks engage in cycling, heating, and food shopping across intersecting systems. We identified four recurring dynamics: contesting (resource struggles and competition), adjusting (low-agency navigating), reconfiguring (fragile innovation), and converging (tactical alignments). These dynamics reveal that practice constellations emerge not simply from personal choices, but from situated negotiations with uneven infrastructure, policy logics, and socio-material conditions. Vulnerability, in this context, is not a fixed attribute, but a relational outcome of systemic entanglements.

A vignette-based approach can deepen understanding of how social-ecological-technological systems unfold unevenly across space, time, and institutional context. Methodologically, the persona approach helped translate abstract dynamics into tangible, lived experiences and often hidden maladaptation practices within inefficient systems. However, it carries the risk of reinforcing stereotypes or deficit framing (Torma and Aschemann-Witzel 2023). To mitigate this, we incorporated participant validation and cross-disciplinary reflection, ensuring that the vignettes remained both empirically grounded and critically reflexive (cf. Brandsen et al. 2018; Osborne et al. 2016). While not statistically generalisable, the vignettes offer conceptual insights into how multi-system interactions are lived. Future research could further explore how such constellations vary across actor groups (e.g., unhoused individuals, single mothers, migrant families) and geographies (e.g., through more detailed analysis of spatiotemporal configurations of place, space, and scale building on geography and planning debates, cf. Jones and Murphy 2011), and how intersectional dimensions (e.g., gender, age, legal status) shape strategies or constraints.

Our findings carry practical implications. The multi-system practice constellation framework can help identify where misalignments disproportionately burden vulnerable populations, informing interventions such as enabling infrastructure, support for bundled routines, and redesign of values and skills alongside material change. It advocates for multi-system coordination, aligning climate and health in provisioning systems to reflect interlinked practices. Policy examples include:

- Targeted, low-cost infrastructure interventions, such as continuous cycling-walking networks linking housing, schools, and essential services, sheltered bicycle parking, benches and shade along pedestrian routes, or safe crossings near schools and social

infrastructure, are modest compared to large-scale redevelopment, yet can meaningfully reconfigure the conditions under which everyday practices are performed.

- Public provisioning can address multiple system pressures simultaneously. For example, providing free, ecologically sustainable and nutritious school lunches can enhance short-term health outcomes, shape dietary practices in the long term, and support larger-scale value chains around public food provisioning, as well as reduce burdens on low-income families, particularly women, who remain primarily responsible for household nutrition. Combined with time-sensitive service coordination, for instance aligning public transport timetables with care responsibilities and shift work can reduce mobility burdens and enable access to food, education, and health services without requiring additional private resources.
- Practice-sensitive subsidy reform could account not only for income thresholds but also for constrained routines and intersectional barriers, for instance by linking heating or mobility support to building condition and health needs rather than household averages.
- Recognising and supporting informal systems, including shared mobility, neighbourhood care networks, or community food exchange, offers a pathway to stabilise and legitimise small-scale resilience already functioning as social infrastructure, for example through stable funding or enabling regulation.
- Integrating supply and demand can improve low-carbon food access for vulnerable groups in particular when aligned with mobility and care needs. Otherwise, context-sensitive initiatives such as community-supported agriculture, social supermarkets, or food cooperatives continue to face challenges integrating into dominant supply chains and effectively reaching low-income and often excluded groups (Zoll et al. 2024).

These interventions require cross-sectoral governance coordination that aligns climate, health and social objectives across housing, transport, food, and social policy, reflecting the interdependence of practices across systems.

Taken together, this approach could complement existing frameworks, including health-in-all policies and assessment tools (e.g., HIA, EIA) by explicitly linking system-level dynamics to everyday practices. Mapping practices along a continuum of agency can support more tailored, equity-informed policy design, particularly in areas like chronic illness, socio-spatial or socio-economic exclusion, while supporting communication of targeted interventions by identifying where frictions and bottlenecks occur across interconnected systems.

Multi-system practice constellations offer a grounded lens for understanding transitions not as top-down restructurings, but as embodied, negotiated processes unfolding in everyday life. As Schwane (2021) reminds us, even a digitalised cycling scheme fails if people lack skills, infrastructure, or cannot afford digital payment systems. By foregrounding the entanglement of materials, meanings, and competences, we centre the agency of non-privileged actors, those often navigating transitions through improvisation or fragile alignment. This perspective addresses the tension between the urgency of sustainability transitions, and the slow, uneven ways transitions are lived and practiced. Recognising practice constellations highlights the deep systemic inequalities embedded in everyday life, and the need for transition strategies that are not just technically sound, but anchored in lived experiences, collective capacities, and structural transformation alike. Yet, without structural transformation and the accountability of powerful actors, transition efforts risk reinforcing the very inequalities and long-term risks they aim to resolve.

CRediT authorship contribution statement

Astrid Krisch: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Data curation, Conceptualization. **Christina Lamp:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Data curation. **Andrea Schmidt:** Writing – review & editing, Investigation. **Ernest Aigner:** Writing – review & editing, Writing – original draft, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix: Workshop participants' institutional affiliations

Represented organisation	Represented population group
Caritas Wien ($n = 1$)	People living with poverty
Caritas Vorarlberg ($n = 1$)	People with addiction

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Represented organisation	Represented population group
Volkshilfe Wien (n = 1)	Families living with poverty
FemSüd (n = 1)	Women's health
Neunerhaus Gesundheitszentrum (n = 1)	People experiencing homelessness
Armutskonferenz (n = 2)*	People living with poverty
Marienambulanz Graz (n = 2)*	People without health insurance
Fachhochschule Salzburg, Social Work (n = 1)	Applied Social Sciences in Social Work

*Two representatives from these organisations were invited to reflect their complementary roles focused on internal organisational matters and on outward-facing policy engagement.

Data availability

The data that has been used is confidential.

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