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Transition and Transformation in Electric Mobility

Exploring Narratives, Institutional Contexts, Governance, and Agency through a Regional EV Case Study and Conceptual Expert Interviews

By the School of Sustainability of Leuphana University Lüneburg for the award of the degree

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Dedication

This thesis is dedicated to all those who continue to show unwavering commitment to the energy transition at every level—from small municipal units to larger governance bodies—and who generously supported this project with their time and insightful knowledge.

I extend my deepest gratitude to my supervisors, Paul Upham and Jens Newig. Paul, for believing in my potential to complete this project before I could fully grasp its scope, and for your constant presence and support. Jens, for graciously accepting me into the research group and providing access to resources, along with your insightful guidance and valuable comments throughout this journey.

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Abstract

Decarbonizing transport is essential for meeting European and German climate targets. This dissertation investigates how narratives, policy frameworks, and actor perspectives jointly shape the transition to e-mobility, with a regional focus on Lower Saxony. Adopting lenses from socio-technical transition research and the literature on socio-ecological transformation and resilience, the study pursues three objectives: (1) analyse how narratives mediate socio-technical change in the context of electric mobility; (2) examine the policy mix and governance arrangements for e-mobility in Germany and explore how actors interpret barriers and enablers, with particular attention to the regional context of Lower Saxony; and (3) investigate how leading scholars conceptualize agency, governance, and resilience in sustainability change, thereby clarifying distinctions between transition and transformation. Across these objectives, the thesis applies qualitative interview research to understand how sustainability change is interpreted, governed, and experienced across analytical levels.

Empirically, the research draws on two sets of expert interviews (regional actors and leading scholars) combined with a systematic policy review. Analytical methods include narrative analysis, policy review, and a two-phase inductive/structured content analysis. Findings from the first data set show that charging infrastructure and institutional coordination consistently emerged as central concerns across actor groups; fragmented responsibilities and limited institutional capacities hinder effective implementation. Narratives and meta-narratives vary in alignment with governance objectives, affecting perceived legitimacy and momentum. Findings from the supplementary dataset (expert scholars' reflections) demonstrate how conceptual ambiguities between 'transition' and 'transformation', and their links to conceptualizations of agency, governance and resilience, can obscure strategic direction if misinterpreted.

Overall, the dissertation argues for a governance-centred approach that aligns policy instruments with situated narratives and builds systemic capacities including the perspectives of central actors. The integrated, actor-centred perspective offers practical insights for policy design and contributes to debates on how to connect socio-technical and socio-ecological understandings of sustainability change.

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1. Introduction

Limiting global temperature rise below 2 °C, as set out in the Paris Agreement (United Nations, 2015), requires coordinated decarbonization across multiple sectors. The transport sector alone accounts for nearly a quarter of global CO_2 emissions (IEA, 2021a), with light-duty vehicles being the largest contributors (IEA, 2021b). Consequently, shifting away from fossil-fuel mobility systems toward electrified and low-carbon modes is a critical element of climate policy. In this context, **electric vehicles (EVs)**—encompassing both **battery electric vehicles (BEVs)** and **plug-in hybrid electric vehicles (PHEVs)**—is widely recognized as a key lever for reducing emissions and modernizing transport infrastructures. However, changing mobility systems is complex, requiring strategic policy to reduce risks and foster innovation. While the decarbonization of transport is often framed in technical terms, this study highlights that successful transitions depend equally on how policy frameworks align with stakeholder perspectives and the narratives through which actors make sense of change. To provide this type of insight, here I integrate detailed personal accounts and policy analysis for a case study region. In addition, the work draws on conceptual insights from sustainability transformation research to better understand how governance, agency, and resilience are perceived and enacted in change processes. In my dissertation, I examine the policy landscape and instruments with respect to e-mobility in Germany, analysing how actors from different sectors perceive and navigate the evolving niche of electric vehicles. Lower Saxony provides a representative case to explore how policy is mediated across local, regional, and national levels in the context of an automotive region with transformative potential. Complementing this empirical focus, the third paper broadens the analytical scope by examining how leading scholars conceptualize agency, governance, and resilience in sustainability transitions and transformations, offering a meta-perspective that situates the empirical findings within wider debates of systemic change.

The overall research is structured around three peer-reviewed manuscripts each of which examines aspects of sustainability change and complements the others. Two of the three manuscripts focus on the potential transition to e-mobility with a higher prevalence of electric vehicles from the perspective of the actors involved. The most recent article takes a more fundamental approach to the question of how sustainability transformation processes, such as the case study, can be conceptualized. The cumulative dissertation thus consists of:

1. a **conceptual study** that explores how scholars understand *agency, governance, and resilience* in discourses and the context of sustainability transformations and transition.
2. an **empirical study** that examines the policy mix and governance instruments; analyzing the perspectives of stakeholders and institutional orientations, and
3. a **narrative analysis,** that identifies and synthesizes meta-narratives that illustrate how actors understand in interpret transition processes.

Taken together, these studies offer a multi-level perspective on how systemic change can unfold in practice—linking the conceptual debates on sustainability transformation with the realities of policy and implementation. The use of an integrative approach with a combination of objects of analysis enables a multidimensional understanding of e-mobility, which includes consideration as a system innovation and goes further theoretically and conceptually than a flat consideration of the replacement of drive components (Augenstein, 2015).

Positioning between Policy, Governance, and Actor Perspectives in Sustainability Transitions

Research on socio-technical transitions often emphasizes technological innovation, policy instruments, or institutional design (Kanger, 2021; Muratori et al., 2021). While these approaches have advanced understanding of energy and mobility transitions, they tend to underplay the political and interpretive dimensions that influence change. In contrast, scholarship on **sustainability transformations** highlights the socio-ecological, cultural, and governance aspects that determine whether systemic change is incremental or transformative (Olsson et al., 2014; Patterson et al., 2017). This thesis draws on both traditions, seeking to integrate their insights into a more comprehensive understanding of mobility transition governance. From this perspective, policy frameworks are not neutral instruments but dynamic arenas where competing interests, ideas, and sometimes normative orientations interact. To better understand how innovation is supported or constrained by policy, identifying "bottlenecks" for policy intervention (Kanger et al., 2019) can prove a resourceful analytical step. Actor perspectives can shed light on particular aspects of implementation —for example, limited local coordination, insufficient charging infrastructure, and fragmented responsibilities—that influence effectiveness at different levels. Finally, analyzing narratives offers insight into how actors interpret these challenges and assign meaning to transition efforts, potentially bridging the gap between institutional structures and lived experience.

Research focus and objectives

Adopting lenses from socio-technical transition research and the literature on socio-ecological transformation and resilience, this thesis pursues three objectives:

1. to analyze narratives as mediators of socio-technical change;
2. to examine the policy mix and governance arrangements for e-mobility in Germany, including actor perspectives on barriers and enablers with emphasis on the regional context of Lower Saxony; and
3. to explore how sustainability researchers conceptualize agency, governance, and resilience in transformation processes.

Together, these objectives connect empirical insights on policy and actor perspectives to form a comprehensive view of governance and interpretive frames that influence e-mobility transitions in Lower Saxony Germany and beyond. Added with conceptual reflections from sustainability transitions and transformation research, an integrated view on systemic change processes is being offered to the readers.

2. Theoretical Background: Governance, and Agency in Sustainability Change

This chapter follows a conceptual logic by first outlining the foundations of sustainability transitions and transformations before focusing on governance, agency, and narratives as the three analytical lenses that structure this dissertation conceptually. A summary at the end synthesizes the links between the different concepts and their respective scientific articles of the cumulative dissertation. In this way an integrative perspective on governance, agency and narratives in sustainability change processes is presented.

2.1 Sustainability Transitions and Transformations

Sustainability transitions (ST) and sustainability transformations (STF) are two interrelated but distinct approaches to understanding and guiding systemic sustainability change. While they share a focus on radical and non-linear change, they differ in their disciplinary origins, analytical scales, and assumptions about what drives societal reconfiguration (Hölscher et al., 2018). ST studies primarily examine transitions within socio-technical systems — such as mobility — whereas STF scholarship expands the perspective toward socio-ecological restructuring, power dynamics, and normative development.

Sustainability transitions conceptualize change as a shift in socio-technical regimes shaped by technological innovation, institutional evolution, and multi-actor strategies (Geels, 2004; Geels & Schot, 2007). The multi-level perspective (MLP) remains a central analytical lens, emphasizing interactions between niches, regimes, and broader landscape pressures (Hölscher et al., 2018; Loorbach et al., 2017). Complementary frameworks such as Transition Management, Strategic Niche Management, and Technological Innovation Systems extend knowledge on governance and innovation dynamics. These frameworks have been particularly influential in mobility transitions research, where electrification of transport — and electric vehicles (EVs) in particular — is examined as a niche development responding to climate policy pressures and efforts to destabilize the fossil-based automobility regime (Berkeley et al., 2017; Ryghaug & Toftaker, 2014).

Sustainability transformations, in contrast, apply a broader socio-ecological lens. They highlight structural change in values, cultures, and governance, underpinned by concerns about resilience and social justice (Feola, 2015; Patterson et al., 2017). They consider societal systems as embedded within ecological limits and emphasize deliberate intervention in power structures, knowledge systems, and dominant paradigms. Transformation frameworks reflect this breadth:

(1) **Leverage points** conceptualize deep vs. shallow intervention (Abson et al., 2017; Meadows, 1999)
(2) **Three spheres of transformation** distinguish practical, political, and paradigm arenas (O'Brien, 2018)

Their diversity also makes it difficult to define what constitutes a "successful" transformation or how to assess directionality — particularly regarding social outcomes (Salomaa & Juhola, 2020).. Both strands recognize non-linear dynamics and the role of disruption in opening windows of opportunity.

While STF literature foregrounds paradigm shifts triggered by crises, ST research frequently analyzes regime destabilization and niche acceleration as mechanisms for change (Hammond, 2020; Johnstone et al., 2020; Kivimaa et al., 2021). To summarize key distinctions and complementarities, the following table provides a brief conceptual overview:

Table I: Differences and characteristics of sustainability transitions and transformations (conceptual)

Aspect	Sustainability Transitions	Sustainability Transformations
Definition	Refers to long-term, systemic changes in socio-technical systems (e.g., energy, transport) to address sustainability challenges.	Involves broader, more fundamental shifts in societal values, behaviors, and structures to reimagine systems entirely.
Focus	Process of change emphasize gradual, multi-dimensional shifts in technology, institutions, and culture.	Processes of change aiming for radical reconfiguration of systems and paradigms.
Scope	Typically addresses specific sectors or domains (e.g., energy systems).	Encompasses holistic and cross-sectoral changes at larger scales (e.g. international)
Approach	Often incremental and sometimes guided by governance frameworks like Transition Management.	More disruptive and transformative, often requiring shifts in power dynamics and deep cultural changes.
Timeframe	Long-term processes spanning decades (e.g., 25–50 years or more).	Can also be long-term but emphasizes the urgency of radical change.
Examples	Transitioning from fossil fuels to renewable energy systems.	Transforming societal norms around consumption and equity to create a just and sustainable society.

At the same time, transition and transformation research increasingly converge on the understanding that **innovation, experimentation, and participation** are crucial for systemic change. Real-world laboratories and pilot projects enable testing and scaling sustainability solutions in practice (Wamsler et al., 2018). Social movements, public deliberation, and shifting societal values form another essential driver of change (Brand, 2016; Wittmayer et al., 2020).

This cumulative dissertation draws on both strands: the transitions perspective informs the analysis of mobility and EV system change, while transformation scholarship provides a conceptual anchor for examining ideas of agency, governance, and resilience — explored in depth in Article 3. Taken together, these literatures highlight that the decarbonization of mobility is not only a technological challenge, but a **multi-dimensional societal process**, shaped by actors' agency, governance interventions, and contested interpretations of change. Against this backdrop, Section 2.2 examines the mobility transition as a concrete manifestation of sustainability change — focusing on governance and policy as key structuring forces.

2.2 The Role of Governance and Policy in Mobility Transitions

The decarbonization of transport requires significant changes to institutional structures and policies within the socio-technical system of automobility. Governance and public policy play a key role in guiding these processes of change by influencing technological and infrastructural development and user acceptance. In sustainability transitions research, governance is understood as the coordination and steering of change across multiple actors, institutions, and decision-making levels, while policy refers to the instruments and strategies that structure — and respond to — actor behavior within transitions (Köhler et al., 2019; Markard et al., 2012).

Electric vehicles (EVs), powered either by battery or hydrogen, are widely regarded as crucial to destabilising and transforming fossil-fuel dependent mobility systems (Berkeley et al., 2017; Ryghaug & Toftaker, 2014). Their diffusion, however, depends on interlinked technological, economic, infrastructural, and institutional conditions. Research on e-mobility governance therefore emphasizes **policy mixes** — combinations of regulatory and strategic market-based instruments that jointly influence innovation, deployment, and adoption of technology (Flanagan et al., 2011; Howlett & Rayner, 2007; Rogge & Reichardt, 2016). These policy mixes are expected to function coherently at the system level, minimizing conflicts among policy goals and enabling targeted acceleration of change.

Transition governance scholarship highlights that governing socio-technical change is not limited to fostering technological substitution. It also requires reflexive and adaptive steering to accommodate uncertainty, contested interests, and path dependencies (Kemp et al., 1998; Laes et al., 2014; Lange et al., 2013). In EV transitions, the development and spatial distribution of charging infrastructure is a central prerequisite for adoption (Almeida Neves et al., 2019; Liu et al., 2024; Vassileva & Campillo, 2017) and demands coordinated planning and institutional alignment across mobility and electricity sectors (Berkeley et al., 2017; Markard et al., 2020). Continuous learning, stakeholder engagement, and flexible adjustment of strategies are therefore essential elements of effective governance (Flipo et al., 2023; Mota-Nieto & García-Meneses, 2024; Polydoropoulou et al., 2020).

Governmental bodies face the persistent public policy challenge of supporting EV diffusion to meet decarbonization goals, including energy system integration and the emergence of low-carbon electricity markets. Innovation-friendly market environments and incentives such as decentralized renewable energy production (e.g. photovoltaics) facilitate transition progress (Hübner et al., 2001; Kotilainen et al., 2021). To guide these developments strategically, transition governance requires reflexivity in linking long-term visions with iterative near-term actions (Halbe et al., 2015; Laes et al., 2014). Likewise, the formation of coherent policy mixes is needed to sustain rising EV market shares (Obrecht et al., 2018).

These governance tasks unfold in multi-level institutional structures. National governments typically set strategic direction through regulation and finance, regional governments translate these ambitions through planning and capacity-building, and municipalities implement infrastructures and shape local mobility environments (Lanzini & Khan, 2017; Otero-Romero et al., 2025). Local authorities can drive modal shifts through planning, public transport improvements, and pricing instruments, while national and EU-level regulation provides binding standards and market-shaping incentives (Lanzini & Khan, 2017; Liu et al., 2024).

In this context, diverse actor perspectives become central for resolving competing priorities and overcoming institutional frictions (Juerges et al., 2020). In the German federal system, regional and local practices influence the implementation of supranational and national e-mobility goals. This compiled study uses the example of the federal state of Lower Saxony, with its historically strong automotive industry and growing renewable energy sector, to show how regional industrial structures and governance capacities can influence the diffusion and adoption of electric vehicles.

However, policy implementation is not a linear translation of intent into outcomes. It is interpretative and negotiated, shaped by discretionary judgement and interaction among actors positioned within the system (Albrecht, 2017; Albrecht et al., 2017). Actor decisions regarding technology adoption, collaboration, problem framing, and prioritization influence whether and how policies take effect (Upham et al., 2018, 2020). Yet, conceptual work connecting macro-level policy dynamics with micro-level agency remains limited (Bögel & Upham, 2018). Recent studies show that actors encounter multiple barriers in implementing EV policy — such as fragmented responsibilities, limited institutional capacity, and asynchronous sectoral priorities — which constrain progress even in supportive regulatory environments (Ball et al., 2021; Corradi et al., 2023; Truffer et al., 2017). Additionally, transitions depend not only on governance capacities but also on shared expectations and socio-technical imaginaries, which shape perceived futures of mobility and influence both policy development and public acceptance (Graf & Sonnberger, 2020; Mutter, 2021; Ryghaug & Toftaker, 2016; Sovacool et al., 2020). Examining how these actors perceive implementation barriers thus provides analytical leverage for improving governance and institutional arrangements, as well as policy coordination. Summing up the literature, mobility transitions require supportive policy mixes and infrastructural investment, but also attention to sociocultural dimensions that enable public engagement and acceptance. Governance in mobility transitions in concerned with socio-technical and political processes. Transitions depend not only on technological innovation but on the alignment of governance capacities, actor agency and shared expectations within the evolving system (Markard et al., 2012, 2020) - a conceptual bridge to the next section, which focuses explicitly on actors and agency as key forces in shaping transition pathways.

2.3 Actors and Agency in Sustainability Change Processes

Sustainability transitions are fundamentally shaped by the actors involved in them. Actors are understood here as individuals or collectives—such as policymakers, businesses, civil society organizations, or research institutions—who participate in or influence socio-technical change. They differ in their resources, organizational capacities, institutional mandates, and problem framings, and can therefore accelerate, redirect, or obstruct sustainability efforts (Bodenheimer & Dütschke, 2021). Understanding actors requires an understanding of agency, defined as the capacity to make choices and act upon them. Agency is relational rather than autonomous: it is enabled and constrained by broader institutional, political, and material structures (Grin et al., 2011). Drawing on strong structuration theory (Stones, 2017), agency emerges at the intersection of actors' internal dispositions (e.g., values, knowledge, identities) and external contextual conditions (e.g., governance arrangements, infrastructures, cultural norms). In transition studies, actors are not merely passive implementers of technological innovations, but agents of change embedded in multi-actor systems. Within the multilevel perspective (MLP), actors operate at niche, regime, and landscape levels, shaping both stability and disruption of socio-technical systems (Farla et al., 2012; Fischer & Newig, 2016).

Incumbent actors may defend existing regimes, yet under shifting political and market conditions may also become transition advocates—as illustrated in national energy transitions (Ramanauskaitė, 2021). Local practitioners and professionals, often overlooked in transition research, increasingly gain attention as **intermediaries** who translate sustainability visions into practice, enabling learning and innovation (Moilanen & Alasoini, 2023). Successful transitions—such as those observed in the green building sector—are often contingent on multi-actor constellations where governments, businesses, NGOs, and citizens co-create and reinforce change (Zhang & He, 2022). Because actors differ in motivations, power, and legitimacy, studying their roles enables insights into conflicts, alliances, and leverage points for intervention (Rotmans & Loorbach, 2009; Wittmayer et al., 2017). Even global organizations such as development banks can shape sustainability trajectories by influencing financial flows and dominant discourses (Lesch et al., 2023). Accordingly, the study of actors reveals transition governance as a dynamic, multi-scalar process that relies on evolving role constellations. A crucial aspect of agency is that it is interpretive. Actors make sense of system change through stories — shared or contested — that articulate what forms of sustainability are possible and desirable and how sustainability objectives are enacted across scales (Nordt et al., 2024). These narrative processes mediate how agency is expressed and how structures are reproduced or challenged (Upham & Gathen, 2021). This interpretive dimension provides an important conceptual bridge to the following section.

Recent sustainability scholarship has increasingly emphasized the importance of better theorizing how actors become capable of altering system trajectories. Sustainability transformations cannot be fully understood without considering how actors reflect on and position themselves within structures of power, meaning, and materiality (Ruhrort & Allert, 2021). This aligns with structuration theory (Zamora & Giddens, 1985) and its development into strong structuration theory (Stones, 2017), which conceptualizes agency as an ongoing interaction between internal dispositions (e.g., values, identities, knowledge) and external structures (e.g., institutions, infrastructures, norms). Agency is thus relational and unevenly distributed (Heinz, 2009): actors' capacity to act differs depending on their social position, political opportunity structures, and system-level constraints. This resonates with transition scholarship that calls for deeper attention to the sources and forms of agency across both state and non-state actors, and to the institutional conditions that enable or suppress transformative action (Dolfsma & Verburg, 2008; Kok, 2023; Patterson et al., 2017; Pesch, 2015).

From this perspective, agency becomes especially visible in moments when systems are contested or disrupted. Findings from transformation research suggest that the activation of agency depends on whether surrounding governance arrangements open space for experimentation, alliance-building, and cross-sector collaboration. Individual actors may catalyze change, but durable transformation relies on collective networks that reinforce and scale emerging practices.
Two complementary modes of agency can thus be distinguished:

(3) **relationship-building**, rooted in shared visions and narratives that align diverse actors, and
(4) **cross-sectoral collaboration**, focused on coordinating resources and strategies across institutional boundaries.

These dynamics are central to the empirical contributions of this dissertation: Paper 2 demonstrates how institutional context shapes actors' ability to translate EV policy into practice, while Paper 3 investigates how scholars conceptualize competencies and structural conditions necessary for agency to contribute to sustainability transformations. This provides the conceptual bridge to the next section, where the narrative dimension of agency is explored in more depth.

Figure II provides a schematic overview of key actor categories in socio-technical transitions — niche actors, incumbents, regime actors, landscape-level influences, and transnational actors — each embedded within wider structuration contexts. The figure supports how diverse actors are positioned within structures and influence(d) by their capacity for agency, as well as their role in transition narratives.

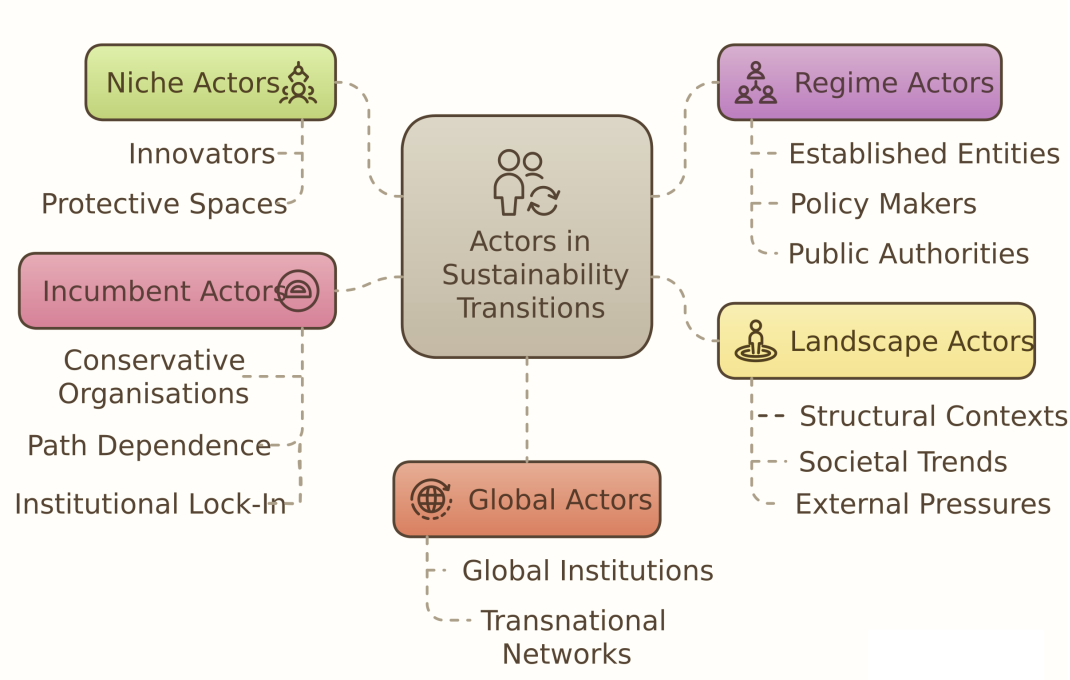

Figure I: Scheme of Actors in Sustainability Transitions (own illustration)

2.4 Understanding Narratives as Mediators of Agency and Structure

Narratives are increasingly recognized in sustainability transitions research as interpretive frameworks through which actors make sense of system change (Luederitz et al., 2017). They provide meaning in situations of uncertainty, helping to define what forms of mobility are viewed as desirable, feasible, or necessary in societal transitions. In this sense, narratives reflect how actors position themselves and others within evolving socio-technical systems. Within transition studies, narratives function at the intersection of institutional structures and actor agency (Hermwille, 2016). They mediate between internal dispositions such as values or professional identities and external structures such as policy frameworks and infrastructures. Through shared storylines, narratives contribute to coordination across governance levels, while diverging narratives may signal contestation within transitions.

Narratives can also influence expectations about future system development. For example, research on electric mobility highlights how emerging actor narratives around technological performance, environmental benefits, or infrastructural constraints shape acceptance, adoption and diffusion dynamics (Axsen et al., 2012). In other sectors, competing narratives have been shown to maintain incumbent structures or slow down phase-out efforts when dominant actors frame sustainability transitions as undesirable or risky (Trencher et al., 2019). Cross-sectoral reviews further illustrate the diversity of sustainability narratives and their relevance for understanding how societal goals are interpreted (Stefani et al., 2022). The analysis of how actors understand their capacities and constraints, provide insight into the structure–agency relationship (Wiles et al., 2005). Narrative alignment provides indications whether governance processes are perceived as enabling or restrictive, and where coordination challenges emerge.

The thesis adopts these narrative concepts in article one to examine how actors in Lower Saxony articulate their experiences of the electric mobility transition. Drawing on a strong structuration perspective, the analysis considers how narratives reveal situated or conjunctural knowledge about structural conditions, opportunities, and perceived roles within the system. **Strong structuration theory** extends Giddens' original formulation by analytically distinguishing between different dimensions of structure and agency (Stones, 2017), emphasizing that actors draw on both **external structures** (e.g., institutions, rules, infrastructures) and **internal structures** (e.g., professional identities, knowledge, norms) when interpreting situations and making decisions. Structural conditions are therefore not only constraining but also enabling. Conjunctural knowledge refers to the situated understandings actors develop about what is possible or appropriate within a specific context, informed by past experience, perceived role expectations, and interpretations of rules-in-use. Strong structuration is thus a useful approach for transition studies because it highlights how systemic change is shaped by actors' interpretations of their structural environment and by their capacity to act upon these interpretations. Article one applies this perspective to analyze how actors' narratives express conjunctural knowledge related to electric mobility implementation in Lower Saxony, revealing how structural conditions are perceived and negotiated in practice.

In summary, understanding narratives as mediators of agency and structure offers a perspective how actors perceive transition processes, how agency is expressed, and how socio-technical change is interpreted in context. This supports a more comprehensive analysis of mobility transitions as shaped by governance arrangements, evolving actor roles, and meaning-making processes.

3. Methods

The dissertation investigates the electric mobility transition in Lower Saxony by examining how actors interpret change, navigate governance frameworks, and articulate agency within a sustainability change process – more specifically in a socio-technical system under transformation. To address this, the overall research design connects three qualitative sub-studies based on interview data and interpretive analysis.Each sub-study relates a research question as stated in the next section and to the overarching meta-question:

> *What insights do actors' perceptions and strategies in the evolving electric vehicle niche provide about systemic change, particularly when examined through scholarly conceptualizations of agency, governance, and resilience in sustainability transitions and transformations?*

Each article with its respective research question focuses on different but complementary aspects of system change — narratives (1), governance and policy interpretations (2), and conceptual foundations of agency in transition contexts (3). The combination can be viewed as coherent in its methodological strategy the following way: understanding sustainability transitions as actor-interpreted and institutionally embedded processes.

3.1 Research Design

This study applies a qualitative, multi-method research design to explore how actors in the e-mobility transition interpret policy, exercise agency, and construct narratives of change. Combining interview studies and policy review is an approach recognized as valuable in transition studies (Zolfagharian et al., 2019), yet it has only been applied in a few individual cases (Kolde & Wagner, 2022). Grounded in an interpretive-constructivist epistemology, this study combines semi-structured expert interviews, policy document analysis, and interpretation of central and meta-narratives to capture the multi-layered dynamics of sustainability transitions. The empirical focus is on Lower Saxony as a case region in the German automotive landscape. The twenty interviews were conducted across seven actor groups. Groups included public officials, industry representatives, engineers, lobbyists, and users—each selected purposively and through snowball sampling to reflect their engagement with the regional EV system.
The research evolved through three qualitative sub-studies that remained coherent in their analytical grounding and shared focus on structure–agency dynamics:

(1) a narrative analysis of actor perspectives in the regional e-mobility transition in Lower Saxony
(2) an actor-centered review of Germany's EV policy mix
(3) a conceptual investigation of sustainability change discourses with leading scholars

Together, these sub-studies address how narratives, governance arrangements, and actor interpretations shape the trajectory of e-mobility transitions.

The research questions guiding the sub-studies are:

> **Article 1:** *Which narratives and meta-narratives can be identified from interviews with central stakeholders of e-mobility in Lower Saxony within a strong structuration frame?*
> **Article 2:** *How do different types of actors perceive and address challenges to implementing EV policy, particularly from their positions in the e-mobility system?*
> **Article 3:** *What do expert perspectives reveal about conceptual dimensions of sustainability transitions and transformations, particularly regarding agency, governance and resilience?*

The methodological approach was selected to allow each research question to be answered at the appropriate analytical level — while maintaining comparability across studies through shared qualitative foundations. For the regional sub-studies (Papers 1 and 2), stakeholder interviews in Lower Saxony provided insight into institutional contexts, situated actor experiences and interpretations of policy, as well as suggestions for improvement. Each actor was selected purposively and through snowball sampling to reflect their engagement with the regional EV system The third sub-study (Paper 3) uses a similar interview approach, but with an international academic sample, to address conceptual aspects of sustainability change processes. The participants were selected through a standardized procedure, including Scopus and the h-index. In Paper 2, the interview analysis was complemented by a systematic review of key German EV policies to assess actor interpretations of implementation challenges and governance capacities.
The policy component included a review of national strategy documents such as the *National Development Plan Electromobility*[1] and *Masterplan Charging Infrastructure*[2], as well as legislative instruments like the *Electromobility Law (EMobG)* and tax exemptions. Here, the analysis unfolded iteratively, with interview data informing document interpretation and vice versa. Although the three studies evolved successively during the research and publication process, they remained coherent with their qualitative foundations and aligned focus on structure–agency dynamics. While not conceived as a top-down strategy, the methodological integration evolved organically, reflecting the cumulative structure of the dissertation and the layered nature of transition governance. Figure II illustrates how analysis progressed iteratively across studies, with insights from one informing the interpretive framing of the others.

Thus, this study adopts an interpretive-constructivist epistemological orientation, which holds that social realities — particularly in the context of sustainability transitions — are constructed through situated processes of meaning-making.

[1] Federal Government Germany (2011): Regierungsprogramm Elektromobilität. Available under https://www.bmwk.de/Redaktion/DE/Downloads/P-R/regierungsprogramm-elektromobilitaet-mai-2011.pdf (7.12.2025).

[2] Federal Ministry for Digital and Transport (BMDV), *Master Plan Charging Infrastructure II*, October 2022, available at: https://www.bmdv.bund.de/SharedDocs/DE/Anlage/G/masterplan-ladeinfrastruktur-2.pdf. (11.05.2025)

Following constructivist traditions in transition studies and environmental governance (Avelino & Wittmayer, 2016; Meadowcroft, 2011), this perspective aims to understand how actors interpret change, articulate agency, and navigate socio-technical uncertainty. The approach is well-suited to fields such as energy and mobility transitions, where competing visions, values, and framings are central to shaping the trajectories of governance and systemic transformation. Recent work in transition studies increasingly reflects this orientation (Geels, 2020; Grin, 2016). Aligned with the epistemological stance outlined in Section 2, this design assumes that transitions are shaped by how actors make sense of change, and that these interpretations can be revealed through qualitative inquiry. Accordingly, the methodological choices serve the goal to understand how narratives, policies, and actor perspectives co-constitute the e-mobility transition, with Lower Saxony as an embedded case through which these dynamics become empirically visible.

Within this epistemological framework, qualitative methods such as semi-structured interviews, narrative analysis, and policy discourse analysis are particularly appropriate, enabling researchers to explore how actors construct meaning, negotiate roles, and imagine alternative futures.

3.2 Research Data

Qualitative data in the social sciences focuses on understanding complex human experiences and meaning-making in context (Goodrick & Rogers, 2015; Seers, 2012). The empirical materials used in this dissertation are non-numerical, rich in detail, and embedded in real-world contexts. They allow exploration of how actors construct meaning and enact agency within evolving socio-technical systems, particularly in the context of electric mobility. Understanding sustainability transitions requires attention to social, institutional, and geographical contexts. This dissertation therefore adopts a case-based design reflecting how transitions unfold and are interpreted in practice. Lower Saxony, a region where electric mobility adoption is actively developing, provides a suitable case for investigating transition dynamics in a specific regional context. Factors such as regional energy infrastructure development, ongoing charging network expansion, and the involvement of diverse local actors provide a relevant setting for exploring governance coordination, institutional change, and user perspectives on e-mobility. The heterogeneity of actor perspectives—ranging from EV users and energy providers to city planners and lobbyists—is essential for understanding regionally embedded transition processes (Bögel et al., 2022). Although the interview sample is not representative of the entire state, the data reveal how municipal actors, utilities, and planning bodies interpret and navigate transition pressures in context-specific ways. Lower Saxony represents a case for understanding how narratives, policies, and actor roles are configured in an automotive region undergoing transformation. These diverse viewpoints provide analytical leverage for examining how narratives, policies, and actor roles interact in a live transition environment. In addition to the regional case, a second data set introduces a conceptual perspective on sustainability change. Expert interviews with sustainability scholars support theoretical clarification around agency, governance, and resilience in transition and transformation scholarship. This parallel dataset operates at a different analytical level, enabling interpretation of findings in relation to broader academic debate. Together, the regional and conceptual data contribute to the central subject of the dissertation: explaining how structure–agency dynamics manifest within an ongoing sustainability transition and are explicated through narratives, institutional arrangements, and governance practices.

To address the research questions of the three sub-studies, complementary data sources were used:

Study A – Regional Expert Interviews
Fifteen semi-structured interviews were conducted online in April–May 2020 with stakeholders in Lower Saxony's e-mobility transition, including scientists, engineers, EV users, administrative staff and representatives of energy providers and grid authorities. Purposeful sampling combined with snowball recruitment ensured coverage of key actor groups(Taherdoost, 2018; Yin, 2018). Questions probed experiences related to system rules, resources, and social barriers to EV adoption (Stones, 2005; Lin & Sovacool, 2020). Transcripts were thematically coded to identify interpretations of technological, organizational, and practice-level challenges.

Study B – Policy Review and Coded Actor Interviews
In the second study related to the interview data, policy documents—including national e-mobility strategies and legislative instruments—were analyzed to identify policy-mix elements (Knoepfel et al., 2007). The same interview data as in Study A were then re-coded using a policy implementation lens to analyze how actors interpret institutional constraints and enablers in applying e-mobility policy in practice.

Study C – Expert Interviews on Transitions and Transformations
Sixteen semi-structured interviews with leading sustainability scholars (Scopus-based identification; h-index ≥ 15) were conducted in 2023. A two-phase analysis with the general inductive approach (Thomas, 2006) and structured content analysis (Flick, 2019)was used to derive themes related to agency, governance, and structure in sustainability change. This dataset enhances the conceptual grounding of the dissertation by clarifying linkages between transition and transformation scholarship.

In summary, regional actor interviews, policy analysis, and conceptual expert perspectives supports a comprehensive understanding of the research questions (here simplified:

How do actors narrate roles and change in the EV transition?
How do actors perceive and address challenges in EV policy implementation?
How are agency, governance, and resilience conceptualized in sustainability change research?

This integrated data approach provides a robust foundation for investigating how narratives, policies, and agency shape the evolution of electric mobility in Lower Saxony.

3.3 Data Analysis

The analytical approach taken in this study reflects the interpretive-constructivist holding of the overall research concept. The analysis followed a **multi-method strategy**, adapted to the the research questions and the data material. Across all three sub-studies, the emphasis was on understanding how actors interpret, narrate, and respond to sustainability challenges and systemic change, particularly in the context of the electric mobility transition.

In Study A (article one) we focused on narrative content from the regional expert interviews. The aim was to identify how actors articulate their experiences, position themselves within the socio-technical system, and express meaning through storytelling. Transcripts were systematically screened for narrative sequences, typically those containing emotional, metaphorical, or representational meaning. These were then coded according to categories derived from the interview guide, structured around key regime features relevant to the electric vehicle system (van Bree et al., 2010), including "regulations and policies, road infrastructure and traffic system, maintenance and distribution network, production system and industry structure, markets and user practice, fuel infrastructure, automobile, culture and symbolic meaning" (Upham & Gathen, 2021). In a second analytic phase, **meta-narratives** were inferred by comparing interpretive patterns across interviews. We examined how actors' conjunctural knowledge shaped their framing of the system, causal attributions, and perceived access to structural resources. Drawing on Stones' (2005) strong structuration theory, narratives were treated as expressions of conjunctural knowledge—practical understandings that enable actors to navigate structure–agency dynamics. Selection of meta-narratives for presentation was based on qualitative richness and prevalence across the sample.

Study B (article two) used the same interview material, but a **policy-oriented analytical** lens. A two-stage thematic coding approach was applied to identify actor-specific interpretations of policy dynamics and implementation challenges. In the first round, high-level, concept-driven codes were used to match interview content to domains such as regulation, infrastructure, socio-technical transition, and user practices (Hoffmann et al., 2017). In the second round, sub-codes enabled finer analysis of perceived institutional constraints and conflicts. Coding was supported by visual tools within MAXQDA to track distribution across actor groups. In a third analytical step, the data were examined through Scott's (2013) **institutional pillars framework**, namely regulative, normative, and cognitive elements. Normative orientations—here understood as value-based or moral stances—were particularly relevant for understanding how actors assess the legitimacy of policy interventions. This lens facilitated interpretation of institutional tensions, barriers, and leverage points in EV policy implementation.

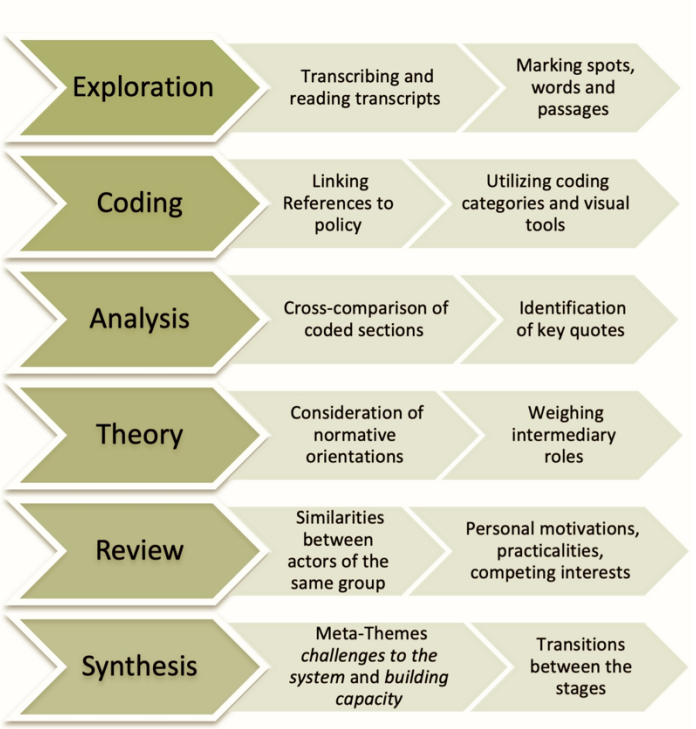

Figure II: Process of Analysis (Gathen, Upham and Newig, 2025)

Analysis of Study C (article three) required a slightly different procedure given the conceptual focus and expert audience. A **two-phase analytic design** was implemented. First, a general inductive approach (Thomas, 2006) enabled themes to be derived directly from the material while retaining close alignment with the research questions. Transcripts were reviewed iteratively, with multiple rounds of listening and open annotation (Chen et al., 2021). Rather than using the interview guide as a rigid structure, the analysis followed emergent patterns around central concepts including governance, agency, and resilience. In the second phase, a **coding scheme** was developed for theoretical consolidation, enabling detailed comparison of convergent and divergent interpretations across the expert sample. MAXQDA supported the organization and interrogation of the data, including examination of **meta-content** such as underlying assumptions about sustainability change. Across all three sub-studies, MAXQDA facilitated systematic comparison and iterative development of insights. As shown in Figure II (derived from Gathen, Upham & Newig, 2025), the process moved through multiple iterative stages—immersion, thematic and narrative coding, and interpretive synthesis—allowing both depth and breadth of analysis. This layered strategy enabled the study to capture individual sense-making while identifying structural patterns across actor groups and analytical levels. In sum, these analytical approaches reflect the broader epistemological orientation of the study: knowledge is constructed through interpretation, situated in context, and shaped by interplay between agency and socio-technical structures. By tailoring analytical strategies to each sub-study while maintaining interpretive coherence, the dissertation develops a differentiated explanation of how narratives, policies, and institutional contexts shape the unfolding electric mobility transition.

The following chapter builds directly on these analytical outcomes, presenting the empirical findings in relation to the research questions and theoretical framework.

4. Findings & Synthesis

Here I present the empirical findings and their synthesis across the three sub-studies of this dissertation: Each study addresses a different but interrelated aspect of the e-mobility transition in Lower Saxony: a) conceptual framings of sustainability change (article three), b) governance and actor perspectives on policy implementation (article two), and c) stakeholder narratives (article one). The synthesis aims to identify thematic linkages that explain how structural and agentic factors interact in shaping transition dynamics.

The chapter first summarizes conceptual distinctions derived from interviews with leading scholars in sustainability transitions and transformations. These perspectives provide a framing for interpreting findings from the regional case. This section is followed by a description of actors' situated views on barriers and enablers of e-mobility implementation, with particular attention to charging infrastructure against the background of Germany's e-mobility policy landscape. Finally, the third section summarizes results from the analyses of stakeholder narratives, highlighting how storylines reflect and shape perceptions of change, legitimacy, and agency. A synthesis highlights commonalities across the different analytical levels.

4.1 Conceptual Distinctions of Governance and Agency

In interviews with scholars we examined how sustainability transitions and transformations are conceptualized, differentiated and understood in current discourse by academic experts with a focus on governance and agency (see article 3, annex). While terminological boundaries remain fluid, it was stressed that sustainability transitions often emphasize structured, sectoral shifts in socio-technical systems, whereas the concepts of sustainability transformation foregrounds broader socio-political reconfigurations and normative change. Participants noted complementarities between both perspectives. The findings reflect disciplinary diversity and academic experience in how governance and agency are framed. Across interviews, two themes were prominent: (1) who has agency in sustainability change and how it operates, and (2) how governance shapes and enables change.

Agency was described as essential for initiating and sustaining sustainability change, highlighting its importance for activation and collective mobilization. Scholars emphasized different sources and scales of agency: Many interviewees emphasized individual and organizational actors such as innovators, municipalities, and niche initiatives that experiment with new practices and technologies and support bottom-up change. Examples referenced local renewable energy movements in Denmark and Germany as successful pathways where initially small initiatives gained traction and were scaled. Others focused more on collective and systemic agency, stressing the importance of coalition-building, social movements and wider publics capable of shifting norms and priorities — particularly when institutional change is required.

Across perspectives, **agency** was viewed as relational and contextual — becoming particularly visible in disruption or crisis situations. The capacity to act was seen as strongly influenced by governance arrangements, political opportunity structures, and the ability of actors to form alliances across sectors. Several interviewees also stressed tensions between individual initiatives and the need for collective mobilization to sustain transformation. Two operational modes of agency emerged from the data: In the transformation-oriented accounts the mode of relationship-building and alignment of visions was stronger prest, in the transition-oriented accounted cross-sector collaboration was viewed as more important to scale innovation. From a more general stance of the sample, sustainability change depends on both dispersed actor initiative and capacity for coordinated, collective mobilization rather than a single dominant source of agency.

Governance was the most frequently referenced concept in the dataset during coding procedure. Discussions focused on how power is exercised, who is included in decision-making, and what institutional conditions enable capacity for change. Governance was mainly viewed in the context of institutional steering, participation and power dynamics. Two main modes of governance were highlighted: policy-driven governance and polycentric-participatory governance. With the latter, many scholars emphasized the role of the state — through regulation, incentives, and multi-level planning — in supporting niche development and destabilising unsustainable regimes. However, state intervention was seen as limited without coordination with multiple actors. Polycentric and participatory governance on the other hand focused on the inclusion of marginalized groups and deliberative processes were seen as necessary conditions for durable transformation. Transformations scholars also particularly stressed distributed decision-making and co-creation to secure legitimacy and avoid resistance from those affected by change. Discussions of governance frequently turned to power and legitimacy — specifically, how incumbents influence system trajectories and how governance needs to identify who holds power and whose voices are excluded: This highlights governance not only as a structuring mechanism but also as a field where contestations and systems critique are processed and handled.

These conceptual insights from article on provide a helpful complimentary lens for interpreting how governance and agency play a role in the interpretation of actors perspectives on policy - the regional case of electric mobility in Lower Saxony, examined next.

4.2 Policy Framework and Actor Perspectives

How do actors perceive and apply policies for e-mobility within the regional context of Lower Saxony? Here we provide insights into the results of an exploration of the changing policy landscape for e-mobility in Germany, based on a combination of policy analysis and expert interviews. What we can see in the policy data is that national e-mobility policy in Germany has developed into a more detailed and structured system over the past two decades. To support analytical clarity, figure III maps policy elements at national level.

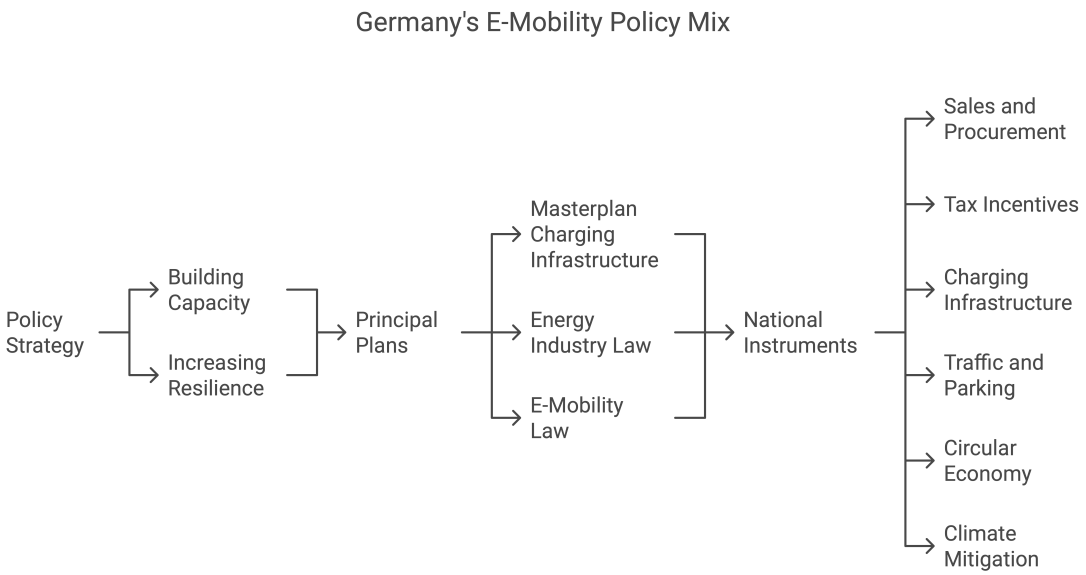

Figure III: Overview of Germany's E-mobility policy mix (Gathen et al., 2025)

Guided by Rogge and Reichardt's model (Rogge & Reichardt, 2016), the analysis comprehended and followed the development of strategic plans, regulatory frameworks, and funding instruments from early initiatives to more recent measures.

Actors' Perceptions and Institutional Orientations

Using the interview data, we reviewed the experiences of actors responsible and involved in implementation.

The analysis examined how actors interpret and apply the changing policy framework against the light of Scott's institutional theory. Charging infrastructure was highlighted as a major concern, with distinct emphases across actor groups: In short, the following groups stressed specific aspects of infrastructure:

- business representatives → payment complexity
- engineers → grid capacity
- public authorities → role clarity

These interpretations link technical challenges with differing normative goals and role expectations. Table II summarizes identified policy-relevant challenges and associated options for improvement in the context of a further technological diffusion.

Increasing Capacities to Support Transition

Actors also identified capacities needed to support transition progress. Drawing on transformative capacity literature, four categories were identified: technological, institutional, cultural-cognitive, and educational (Table II). The findings illustrate how capacity gaps are interconnected. For example, charging reliability relates not only to technology but also to regulation and coordination. Similarly, range anxiety is linked to both technical gaps and a lack of clear communication and education.

Table II: Measures to advance capacities in the socio-technical system from actors' perspective (Gathen et al., 2025)

Field of capacity	Objectives	Suggested improvements	Policy Options
Technological	Expand and improve the charging station network	▪ Increase public charging spots ▪ Enhance accessibility ▪ Ensure compatibility ▪ Install fast chargers ▪ Set up charging facilities for larger utility vehicles ▪ Streamline maintenance and payment service of charging spots ▪ Improve technical reliability ▪ Create virtual connectivity with software	Further promote development of charging infrastructure according to masterplan, legally mandate technical reliability including sanctions, and promote research for the integration with vehicle-to-grid systems.
	Further develop the technology required for low-carbon electric vehicles	▪ Expand the range of vehicle models ▪ Adapt available technology to larger utility vehicles ▪ Increase battery range ▪ Optimize thermal management ▪ Propel research, development, and innovation ▪ Enable integration into vehicle-to-grid systems	
Institutional	Advance effective policy-mix	▪ Balance incentives and regulations. ▪ Support the integration of evolving technology into the landscape. ▪ Administer programs for the diffusion of socio-technical solutions. ▪ Coordinate public invitations to tender. ▪ Endeavor synchronization of collaboration among stakeholders. ▪ Refine public procurement guidelines. ▪ Foster public or public-private collaboration. ▪ Enable the electrification of public transport.	Continue the political work for a balanced policy mix that combines incentives and regulations, supports stakeholder collaboration, and integrates evolving technologies into public procurement and public transport systems.

Cultural-cognitive	Advocate a shift in mobility conceptions	▪ Cultivate a shift in attitudes, norms, and beliefs toward e- mobility ▪ Heighten awareness about electric vehicle advantages ▪ Dispel and clarify misconceptions ▪ Foster a culture supportive of eco-conscious, localized solutions. ▪ Address mobility behavior to align with vehicle capabilities ▪ Embrace the challenge trio: digitization, electrification, and connectivity ▪ Consider novel usage patterns, emergent business models and innovative mobility services ▪ Foster an overarching trans-formation in mobility paradigms.	Investing in awareness-raising campaigns social perception and behavior towards e-mobility (such as *Schaufenster E-mobilität)*, offering consulting options through funded intermediaries to clarify misconceptions and continue to promote a culture of environmentally conscious mobility, e.g. through municipal offices for climate protection and appointed climate protection managers/officers.
Educational	Strengthen skills and competencies in the field	▪ Offer trainings to stakeholders in the field ▪ Increase awareness about electric mobility ▪ Disseminate knowledge about the latest developments in the field. ▪ Provide qualifications through training for experts in the field	Support capacity building through co-funding specialized training programs and encourage transfer of knowledge and training initiatives for stakeholders and professionals in the field.

Fragmented Engagement and Governance Implications

Across the interviews, actors predominantly framed challenges from the vantage point of their own organizational responsibilities. This institutional orientation led to a limited consideration of interdependencies within the wider e-mobility system. Cross-organizational coordination was mentioned only occasionally and mostly in cases where responsibilities were perceived as unclear. As a result, problem perceptions remained fragmented, reflecting the regulative and normative expectations of the institutions in which actors are embedded (Scott, 2013). The findings indicate that system-level perspectives were less pronounced than operational concerns rooted in local mandates and resource constraints.

In summary, both the structure of policies and the ways actors respond to them shape how e-mobility is implemented. While the policy framework provides useful tools and incentives, real-world application is shaped by how actors interpret their roles, the challenges they face, and the resources they have. The next section examines how public and professional narratives influence these interpretations and affect the ability of actors to support change.

4.3 Narratives and Situated Agency

In this section the results of our study on narratives and situated agency are being described and reflected. Narratives were drawn from the expert interviews as described in the previous chapter and reflected personal experiences, the meta-narratives inflected are by definition are on a higher level. They are de-situated, more abstract and general in terms of broader systemic dynamics. (Upham & Gathen, 2021). The interview data reveal how actors narrate their roles and responsibilities in the regional e-mobility transition, demonstrating how individual experiences are shaped by—and can recursively influence—structural conditions within the socio-technical system.

A first set of narratives frames the EV transition as system-challenging and misaligned with current infrastructures and expectations. A rural car dealer, for example, questions the logic of rapid electrification given the current energy system:

> *"Electric makes no sense as long as we produce this with coal… it just doesn't fit into the world as it is."*
> (Car dealership owner)

Such narratives emphasize the persistence of incumbent structures and problematize assumptions of linear adoption trajectories (*meta-narrative 1*).. A manager of the municipal depot recounted that personal initiative can make a considerable difference, and explained how in addition early national funding programmes, helped scale up EV adoption in his municipal fleet. He grounds his argumentation in a combination of organizational planning, proactive mindset and commitment to transformation. Such stories remind us that even within structured systems, individuals often find ways to influence trajectories:

> *"With the help of funding programmes, we started to procure the first vehicles… and they established themselves very quickly."*
> (Depot manager)

These narratives reflect individual initiative operating within—and making use of—favourable structural conditions (*meta-narrative 6*). Perspectives from municipal actors illustrate governance tensions, where sustainability ambitions meet spatial and institutional constraints. A municipal officer for mobility demonstrates how different sustainability goals intersect: promoting EVs and cycling, while also negotiating the constraints of urban space and institutional responsibilities:

> *"The electric car needs a road just like the internal combustion engine… it consumes a lot of space which other users lack."*
> (Mobility officer)

His colleague likewise reflects how current thinking around e-mobility often falls short of its transformative potential. He advocates for a broader consideration of the mobility system, challenging the idea that technological substitution alone is sufficient. Here, actors articulate agency not as free choice but as role-embedded action, conditioned by planning mandates and system logics. Finally, user narratives center everyday frictions and symbolic contestations surrounding new infrastructures. They show how everyday experiences can generate frustration and conflict, whether it's inaccessible charging stations or territorial disputes over parking.

The social dynamics surrounding infrastructure reveal deeper uncertainties in the transition, and interactions reflect not just technical gaps, but also symbolic tensions—who belongs, who adapts, and who benefits:

> *" […] conventional cars sometimes occupy these spaces… they don't need the electricity… that can create conflict."*
> (EV user)

The narratives reveal how socio-technical change interacts with status, identity, and perceived fairness—dimensions not easily addressed through formal governance alone. As demonstrated through the analysis, narratives are more than descriptive—they are constitutive. They actively shape how people engage with transition processes, what they consider feasible or fair, and how they interpret system change.
Taken together, the narrative analysis shows that:

- ⇒ agency is relational, contingent on structural positioning and resource access
- ⇒ institutional logics strongly mediate what actors view as feasible or legitimate
- ⇒ emotional and symbolic meanings shape alignment with transition goals
- ⇒ narrative alignment—or misalignment—signals potential sites of resistance or leverage

By making visible these structure–agency interactions, the narratives offer insights to both diagnostics and strategic guidance, they help to identify where the EV transition in Lower Saxony gains momentum, encounters friction, or becomes contested in practice. The actor perceptions and their analysis thus bear opportunities for alignment between policy, practice, and lived experience.

In addition to the narratives, across the sample, six shared meta-narratives were also inferred, representing recurrent patterns across individual accounts rather than isolated viewpoints. Table III summarizes these meta-narratives and their links to structural dynamics, drawing on strong structuration concepts of conjunctural knowledge, position-practices, internal and external structures, and access to rules and resources (Giddens, 2004; Stones, 2017). These range from the view of EVs as disruptive and system-challenging, to infrastructural and technical frustrations, to the importance of public understanding and individual initiative. While each story originates from a specific individual, the shared patterns across them point to wider social and institutional dynamics. In that sense, the meta- narratives are not isolated—they reflect broader currents in the socio-technical system. Narratives mediate between inner and outer worlds, connecting belief systems, organizational norms, and institutional frameworks.

Table III: Meta-Narratives and their structural dimensions (Upham & Gathen, 2021)

Meta (implicit) narratives	Example individual stakeholder quotation	Structures referred to in the quotation	Implications regarding rules and resources
1. EVs as more system-challenging than is commonly realised	*The typical view is that you simply exchange vehicles and then think that this should work. And when it then becomes apparent that it is not going to work, because the… the fact is that the different requirements or organizational modes of mobility are not transferable one-to-one with electric vehicles.* (B1, l. 93 - 105)	External and internal structures of actors through the regime: successfully managed change will require intervention at multiple, reinforcing points and this is not yet happening to the required extent.	Wide-ranging: changes are required across the existing transportation regime in terms of thinking, skills, infrastructure etc (both internal and external to actors).
2. EV charging is beset with technical and administrative challenges	*So, the problem is that the city cannot provide the power that should arrive at the charging station and the networks, the electricity networks, are not designed to feed so much into the cars.* E2. L. 86 – 103)	External and internal structures relating to charging infrastructure deployment by municipal and private administrative, planning and executive organisations.	Increased allocation of public and private resources to planning and physical deployment; concomitant changes in the political willingness to deploy resources thus.
3. Publics as under-educated about EVs	*I'd say we still do a lot of educational work here. Once you have talked to people sensibly and explained the principle, then people realize, okay, it's not all that bad.* (G1, l. 127 – 134)	Internal structures of consumers/users: their beliefs and preferences regarding charge points and range.	Direct resources to changing the internal rules, views and preferences of users.
4. EVs are technologically superior to internal combustion vehicles – but are let down by charging infrastructure	*And there are so many charging stations, which I think are all bullshit. So what's the point of going to an eleven kilowatt AC charging station where the charging time is eight hours?* (D2, l. 96 - 98).	External: the material infrastructure of charging points.	Direct resources to developing the material infrastructure of charging points; concomitant changes in the political willingness to deploy resources thus.
5. EVs need to work with the existing regime and its norms	*So sustainability is the core argument, but if you really want to make a difference - I often have the experience with customers that yes, electric mobility, what is it anyway, nobody needs it. And then I said, I have a bomb electric car, let's go for a drive and afterwards everyone has the famous Tesla grin on their face."* (G1, l. 98- 105)	Prioritise changes to external, material structures, not internal structures.	Do not seek to significantly change regime architecture, nor the rules underpinning it.
6. Change is possible through individual initiative	*"Because in 2015, when I came here, the discussion about e-mobility was not quite as massive…That politics has also changed a lot…funding programmes have also been launched. And so we were able to do so relatively quickly, or I then tried to take up the issue relatively quickly."*	External and internal structures of regime actors can be changed – in this case through the individual initiative of actors with positional authority	Actors with positional authority could do more to mobilise the resources to which they have access.

Taken together, the findings from conceptual framings (4.1), governance and institutional arrangements (4.2), and situated narratives of regional actors (4.3) provide access to a type of knowledge that is embedded, relational, and inherently social. They show how structure–agency dynamics are interpreted and enacted in everyday transition contexts and reveal how actors' lived experiences shape expectations, perceived responsibilities, and legitimacy in the e-mobility transition. This suggests that successful change depends not only on policy design and technological development but also on whether strategies resonate with the stories people tell about their roles within evolving socio-technical systems. I consider this, the final component in our examination of the EV system and its conceptual framework (a), the political framework conditions from the perspective of stakeholders (b), and now here meaning, actor roles and their interpretation. The next section synthesizes these perspectives to identify cohesive patterns that show how structure–agency relations influence the development and diffusion of e-mobility in Lower Saxony.

4.4 Synthesis: Main Themes of Agency-Structure Interaction

Synthesising the findings across the three studies provides insight into how structure–agency interactions shape the development of e-mobility in Lower Saxony. While the studies address different analytical dimensions—conceptual framings (Study C – article three), institutional and governance arrangements (Study B – article two), and situated experiences and narratives (Study A – article one)—their integration reveals patterns in how actors interpret and navigate transition dynamics in a regional context.

1) Fragmented governance structures constrain coordination and implementation

Study B shows that German e-mobility policy has evolved into a comprehensive but fragmented instrument mix. Local actors frequently face unclear responsibilities and coordination gaps, particularly regarding charging infrastructure and spatial planning. Interviews indicate that the success of national instruments depends strongly on local capacity and role clarity. This fragmentation limits opportunities for collective problem-solving and produces uneven implementation trajectories across municipalities.

2) Agency is interpreted differently depending on system position and organizational mandate

Insights from Study C highlight that scholars conceptualize agency in sustainability change along different lines: as individual initiative, as collective mobilization, or as institutional capacity. Study A confirms this diversity empirically: public officials emphasize systemic alignment, engineers focus on technical adaptation, and small businesses are concerned with economic viability. The link between perceived responsibility and perceived capacity becomes visible here: where actors see little room for influence, they tend to prioritize operational concerns over systemic change.

3) System position shapes problem framing, expectations, and perceived fairness

Across Studies A and B, actors describe the transition from their local realities, which differ between metropolitan and rural settings, central and peripheral locations, and incumbent versus newcomer roles. Spatial context is particularly relevant, influencing both access to charging infrastructure and perceptions of urgency. This results in parallel transition narratives within the same region—from proactive scaling to cautious skepticism—indicating that socio-technical change is experienced unevenly.

4) Narratives express strategic orientations and areas of tension in the transition

Study A shows that actors construct shared storylines that reflect friction points such as infrastructural uncertainty, market viability, or conflicting mobility priorities. These meta-narratives reveal where actors see risks and opportunities, and how they legitimize their stance within the transition. Rather than reflecting individual opinion alone, narratives signal emerging alignments and conflicts that may affect implementation processes.

5) Participatory and adaptive governance is viewed as a prerequisite for transition progress

Study C underscores a broad academic consensus that sustainability change requires inclusive, deliberative, and reflexive governance structures. While this view is less explicit in the regional material (Studies A and B), actors frequently call for improved communication, co-ordination, and involvement in decision-making to reduce uncertainties and strengthen commitment. This suggests that participatory governance is not yet a core practice in the regional EV context, but clearly an area of need.

Table IV illustrates my understanding of the key themes emerging from the synthesis of all three studies, in the context of structure-agency interaction.

Table IV: Synthesis - main themes of agency-structure interaction across the three studies with published articles

Agency-Structure Interaction	**Evidence from**	**Empirical interpretation**
Institutional and governance fragmentation	Study B · Study A · Study C	Actors perceive confusing responsibilities and mismatched priorities across governance levels and organizations, creating coordination challenges.
Varied perceptions of agency and responsibility	Study A · Study C	Actors differ in who they believe should take the lead in driving transition — state actors, industries, or individuals/communities/NGOs.
Different system positions → different problem framings	Study A · Study B	Perceptions and priorities are structured by organizational mandates and position in the system, leading to partial system views. Rural-urban context influences perceptions of EV relevance, feasibility and access to charging
Narratives as expressions of strategic themes and friction	Study A · conceptually strengthened by Study C	Narratives capture contested expectations, perceived system dynamics, and guidance actors use to navigate transition processes.
Participatory and adaptive governance as a normative aspiration	Strong in Study C · partially reflected in Study A/B	Expert discourse emphasizes inclusion and reflexivity, though this is not consistently recognized or practiced by local actors.

Taken together, the findings indicate that regional transition processes unfold through a dynamic interplay of structural arrangements and situated agency, mediated by different interpretive frames and system positions. By linking conceptual, institutional, and experiential perspectives, the synthesis highlights where transition dynamics align—and where frictions persist that may slow further diffusion of electric mobility in Lower Saxony.

5. Discussion

The combined findings of this dissertation advance understanding of how actors interpret and engage with the changing structures of the e-mobility system in Lower Saxony, and how these interactions influence transition dynamics. By bringing together a conceptual analysis of sustainability transitions and transformations (Article 3), policy and governance arrangements (Article 2), and actors' situated narratives and position-practices (Article 1), the research offers an integrated view on structure–agency relations in a regional transition context. Following strong structuration theory (Stones, 2005), the discussion highlights how actors draw upon and shape external structures—policies, infrastructures, institutional norms—through their internal interpretations and practical engagements. Across studies, one consistent observation is that actors interpret the transition from their institutional positions and spatial contexts. As shown, narratives provide insight into how local experiences and expectations are shaped by responsibilities, values, and professional identities. These narratives do not merely reflect personal attitudes but signal frictions and alignments within broader socio-technical developments. Rural and urban contexts, for example, result in different assessments of feasibility: sparse charging infrastructure or unclear technical requirements can translate into scepticism or resistance, whereas embeddedness in planning administrations may support more systemic perspectives on change. These findings reinforce the importance of attending to spatial difference in transition governance, as it influences both access to technology and how the transition is socially imagined.

Insights from study B (Article 2) show that actors operate within a policy framework that has become structured over time, with different instruments at different levels. The development from early experimentation to broader diffusion puts pressure on the requirements for coordination across actor groups and governance levels. This development aligns with established research in policy transition studies: as a technology moves from niche to diffusion, the policy mix must evolve from market formation to scaling, including regulatory clarity, grid integration, and planning instruments suited for heterogeneous local conditions (Obrecht et al., 2018; Skjølsvold & Ryghaug, 2020). The capacity requirements associated with this expansion are therefore not deficits alone but inherent to system scaling. Actors in Lower Saxony recognize progress, yet also note bottlenecks emerging when institutional, cultural-cognitive, or technological capacities do not expand at the same pace—a point that remains central to understanding uneven transition progress (Hyvönen et al., 2023; Sihvonen et al., 2025)

Article three complements these insights by highlighting how governance and agency are understood within academic debates on sustainability change. Experts emphasize the complexity of steering systems characterized by competing values, uncertain pathways, and multiple forms of agency. Their perspectives show that transitions require continuous realignment between systemic ambitions and locally embedded practices. Importantly, governance is viewed as both structuring and enabling: policies set conditions for action, yet change is driven by how actors mobilize rules and resources in situated contexts.

Interviews with regional practitioners illustrate this dynamic: individual initiative can leverage policy incentives and organizational capabilities to drive adoption, while limited interpretive resources or unclear role expectations can constrain action. These findings reaffirm a central message in strong structuration approaches: structure and agency are analytically distinct but mutually constitutive in practice.

All three studies show how sustainability transitions unfold across analytical levels and how their progress depends on maintaining coherence between them. Policies alone do not generate change unless they resonate with narratives and practical contexts; conversely, engaged actors require institutional support and recognition to translate their efforts into systemic outcomes. The conceptual distinctions between "transition" and "transformation" do not prescribe change but frame how it is understood and discussed — highlighting different assumptions about agency, power, institutional roles, and the trajectories of societal change. Recognizing these distinctions helps illuminate why actors talk about sustainability change in divergent ways and why they sometimes pursue different strategic orientations.

The dissertation also exposes areas for future exploration. The empirical focus is placed on a single region with a modest sample size, limiting the generalizability of insights. Moreover, the research does not systematically address industrial restructuring, battery supply chains, or global equity concerns—issues increasingly recognized as integral to mobility transformations. Comparative research across regions and countries could examine how structure–agency relations differ under varying economic, infrastructural, and institutional configurations, and how governance can better anticipate evolving capacity needs during large-scale diffusion. Future studies could provide valuable insights here.

Overall, the discussion emphasizes that e-mobility is more than a technological substitution project. It is a negotiated change process that intertwines infrastructures, policies, identities, and everyday practices. Aligning systemic ambitions with the lived realities of diverse actors—urban and rural, professional and private—remains critical for both legitimacy and effectiveness. By integrating conceptual insights, analysis, and the consideration of situated actor experience, this dissertation strengthens the argument that sustainability transitions benefit from approaches attentive to social meaning, positionality, and adaptive governance. In this way, the work contributes to broader scholarship seeking to understand and support transitions that are technically feasible, institutionally grounded, and socially embedded.

6. Conclusion

This cumulative dissertation set out to examine how sustainability transitions unfold when viewed through multiple analytical lenses: conceptual framings of governance and agency (Study C), institutional and policy environments (Study B), and lived, narrative experience of actors embedded in an evolving socio-technical system (Study A). Using the case of e-mobility in Lower Saxony, the research assembled a multi-perspective account of how structure and agency interact in shaping sustainability change. The combined insights illustrate how transitions are produced not by single drivers, but by the negotiated alignment of ideas, institutions, and practices across scales. Across the three studies, sustainability change is viewed as a process shaped by the interaction between actors and structures. The conceptual study highlights that scholarly perspectives on transitions and transformations are diverse, particularly regarding the nature of agency, the role of governance, and the influence of power relations. These distinctions provide a theoretical backdrop for interpreting the empirical findings of the case study and emphasize that the meaning of "transition" is itself shaped by disciplinary assumptions and normative orientations.

The policy analysis shows how national strategies, regulatory frameworks, and local responsibilities form a multi-level governance landscape that both enables and constrains agency. The evolution of Germany's policy mix—especially the shift from niche support to large-scale diffusion—illustrates how adaptive institutional environments are required as technologies mature. For actors in Lower Saxony, institutional clarity, coordination, and sufficient capacities remain crucial for translating policy ambition into locally workable solutions. Narrative analysis complements these insights by revealing how actors make sense of infrastructural constraints, conflicting responsibilities, and broader societal expectations. These situated accounts demonstrate that transitions are experienced unevenly, shaped by spatial differences and professional roles. They show how meaning-making, expectations, and practical concerns inform what actors view as feasible, legitimate, or desirable—highlighting a psychological and interpretive dimension often underrepresented in policy debates, especially with regard to charging infrastructure.

Taken together, the studies illustrate how structure–agency relations manifest in sustainability transitions and how coherence across conceptual, institutional, and experiential levels is relevant for progress. They also show the value of applying strong structuration as an interpretive lens, allowing examination of how actors draw on internal dispositions and external structures when navigating system change. While the regional focus limits generalizability, the sequential combination of empirical and conceptual study adds interpretive depth, helping to situate the case findings within wider discussions of agency, governance, and sustainability change processes. Overall, the case of e-mobility in Lower Saxony contributes broader lessons for sustainability transitions. Effective pathways require institutional adaptability, conceptual clarity, and sensitivity to lived experience. Policies must be designed in ways that resonate with everyday practices and local constraints, while narratives and actor interpretations must be acknowledged as part of the transition process rather than peripheral to it. By bringing these dimensions together, this dissertation contributes to understanding how sustainability transitions can be steered in ways that remain contextually grounded, socially embedded, and institutionally robust.

7. Literature

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8. Annex

8.1 Actors in transitions: narratives of roles and change in the German e-mobility transition (Article 1)

8.2 System capacities and implementation challenges in Germany's electric vehicle policy mix: an actor-centered review of the policy mix (Article 2)

8.3 Between Transition and Transformation: Understanding Sustainability Change through Governance, Agency, and Resilience (Article 3)

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Actors in transitions: narratives of roles and change in the German e-mobility transition

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ABSTRACT

We apply an approach that theoretically connects processes at different scales within a socio-technical sustainability transitions frame, focusing on individual actors. Drawing on interviews with actors involved in the electric mobility transition in Lower Saxony, Germany, we analyse actors' narratives as revelatory of situated or 'conjunctural' knowledge, as viewed from a strong structuration perspective of sociotechnical change. The purpose is to shed a particular type of light on structure-agency processes. Strong structuration is an extended version of Giddens' social theory that takes account of actors' subjective experience of their situation, viewing this as both shaped by - and shaping of - structure, in the sense of rules that are internal and external to individuals. Here we show how actors' narratives of their experiences and positions in the sociotechnical system reveal themes relevant to the on-going structuration electric vehicles in the case study region of Lower Saxony, Germany. We identify general 'meta-narratives' that span more than one individual, as well as personal narratives that are specific to individuals. In addition, the analytic value of narratives in transition literature is discussed.

1. Introduction

Socio-technical perspectives acknowledge that actors' attitudes, values, beliefs and opinions shape the acceptance and speed of diffusion of technologies (Frank W. Geels and Schot 2007). Different actors with differing interests will be more or less involved in the shaping development of a sociotechnical system because they have differing power or capacity to act (Avelino and Wittmayer 2016). Identifying and characterising that power can be undertaken through structural analysis, i.e. examining actors' positions in structures, the rules that shape their behaviour and the resources available to them. Alternatively, or as well, we can probe and infer from the subjective experience of actors within a developing system, to better understand what drives them.

Arguably, the sociotechnical transitions literature has favoured structural, functional and systems-level approaches to agency, paying less attention to subjective experience. The literature has tended to favour perspectives that privilege (and arguably deploy to good effect) macro-level perspectives such as neo-institutionalism (Fuenfschilling and Truffer 2016). This preference for macro level perspectives that recognises individual actors, but that is more interested in the consequences of their actions than in their experience, or how that experience relates to their actions, reflects one half of a division present through the social sciences: that between individualist and collectivist approaches to agency (Barney and Felin 2013). We take the view that there is value for understanding

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sociotechnical transitions through making connections between 'inner' and 'outer' perspectives more systematically and structurally (van den Bergh 2021). This is the explicit purpose of strong structuration theory, which we deploy below, something recognised quite early in transitions thinking (Grin, Rotmans, and Schot 2010) but rather little deployed (Manders et al., 2020; Upham et al., 2018b).

To the extent that it is individual actors who reproduce and change structures, understanding the connections between the inner and outer worlds of those actors is critical if we are to understand more fully how and why change happens. Narratives, both individual and shared, are one way of gaining insight into actors' experience and sense-making of the world around them and – in this case – the sociotechnical systems of which they are a part. Narratives as ways of making sense of the world arguably shape behaviour (Somers 1994); hence understanding narratives helps to understand subjective and/or shared aspects of motivation and hence individual dimensions of causality.

Here we take as our empirical focus stakeholder narratives relating to the socio-technical system of electric vehicles (EVs)[1] in the German state of Lower Saxony (Niedersachsen), Germany's second largest federal state and home to Volkswagen, Europe's largest car manufacturer. In September 2021, 33,655 battery electric vehicles were registered in Germany, increasing their share (17.1%) by nearly 60 percent relative to September 2020 (KBA, 2021). We apply a narrative approach to provide qualitative insights into the situated experience of relevant, exemplar actors. To this end, the paper draws on interviews with expert stakeholders, focusing on narratives that connect the detail of individual experience to developing sociotechnical processes. We theorise the latter within a strong structuration frame (Stones 2005).

The materialities that we are dealing with here are those of subjective experience, inferred from individual narratives. While we recognise that individual actor-level processes are not familiar territory for many transitions theorists, we would nonetheless maintain that actors' experiences frequently mediate other sociotechnical processes. The importance of inner and outer worlds in the causality of system change will vary by context and in terms of the situated power of individuals. The connections between inner and outer – agents' experience and the persistence or change of structures – is also challenging to research. Yet there are concepts and approaches to study available for this purpose (Upham, Bögel, and Dütschke 2020). Narrative adds to those options and invites new research questions. Here, those questions are corollaries of the proposition that individual narratives can help to provide insight into some of the actor-level reasons for why a particular transition is progressing as it is. In terms of our empirical case, market formation for EVs has been challenging internationally. This is specifically with respect to cognitive legitimacy in the broad sense, including attitudinal, which is critical for market formation in transitions contexts (Boon, Edler, and Robinson 2020). Here we probe this through the narratives of an illustrative range of actors in the EV system in a regional locality.

EV diffusion and its challenges are the subject of a sizeable and longstanding literature (Dijk, Orsato, and Kemp 2013), not all of it positive about EVs (Augenstein 2014). As (Augenstein et al. 2020) observe, upscaling per se can lead to reinforcement of unsustainable systems by failing to address their underlying structures, including the path dependencies of private, motorised transport (Geels 2012; Upham, Kivimaa, and Virkamäki 2013). Moreover, EVs need to be charged with renewable power for climate benefit, and materials sourcing needs to respond to the way in which rare metals mining is associated with poor working conditions and indeed slavery in some locations (Sovacool 2021). These problems notwithstanding, the German Climate Action Programme 2030 aims to have up to 10 million EVs and 1 million charging stations on German roads by 2030. This is operationalised in terms of incentives for EV purchase and EV charging, bolstered by elements in a post-covid-19 stimulus package (Die Bundesregierung 2021).

Progress is now rapid but from a low base: averaged across the EU-27, Iceland, Norway and the United Kingdom, in 2019, electric car registrations were close to 550 000 units, up from 300 000 units in 2018. This represents an increase from 2 to 3.5 % of total car registrations (EEA 2021). The uptake of electric vans also increased, from 0.8 % of total registrations in 2018 to 1.3 % in 2019. Battery electric vehicles, rather than plug-in hybrid, accounted for the majority of electric vehicle registrations in 2019 for cars and vans (EEA 2021). For Germany specifically, for the period 01/20-01/21, the share of electric cars (BEV) rose from 0.3% to 0.9 percent%, while the share of plug-in hybrid vehicles grew from 0.2% to 0.5%, giving a total market share of 1.4% (Kraftfahrt-Bundesamt 2021). Norwegian experience, where EV market share of *new* passenger cars is high[2] as a response to strong subsidies underpinned by a renewable power surplus, is that EVs have tended to add an additional car to sub/urban, wealthier households, rather than simply substituting for conventionally fuelled cars (Fevang et al. 2021). In short, while the EV transition is well under way, it has also only just begun.

There is a large amount of prior work on the 'social barriers' to EV adoption: reviewing and inspecting this for its correspondence to the Norwegian context, (Lin and Sovacool 2020) (Tables 6 and 7) list these as including: limited policy incentives, policy uncertainty, the price of EVs, lack of consumer knowledge, lack of charging stations, inadequate roads, limited EV model options, prevailing automobility culture, range anxiety, battery performance and durability. Several of these are reiterated here, but the study contributes beyond this. First, where pre-existing knowledge of the foregoing exists, detail is provided on the underlying situated experience and we illustrate how this information is useful. Second, issues are not framed as barriers, obstacles or indeed reified issues, but are viewed as part of the narratives that reflect participant actors' understandings of the situation: their conjunctural knowledge. How we understand something matters for the inferences that we make. We explain and illustrate why this matters. Thirdly, after an overview of

[1] Following the EEA definition, we take EVs to include battery electric vehicles - BEVs - and plug-in hybrid electric vehicles – PHEV: "BEVs are powered solely by an electric motor, using electricity stored in an on-board battery. The battery must be charged at a charging point connected to the local electricity grid. PHEVs are powered by an electric motor and an internal combustion engine designed to work either together or separately. The on-board battery can be charged from the grid and the combustion engine can support the electric motor when higher operating power is required or when battery charge is low." (EEA 2021).

[2] In 2020 52.2% of new passenger cars registered in Norway were battery electric vehicles (BEV), and another 20.4% were PHEVs (Fevang et al. 2021).

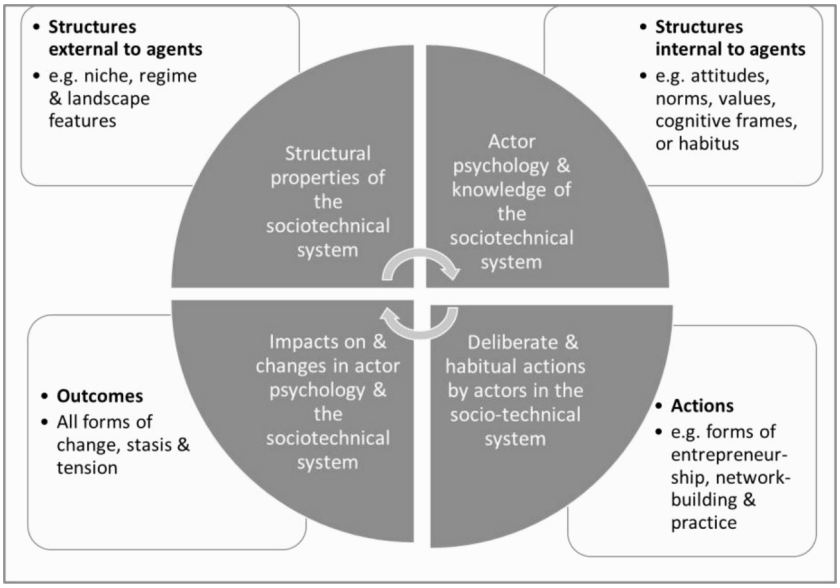

Fig. 1. Applying Stones' (2005) strong structuration to sociotechnical system analysis.
Note: reproduced with permission from (Upham et al. 2018).

the main narratives, we focus in on selected actors, of types who to our knowledge have not been given close attention before.

In terms of the structure of the paper, we first set out the theoretical approach, which consists of identifying core narrative themes in stakeholder perspectives within a strong structuration frame, as a means of connecting micro and macro levels of process in sociotechnical transitions. The analytic method is then explained, followed by results and interpretative conclusions. The novelty of the approach lies in more extensively justifying, articulating and illustrating an approach first set out by (Hermwille 2016a), who also viewed narrative as useful within a strong structuration perspective, specifically for inference of meanings relevant to sociotechnical change. While the value of strong structuration as an analytic frame for connecting process levels in sociotechnical change has been explored by several authors (Hermwille 2016a; Upham et al., 2018a; Upham, Bögel, and Dütschke 2020; Manders et al., 2020), to our knowledge this has not been done before at this level of individual detail.

2. Theoretical approach

Within the sociotechnical transitions literature, theoretical explanation of change often mobilises the idea of interactions between niche, regime and landscape levels, epitomised in the multilevel perspective (MLP) framework (Frank W. Geels 2002). In terms of social theory, the MLP conceives of the niche, regime and landscape levels as reflecting increasing degrees of structuration, in Giddens' sense of rule-following (Giddens, 1984). Such rules and their application are defined broadly and include all forms of regularised behaviour, including their cognitive correlates. Hence niche-level technologies and associated norms and ideas are by definition used and subscribed to by fewer people than regime level technologies. The 'landscape', by contrast, is conceived of as an exogeneous place of widely-accepted, almost taken for granted and slow changing values, ideas and trends.

'Strong structuration' (SST) theory has long been referred to as a candidate for operationalising the structuration theme of the MLP (Grin, Rotmans, and Schot 2010). SST seeks to respond to critical realist critiques of Giddens version of structuration (Stones 2005), separating structures as internal or external to agents and hence affording more emphasis to agents' perceptions, particularly as influenced by their social position. In this description we draw on the account of (Stones 2005) given by (Upham, Bögel, and Johansen 2019), with Fig. 1 (Upham et al. 2018) transposing this for sociotechnical system analysis:

External structures are understood as separate from the agent and set boundary conditions; in a socio-technical context they include laws, regulations, formal and informal institutions, policies and organisations.

Internal structures are divided into two classes: those that are *general-dispositional* (including habitus, norms, values[3], attitudes, worldview etc, depending on one's analytic frame) and those that are *conjunctural*, relating to agents' knowledge and understanding of their immediate and wider context. While these two classes are analytically distinct, in practice they may overlap. Social psychological theory and empirics would likely, particularly inform this element.

Actions (active agency) relate to processes of thoughtful, sometimes strategic action: in this context, active agency would include all forms of entrepreneurship, lobbying, coalition-building, resistance and 'mindful deviation' (Garud and Karnøe, 2001) in general.

[3] In terms of (Geels 2002) MLP, dominant values, in so far as they are slow-changing, can be conceptually located at the 'landscape' level; however their expression is through individuals and their organising practices at the regime level.

Outcomes are any consequence of the foregoing for the agents and their structural context, here including all forms of socio-technical pathway and the tensions that these comprise.

Here we are interested in what ways the conceptions (of socio-technological transition) of actors in the field of electric mobility in Lower Saxony are aligned towards an increasing electrification of the automotive sector. As said, actor narratives are assumed to provide a way of understanding of these conceptions from actors' perspectives. We assume that the narratives of actors within the field of electric mobility in Lower Saxony not only reveal issues relating to the diffusion of electric vehicles within the region, but that, at a more general level, the degree of alignment between the narratives and the regime is itself revealing of the progress of the transition.

Although narrative analysis approaches vary, commonly, narratives are viewed as perceptual frames that can be inferred from the story-like accounts that people tell. In this context, a story-like account means one with information about who did what, when – i.e. an account with a time component, actors who have particular attributes, and causality in the sense of a particular view of cause and consequence. Moreover, in narrative analysis, these accounts may be held to be "*instantiations, particular exemplars of the grand conception*" Feldman et al., (2004) (p. 149). We term these broader ideas 'meta-narratives' that subsume specific accounts that point in a similar direction.

Narratives reflect and are a response to questions of meaning: the larger sense that actors make or infer from their observation or experience of multiple, discrete, individual events. This in turn has a bearing on how actors perceive their own agency and that of others (bearing in mind, also, that those actors may not be animate – an EV can be considered an actor with attributes, as much as may a planning authority that installs (doesn't install) a charging station, or an EV driver. Hence "*Narratives do not simply express independent, individual reality. Rather they help to construct the reality within relationships between the narrator and their external world.*" (Frost, 2011, p. 94). In general, narrative analysis assumes that we can learn about the social (here sociotechnical) conditions of the speaker, and/or how the speaker views the socio(technical) conditions of others. As such, the approach fits well theoretically with the strong structuration concept of conjunctural knowledge as being knowledge held by an actor, influenced by their position in a social (or sociotechnical) system. This knowledge also includes representations of phenomena, here the EV system and components, including users/consumers. These representations tell us about how actors view the world, from which we can also derive insights that go beyond simple description, particularly in terms of perceived causalities – reasons for a situation. Others have used narrative analysis to examine transitions including EVs: (Kallenbach 2020), for example, examines narratives of urban mobility in Germany in media articles. Here we focus on individual narratives, though we also draw inferences for broader narratives.

Treating narrative as data follows previous advocation of narrative as a means of understanding cognitive, ideational aspects of sociotechnical structuration processes (Hermwille 2016a). Such an approach is intended to help understand the manifold relations between actor, agency and materialized concepts for transitions, whereby narrative acts as an intermediary between individuals' internal and external structures. In terms of strong structuration, narratives serve two functions. Firstly, they represent vehicles for signification. Secondly, they are inter-mediators between the individual's internal structures and the social structures around them. In addition, narratives have a temporality, meaning they include a refined perspective on future developments. Differing from the analysis of narratives in linguistic and literary theory, sociological use of narratives tends to analyse aspects of individual life-stories, as well as analytic and meta-narratives (Arnold and Arnold 2018), as referred to above. Understanding the structure of narrative helps to understand how people give shape to events, how they make a point, their reactions to events and how they portray them (Gibbs 2007).

3. Methodology

The research design is an empirical case study intended to illustrate the value of narrative analysis as conjunctural (subjective, situated) knowledge concerning a sociotechnical system. The case study location is Lower Saxony in Germany, a state that is second among the German federal states in terms of size. Data collection was in Spring of 2020. Although the narratives examined inevitably come from a particular geographical location, the issues raised are more generally relevant to the EV transition and the theoretical approach is intended to be applicable. To provide more detail on the regional sector: Lower Saxony hosts several demonstrations for e-mobility and the headquarters of Volkswagen in Wolfsburg near Hanover. Management of the electrical grid in Lower Saxony is shared mainly between AVACON and EWE and both have established sub-branches focusing on green energy and e-mobility, with teams responsible for establishing and maintaining charging points. According to the federal agency for the national power grid, as of July 2020 there were 1262 charging points in Lower Saxony spread over 47.600 km^2, most concentrated in the metropolitan region, which includes Hannover, Braunschweig and Göttingen (Bundesamt für Kartographie und Geodäsie 2020).

Regarding data collection, semi-structured interviews were used, enabling a set of standard inquiries to be made, while allowing the conversation to build and develop so as to explore new areas (Sovacool et al., 2017). Semi-structured interviews are commonly used when the goal of the research is to understand meanings, perceptions, beliefs and values in individuals' own terms (Drumwright and Murphy 2013). The interviews here were conducted with actors from fields relevant to the EV sociotechnical system, categorised in terms of seven groups, with two interviewees in six groups and three interviewees in a seventh. The questions <Table A1 in Appendix A> were designed to elicit narrative accounts of each actor's experience within the electric vehicle system. The respondents were purposefully rather than randomly selected and involved two interviewees per subfield. Snowballing was used as part of the process for identifying potential participants (Taherdoost 2018).

Group A comprised interviewees from a car retail company and a company specializing in sewerage and water management for the public roads that had adopted EV technology at an early stage of development. The second interviewee group, B, were public administration officials involved in relevant policy development and charging station network development. More specifically, the interviewees in this group were a local climate protection officer and mobility officer. Lobby associations working in the region towards electrification of the mobility sectors were included to provide views of policy struggles and infrastructure claims (group C).

Table 1
Summary of meta-narratives and related structures, rules and resources.

Meta (implicit) narratives	Example individual stakeholder quotation	Structures referred to in the quotation	Implications regarding rules and resources
1. EVs as more system-challenging than is commonly realised	*The typical view is that you simply exchange vehicles and then think that this should work. And when it then becomes apparent that it is not going to work, because the… the fact is that the different requirements or organizational modes of mobility are not transferable one-to-one with electric vehicles.* (B1, l. 93 - 105)	External and internal structures of actors through the regime: successfully managed change will require intervention at multiple, reinforcing points and this is not yet happening to the required extent.	Wide-ranging: changes are required across the existing transportation regime in terms of thinking, skills, infrastructure etc (both internal and external to actors).
2. EV charging is beset with technical and administrative challenges	*So, the problem is that the city cannot provide the power that should arrive at the charging station and the networks, the electricity networks, are not designed to feed so much into the cars.* E2. L. 86 – 103)	External and internal structures relating to charging infrastructure deployment by municipal and private administrative, planning and executive organisations.	Increased allocation of public and private resources to planning and physical deployment; concomitant changes in the political willingness to deploy resources thus.
3. Publics as under-educated about EVs	*I'd say we still do a lot of educational work here. Once you have talked to people sensibly and explained the principle, then people realize, okay, it's not all that bad.* (G1, l. 127 – 134)	Internal structures of consumers/users: their beliefs and preferences regarding charge points and range.	Direct resources to changing the internal rules, views and preferences of users.
4. EVs are technologically superior to internal combustion vehicles – but are let down by charging infrastructure	*And there are so many charging stations, which I think are all bullshit. So what's the point of going to an eleven kilowatt AC charging station where the charging time is eight hours?* (D2, l. 96 - 98).	External: the material infrastructure of charging points.	Direct resources to developing the material infrastructure of charging points; concomitant changes in the political willingness to deploy resources thus.
5. EVs need to work with the existing regime and its norms	*So sustainability is the core argument, but if you really want to make a difference - I often have the experience with customers that yes, electric mobility, what is it anyway, nobody needs it. And then I said, I have a bomb electric car, let's go for a drive and afterwards everyone has the famous Tesla grin on their face."* (G1, l. 98- 105)	Prioritise changes to external, material structures, not internal structures.	Do not seek to significantly change regime architecture, nor the rules underpinning it.
6. Change is possible through individual initiative	*"Because in 2015, when I came here, the discussion about e-mobility was not quite as massive…That politics has also changed a lot…funding programmes have also been launched. And so we were able to do so relatively quickly, or I then tried to take up the issue relatively quickly."*	External and internal structures of regime actors can be changed – in this case through the individual initiative of actors with positional authority	Actors with positional authority could do more to mobilise the resources to which they have access.

Public and private scientists knowledgeable about the regional status quo vis a vis EVs were interviewed to shed light on technological issues, particularly from a local perspective (group D). Mechanical workshops and engineering spaces are considered equally important because they provide in-depth knowledge of technical details and problems (group E). EV car owners accounted for views on user practices (group F). Interviews at an energy supply company and the federal agency for the national grid completed the sample (group G). Three interview-partners overlapped categories in the process, but were assigned subsequently. All participants received a project information letter that informed them about procedures as well as aims and gave their written consent to the interview and data processing.

Fifteen interviewees were male and one was female, reflecting the employment pattern of the German EV system; most of the respondents held a management position as a full-time job in a public or private institution connected to e-mobility. Most were permanent residents in Lower Saxony. Regarding Table A1, the questions were intended to provide an understanding of actors' individual views of EV niche, regime and landscape issues, particularly in terms of their understandings of 'rules' and 'resources', which are conceptual features of Giddens' (Giddens, 1984) and hence Stones' (Stones 2005) versions of structuration. Lin & Sovacool's (2020) criteria were used to cover common social barriers to EV adoption; local and specific knowledge were sought, following (Bogner, Littig, and Menz 2014). To support the elicitation of narratives, participants were encouraged to provide answers with as much detail as possible. All interviews were held and recorded online within the months of April and May 2020.

Regarding interview analysis, the transcripts were first inspected for narrative with meaning relevant to the phenomena being studied. Narrative was selected on the basis of text that contained, explicitly or implicitly, emotional, representational or metaphoric content. While there are many approaches to narrative analysis, here we use a categorical approach, in that we had pre-defined themes of interest, the narratives of which are considered in relation to each other, across multiple interviewees (Lieblich, Tuval-Mashiach, and Zilber 1998). The transcripts were thus coded according to categories based on the interview guideline, which in turn was designed to elicit narrative relating to regime features relevant to EVs, including: regulations and policies, road infrastructure and traffic system,

maintenance and distribution network, production system and industry structure, markets and user practice, fuel infrastructure, automobile, culture and symbolic meaning (van Bree, Verbong, and Kramer 2010).

In the a second analytic phase, we inferred themes in and across the narratives, which we term meta-narratives for the way in which they span more than one interviewee, paying particular attention to the ways that electric mobility is framed and positioned from the interviewees' positions in the sociotechnical system and hence in relation to their conjuncturally specific knowledge. Of the latter, the focus is on inferred meaning, including and in particular, ideas of who the actors are, the causality involved, and their use of rules and resources in a broad sense. Selection of narratives for presentation below is based on the strength of the stories qualitatively and quantitatively: when several interviewees share a similar view, we have selected one of the clearer examples of its type. Overall, the coding and selection of narratives reflects the theoretical frame, highlighting agential reproduction of structure mediated by situated knowledge.

4. Results

4.1. Meta-narratives

In Table 1 below, we first provide a summary of the meta-narratives that we judge to be implicit in the main narratives of the EV system actors questioned, defined as above and with commentary on how the actor narratives help to reveal micro-level detail relevant to the macro-level transition to EVs – i.e., the detail of agent-structure relations in this case. The terms used - external and internal structures, rules and resources – are those of strong structuration (Stones 2005) as explained in Section 2. After explaining Table 1, we provide in Section 4.2 some detailed examples of how the individual narratives underpinning the meta-narratives reveal connections between individual, subjective experience and sociotechnical processes. For reasons of brevity we focus on meta-narrative 6, which highlights individual agency. In Table 1, rules and resources are defined by (Stones 2005) in a way that follows but reconceptualises (Giddens 1984), as described above, and which emphasises phenomena relevant to sociotechnical transitions. Hence rules are internal and external structures in mutual interplay in particular contexts, conditioned by individuals 'position practices', i.e. social relationships within a field. Those positions give access to differing extents of internal and external resources of differing types.

While many of the meta-narratives made in Table 1 are familiar, their identification serves several purposes. First, they function as a check on the status of the transition at a given point in time. Finding that problems or features are on-going in 2020 despite substantial policy and commercial support is notable in itself. Second, they are not the narratives of individuals alone, but are shared: they are collective and implicit in multiple interviews. They thus represent the social of sociotechnical. Third, being nonetheless built upon individual narratives, they indirectly connect individual psychology and sociotechnical change. Fourth, the other columns of Table 1, reflecting elements of strong structuration (Stones 2005), theorise how: through addressing structures that are internal and external to individuals, and in particular the rules and resources that are involved. In short, strong structuration coupled to narrative analysis (Hermwille 2016b) provides a means of theoretically characterising multi-level connections in transitions (Paul Upham, Bögel, and Dütschke 2020). Finally, a focus on narrative enables a check on the alignment of the narratives, which we discuss in Section 5.

In the next sections we provide detailed examples of individual narratives, translated from German, selecting stakeholders whose roles in the EV transition have been less commonly documented in the specifically sociotechnical transitions literature. We connect these to the meta-narratives in Table 1, but rather than select for a mapping of each, as said, highlight stories from types of actors whose stories are perhaps less commonly told, if at all. The types of actors chosen are important in the sense that the development of the EV sociotechnical system will be slowed if garage owners, utility managers, climate mitigation officers, city mobility officers and private EV users (amongst others) do not adequately concur on the value of EVs. To reiterate, narratives are understood here as stories in the sense of involving temporally sequenced events, often with implicit or explicit causality and characters active in the stories. The story may also be autobiographical, about speakers themselves.

4.2. Owner of a small car dealership

This owner of a small car dealership, located in a rural area, where public charging points are uncommon, is relatively unsupportive of the EV transition. He is uncomfortable with the expectation that car technology and hence his business should contribute to climate emissions reduction, and he initially found the technical aspects restrictive. We subsume his story into the first inferred meta-narrative, that the EV transition is more system-challenging than is commonly realised.

"… my personal opinion on the electric car is simply that this is the wrong approach, to save the world…. as long as we don't have enough natural energy sources like sun, wind and the like, electric makes no sense. As long as we still produce this with coal and the like, it just doesn't fit into the world as it is.

"Yes, so of course we started with electric cars with the Tesla for example, because it was pretty much a pioneer with a sensible electric car. We got it into the workshop, and, for example, we had to change winter tyres or were allowed to change them. Whatever we were allowed to do. More was not possible at that time, because there are some requirements to be complied with, in this very tense story. Yes, that is why there is again high expectations in terms of expertise in terms of electrical engineering. You have to be careful."

4.3. The vehicle depot manager

The manager of a public waste management vehicle depot describes an entrepreneurial narrative that we subsume into meta-narrative 6, of change being possible through individual initiative. The manager has a background in vehicle construction

engineering and is now a vehicle depot manager for a public utilities company that operates about 200 vehicles. About a quarter of these are now electric. He tells the story of how EV's have a long history in the organisation, but also how he and others have been important in developing this as fully as possible when programmatic incentives became available:

"I am an engineer for vehicle construction. [The organisation] dealt with the [EV] issue at an early stage. When it was still in its infancy and there wasn't much talk about it, my predecessor bought the first two electric vehicles. And that in 2004.… Because in 2015, when I came here, the discussion about e-mobility was not quite as massive.... politics has also changed a lot…. funding programmes have also been launched. And so we were able to do so relatively quickly, or I then tried to take up the issue relatively quickly. And with the help of appropriate funding programmes, we also started to procure the first vehicles.

"Wherever we have looked, it is possible to remodel them so that they can be for our purposes… So that in 2015, 16 we were able to put the first three vehicles into operation. They then, yes, established themselves very quickly.

"So that by the end of the year we will get to an order of magnitude of 20 electric vehicles here in our fleet. This is also equivalent to about 20,25 percent of the fleet…".

"You mean the electricity we use? Yes. This comes 100 percent from the sewage treatment plant. So we are self-sufficient… And we're even feeding into the grid.

"… There are dozens of ideas, which then develop further. If you think about it, what about the employees? How can you possibly have a fleet or pooling so that they can take advantage of this? Or that they are also being led to electromobility? Is it possible to make vehicles available to the public? Not vehicles, but at least the charging stations? Such things….".

4.4. Climate mitigation officer

This public employee is one of several responsible for climate-related planning in his locality. Unlike the above, his narrative is not so much about his individual role, but is more advocacy-oriented. He is conscious of prevailing substitutional narratives of e-mobility and considers them as both under-estimating the challenges (cf meta narrative 1) and the opportunities. Elsewhere in the interview he describes, for example, how one of the regional energy supply companies has had to repeatedly replace parts of it charging stations to comply with regulatory changes:

"What will actually change fundamentally when we introduce electric mobility? And what does this mean for mobility, and how do we rethink mobility in the course of introducing a new technology? And that is actually the perspective I would take and I try to put it into practice again and again. We are now introducing a new drive technology or, more to the point, simply a new drive unit in a vehicle. But that is not what we are seeing at the moment with the introduction of electric mobility. Rather, it is about the three major challenges: digitisation, electrification and networking, with the whole range of new forms of use, new business models, new mobility services and a completely new approach to mobility. And that is of course a completely different challenge … You can't translate the use that was there before with a combustion-oriented vehicle into a one-to-one use and switch to an electric vehicle. Instead, it makes much more sense to take a holistic approach: what do we actually need to change in the organisation of mobility, in the understanding of mobility and in digitalisation, perhaps also of the services that are currently being provided by a vehicle? And then electromobility can really have a resounding impact with its positive effects."

4.5. City mobility officer

The city mobility officer also has a broader view of mobility, as would be consistent with their role, but (cf meta-narrative 6) they also work to implement a pro-cycling agenda in so far as possible. This they cannot always do without also supporting the car: they tell a story of policy-mandated, interconnected futures for EVs and cycles in their locality, where they are involved in the planning of new cycle parking and EV charging at the town's train and bus station:

"What is the difference in urban space, and also in the transport network, between a combustion engine and an electric motor? … The electric car needs a road just like the internal combustion engine, it consumes a lot of space, *a lot of space*, which other road users lack. Where we know, we have somehow planned the car-friendly city for fifty years now, and the exciting part is actually in the bicycle. […]

"Funnily enough, the municipal directive even makes it mandatory that if you want to have a subsidy for bicycle parking garages, you have to align 10% of the parking spaces for [EV] charging capacity… and these are really enormous areas. This is also potentially enormous power consumption... For commuters on a large scale, I don't even know if this is so extremely interesting - or necessarily at all. I think it would just lead to a shift in the loading point. So, of course, I don't charge at home anymore if I can also charge at the [train] station - and that may be free or simply in my parking ticket - depending on how you do it. […]

"The exciting point is when they built cycle storage in 1997 with 1000 parking spaces. Many people said that they are insane. Why should you need so many bicycle parking spaces? Well, ten years later the thing was overcrowded. And we are now planning cycle park No. 3 and actually No. 4 in parallel."

4.6. The EV user

We end with an EV owner's story. The owner is a retired male, appreciates his EV and charges it with PV panels on his roof. His main concerns relate to securing a charging point when away from home, in fact this issue occupies much of the interview. Problems with, and potential user concern about, access to charging for EVs are well known (Lin and Sovacool 2020). The owner's narrative, though (with connections to meta-narratives 1, 2, 4 and 5), conveys their personal experience of this:

"There are three charging stations on my golf course, but they use normal electricity and are not yet in use at the moment. This means that in the summer, when the hotel is in operation, many Scandinavians come. They are much further ahead than we are in terms of electromobility. They drive a Tesla, predominantly Tesla, and they occupy these spaces. But at a normal charging station, I think you need about twelve hours until it's full… that doesn't really help. […]

"And … these three places - which are very far from the main building … are often used by people who have very large cars. They put them there, even though they don't need to. They don't need the electricity. And there is also a potential for conflict. That is, people who bought such an SUV for a packet and with 400 hp - and I know what these things have - they are proud of their car… They get aggressive too. If you then ask them to put their car somewhere else - I want to charge there - then you usually get snotty answers."

5. Discussion

Each of the individual narratives above tells us something about individuals' attitudes, motivation, experience and understanding in relation to the EV transition. We gain a relatively detailed understanding of how and why they act as they do, what aspects of the structures around them are perceived as relevant, as well as enabling inferences to be drawn regarding the progress of the transition and potential interventions. At a general level, the establishment of new regime configuration (in this case involving the adoption of a new, partly substitutional technology) arguably requires - towards a stage of stabilisation - among various forms of alignment, alignment among the narratives of participants.

Hence in the above examples, the EV user not only needs more suitable charging points, but his story indicates that he would benefit from these being legally reserved for EVs. A commercial narrative of EVs as desirable and practicable would then be aligned with his own narrative of his charging experience. The city mobility officer's sceptical EV and pro-cycling narrative may not ever fully align with all aspects of a pro-EV narrative and nor may that of the owner of the small car dealership. Both favour different technologies for different reasons and both may well be representative of many other individuals – a tension that indicates a lack of narrative and material stabilization to date. The climate mitigation officer's systems narrative is in effect his reading of this situation. The depot manager's narrative is well-aligned with that of EVs, though he does elsewhere in his interview note two potential limits to electrification of his waste management vehicle fleet: first, a statutory requirement to be always-ready, which he interprets as potentially precluding a full EV fleet; and second, limitations as regards extreme heavy-lifting.

We would suggest that the above narratives sum to a larger meta- or meso-level narrative of the EV transition as facing significant challenges that will take many years to work through[4]. Working within a strong structuration frame, our understanding of this is that there has been to date insufficient change in material and cognitive regime rules across relevant actors (at least in the German context studied), and that these rules are in a mutual, two-way relationship with the degree of resource afforded to the EV transition. By mutual relationship is meant that rule changes of many types both require and induce increased resources of many types: as the need for or benefits of EVs are increasingly realised for specific actors and actor types, so will different types of investment follow, which in turn will support different types of rule change (individual-level cognitive, organisational, institutional and policy) at different government and agency levels.

From this we would further suggest that the original premise of differing degrees of structuration that underlies the three levels posited in the MLP merits closer attention in Giddens' original terms. That is, sociotechnical transitions can be understood as requiring, for increased structuration, an increase in supportive rules and resources at all levels (or scales, or contexts). Alternatively phrased, the process of a sociotechnical transition might be considered to be, or to constitute, an increase in supportive rules and resources.

That said, there are limitations of Giddens' (1984) focus on rules and resources: while these are important in relation to structuration processes, the range of relevant processes cannot be reduced to two without losing insights. This is in part why strong structuration extends Giddens' assumption of knowledgeable actors to include the psychology of actors, which can be understood to include the motivational and emotional drivers of behaviour, expressed as preferences, expectations and so on, which others have also identified as being important when seeking to understand relationships between micro- and macro-level social processes (Bodolica, Spraggon, and Tofan 2015). In addition, others have made good cases for the value of abductive, critical realist perspectives of transitions that explain, inter alia, in terms of powers that may or may not be realised (Sorrell 2018)(Svensson and Nikoleris 2018). Without meaning to expand here, connections between narrative alignment and the expression of powers in the critical realist sense could be interesting.

Empirically, at the macro-level of the MLP *landscape* (Frank W. Geels 2002), the Paris agreement (UNFCCC 2015) has supported the consolidation of many types low carbon actor constellations, including those for EVs. At the level of the European vehicle production and use regime are directives that indirectly promote the use of electric vehicles, e.g. (European Union 2009). Yet the translation of policy through to cognitive, organisational and institutional change has been slow globally, relative to the deep and sustained emissions reductions required (United Nations Environment Programme and United Nations 2016).

For EV's, others have described "erroneous" cognitive rules as "mental barriers (beliefs and attitudes) that mitigate against EV uptake (Noel et al. 2020). These include, for example, the belief that public charging stations are more frequently necessary than is the case for the large majority of trips in Europe: 95% of trips are shorter than 50 km (Noel et al. 2020; Ryghaug and Toftaker 2016). Similar beliefs were also explicitly identified as problematic by the actors that we questioned. Nonetheless, the lack of public charging stations is objectively problematic for EV owners who, for example, live in apartments without private charging points. Moreover,

[4] Albeit with the potential to be hastened through technological advances, particularly fast-charge technology.

Table A1
Interview Guideline.

Theme	Central questions	Details	Rationale
1	Describe in a few sentences your position with regard to electromobility in Lower Saxony	For how long have you held this position?	Understand sample characteristics
2	Your affiliation / field	Is this private of public? Size of the enterprise/institution	Understand sample characteristics
3	From your point of view: what are the central arguments for EVs in Lower Saxony?	Summarize the main points	Gain actors' perspectives on EVs
4	What are the barriers that EVs currently face?	Prompts if required: Policy (lack of policy, uncertainty) Markets and user practices (price, lack of knowledge) Charging infrastructure Production systems and industry structure Culture and symbolic meaning	Actors' perspectives on barriers (draws on Lin and Sovacool, 2020)
5	Which major shifts would be required to encourage EV adoption and use?	Probe further	Understand actors' political framing

users likely expect to have the option to drive for a long distance, even if they rarely need to do this or exercise that option, despite this being problematic for EV uptake.

6. Conclusions

We have investigated actors' perspectives of electric mobility in Lower Saxony, drawing on interview material from fifteen experts in the fields of citizenship, public administration, mechanical workshops, retail and science. Narrative analysis has served as a means for interpreting embedded meaning (Wiles, Rosenberg, and Kearns 2005), providing a way to connect the detail of individual experience and reflections with the wider social and spatial relations of which they are a part. This enables inference of actors' accounts of the causality and actors involved in barriers or issues known to be hindering the adoption of EVs - such as range, price and access to charging infrastructure (Kester et al. 2018).

Localised referencing and the detailed understandings evident in people's accounts enables us to answer research questions beyond that which can be answered through content analysis alone. In particular, here the narratives tell us about how the actors view the causality of the situation and who the key actors are, both of which we treat as valuable data in themselves, reflecting and consistent with the social constructionist perspective underlying narrative analysis (Garcia Rodriguez 2016). Empirically this provides fine-grained, insiders' knowledge 'from the positions of individual actors in the field, specifically in the case study location of Lower Saxony. Given that such a transition requires a coming together of a complex set of factors, actors and associated interactions (Frank W. Geels et al. 2018), the approach argues for the value of the subjective understandings and experiences of those actors, as a supplement to other types of localised information relevant to transition processes, such as the network configurations that shape the transition space (Coenen, Benneworth, and Truffer 2012; Coenen and Truffer 2012).

In terms of further work, firstly, the narratives provide directions for follow-up action and research relating to EV user practices, consumer communication and the meaning and symbolism of the combustion engine. Interviewee narratives located problems not only with regard to consumers as actors, but also policy-makers, municipal officials and business employees. Of particular note is the relevance of spatial planning and the actors involved in this. While there is an extensive literature on energy infrastructure relating to the German *Energiewende* (Becker and Naumann 2017; Fischer et al. 2016; Joas et al. 2016), understanding the EV-transition requires a multi-regime perspective that understands intersections of energy and mobility at multiple scales. Others have also previously observed that future research should seek to understand the political and economic processes associated with electric vehicles, generally and in relation to spatial planning (Gailing and Moss 2016). For example, research on the geographical aspects of the EV transition has the potential to contribute to the identification of interrelations in the EV-transition and its surrounding spatial development of energy infrastructure. This could be regarded as an answer to the call for "*concepts and methods that better account for the manifold ways in which apparently territory-specific processes are influenced by distanciated policy interventions, narratives, firms or institutional arrangements*" (Binz et al., 2020, p. 2). It is these institutional environments particular to the territory researched, which shape 'transition spaces' (Coenen and Truffer 2012).While we have not made strong use of geographical context here, place-related narratives offer another avenue for research on transitions that reflects the importance of micro-level processes.

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

Table A1.

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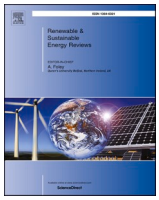

System capacities and implementation challenges in Germany's electric vehicle policy mix: an actor-centered review of the policy mix

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ABSTRACT

Situated within the framework of sociotechnical transitions, this study analyzes the implementation of national e-mobility policy in Germany through the lens of actors operating across seven key fields. By integrating a policy mix analysis with empirical data from expert interviews, we explore how system challenges are perceived and negotiated. Using a sociotechnical transitions framework, we explore gaps in the current policy mix and advocate for a more integrated approach to address systemic deficiencies. The findings emphasize the role of intermediary actors in policy implementation and contribute to SDG 9 by identifying pathways to strengthen infrastructure and innovation in sustainable mobility.

1. Introduction

Electric vehicles (EVs) have developed into a critical technology for the decarbonization of road transport, which contributes to over 20 % of global energy-related emissions [1]. While road transport emissions are expected to decrease over time, the sector is expected to remain a key contributor to overall global emissions according to the European Environmental Agency [2]. At the European level, reducing carbon emissions from traffic significantly has become a key policy goal for the transport sector [3] and in consequence, electric vehicles have become part of the strategy to meet ends. As reported, electric vehicle registrations in Europe rose steadily in 2019, followed by an increase between 2020 and 2023 [4]. While technological advancements in range, model diversity, and performance are evident, questions persist about the state of innovation and the challenges surrounding its acceptance by industry, administration, and everyday users. This study, therefore, examines the challenges posed to the energy and mobility systems by the integration and distribution of these technologies.

Vehicles with an electric drive, either powered by battery or hydrogen play a crucial role in the transition to low-carbon transportation, and the adoption of electric vehicles (EVs) is a central element in destabilizing fossil-fuel-dependent automobility regimes or systems [5]. Only a few accounts are provided in the transition literature on user perspectives of barriers and gaps to adoption [6,7]. This becomes more interesting considering the importance of actor-level decisions, that concern agency - the capacity and willingness to act in transition processes [8,9]. More specifically, while the motivation and behavior of actors strongly influence the adoption and deployment of emerging technologies, work on conceptual frameworks that connect micro and macro levels of analysis in transitions is arguably underdeveloped [10].

With this in mind, we focus on the analysis of challenges to the implementation of e-mobility policies, alongside actor-informed suggestions for strengthening institutional capacity, enhancing infrastructure development, and improving cross-level coordination. In particular, we focus on e-mobility policy implementation from an interpretative perspective, viewing policy implementation not as a simple transfer of national didact through to material change, but a process that involves interpretation, negotiation, and judgment [11]. As EV policy is multifaceted, we draw on the policy mix literature. In this way, we establish connections between the macro-level of policy (mix) and the micro-level of actor interpretation concerning e-mobility-specific topics as charging infrastructure. In contrast to our approach, previous studies e.g., Refs. [12,13] have focalized specific aspects of policy instruments, often overlooking their broader systemic interconnections and practical

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implementation dynamics. Similarly, Corradi et al. [14] have examined barriers to EV adoption with a focus on regime actors but without incorporating personal accounts or experiential perspectives, thus placing less emphasis on agency in policy implementation. Building on this, we summarize the main challenges related to charging infrastructure, as perceived by various actor groups, along with their proposals to enhance infrastructure development, institutional capacity, and policy integration. Building on expert interviews, we document how actors from selected fields contrast, contradict, and reveal unforeseen challenges with implications for their alignment with the national agenda on e-mobility. Aligned with SDG 9, this research explores how e-mobility governance and policy can foster innovation and sustainable infrastructure, supporting the global transition to low-carbon transport systems.

Our main research question concerns *how different types of actors (*e.g. *from administration, research, or energy provision) perceive and address challenges to implementing EV policy, particularly from their positions in the e-mobility system.* As said, our underlying premise is that policy implementation requires policy translation to practice and that understanding more about the obstacles to this, and associated implementation challenges, is useful for policy design. In the course of research, we found that some of the policy actors' recommendations could be categorized in terms of informal institutional forms, such as *technological, institutional, cultural-cognitive, and educational capacities* [15,16]. Thus, we adopt an additional transfer question, that involves the *recommendations actors offer for improving EV policy*. Working with a common definition by Geels [17] we frame actors according to the MLP as: *"social groups such as firms, policymakers, scientists, users, and societal groups that interact within sociotechnical systems, shaping and being shaped by the development and diffusion of innovations."* In terms of structure, the paper begins with an introduction to the diffusion process of EV technology, policy mix principles, and actor intermediation. Information on the research design, data collection, and methods or analysis is provided in the following method section. The analysis consists of two parts: a policy review of e-mobility in Germany and the results of the qualitative analysis. The results are taken up for discussion and all relevant points raised are summarized in the conclusion.

2. Literature discussion

Previous studies of e-mobility in the sociotechnical transitions literature have dealt with various issues: Some have focused on diffusion strategies [18], others on policy mechanisms to accelerate the adoption of EVs [19]; some have debated the role that social status may play in this process [20], and again others have sought to differentiate (segment) consumers' willingness to pay for electric vehicles and their charging applications [21]. Our literature review outlines key arguments on the diffusion of e-mobility as part of the shift toward low-carbon transport. This overview provides a framework for analyzing actors' perspectives on related challenges. We discuss concepts of EV diffusion (2.1), the design of policy mixes for e-mobility transitions (2.2), and the role of intermediary actors in implementing these instruments (2.3).

2.1. Factors affecting EV diffusion

In the first decade of the millennium, the 'electrification' of the transport sector has been viewed as a niche phenomenon, often subject to experimental studies [22,23]. A more recent approach frames transition processes in mobility as interlinked and part of the wider challenges within the landscape of energy and mobility [24]. In this way, the electric vehicle is viewed as representing more than a mere substitute for vehicles with internal combustion engines (ICEVs) using "cleaner, greener" sources for refueling. Most life cycle analyses demonstrate the climate efficiency of battery-electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) relative to fossil-fuelled propulsion, although the production and disposal of batteries still raise questions about the raw materials supply and environmental and social impact [25,26]. Despite policy ambitions, the niche of e-mobility and the associated technology and social embedding has been slow-evolving when taking adoption and diffusion rates into account [27,28]. This is even more so when seen in the context of electric vehicles having been considered a promising technology at repeated intervals over the last century, yet failing to even develop as a niche product in the 20th century [29]. Since the turn of the millennium, the global discourse on climate change, enhanced by scientific reports [30]on climate change and its political corollaries has increased the landscape pressure on carbon-intensive practices and, consequently, forwarded the development of electric drive technology. Thus, the process of diffusion of electric vehicles and their challenges have mostly become the subject of study in the current and last decade [31–33].

At issue here is how to design policy that takes account of the experience of those charged with its implementation, and those (often users, citizens, or consumers), who experience that implementation. Earlier work in that vein has, for example, illustrated the value of personal narratives for understanding actors' situated and conjunctural experience of the EV system [34]. Such narratives can help to indicate the complexes of attitudes, values, beliefs, and opinions of various actors, which in turn play a crucial role in determining the pace and level of acceptance of technological innovations, particularly concerning user adoption. Despite the importance of private user commitment in promoting the diffusion of e-mobility, Dalla Chiara et al. [35] emphasize that multiple factors influence the willingness of drivers to use electric traction. The literature has pointed to user concerns about higher acquisition costs, insufficient charging infrastructure, long charging periods, and relatively low range [36]. Additional factors, acting as social barriers to the adoption of electric vehicles include lack of consumer knowledge, limited EV model options, continuing range anxiety despite technological improvements, a prevailing automobility culture, and the durability of the overall technology including battery life [6]. These hindering factors are assumed to have slowed down the diffusion of electric vehicles by constraining demand. Despite this, electric vehicles run on low-maintenance motors, deliver high torque, and are experienced as significantly quieter than regular cars from a user's perspective [37].

2.2. Policy mix principles

The basic premise of policy mix theory is that multiple policy instruments need to be combined synergistically to address complex policy problems [38–40]. Policy mix rationales thus draw on interdisciplinary frameworks, to integrate different, key aspects of policy design [41]. In the context of e-mobility, a key challenge for policy implementation has been the entrenched incumbency and resistance of the conventional automotive sector [42]. The automotive industry is one of the most dominant industries in Germany and other industrialized countries, such as the U.S.A., Japan, and France [43]. To explain the complexity of cultural meanings associated with the durability of the automobility system, functional, symbolic, and societal frames have been developed [44]. In the context of our study, we view road vehicles as embedded in an extensive road, parking, and refueling infrastructure that facilitates established patterns of motorized, private transport [45,46]. Policy mixes are required to address the deep interconnectedness of the components of such a system. With the theory on policy mixes being developed quite well already, less investigation has been done on policy mixes under current implementation. It is therefore also our concern to study a real-world policy mix [47] in this case.

Conceptually it is first necessary to differentiate between different aspects of policy mix design. Rogge & Reichhardt [41] refer to the building blocks of policy design as (i) policy elements, including strategy and instruments; (ii) policy process; and (iii) policy characteristics. These need to be applied to achieve integrated policy objectives and to

prevent mismatches, coherence, consistency, and congruence [48]. A single policy instrument may imply economic instruments, regulation, legal control, and specified directed information [41]. Some studies have focused on the analysis of single policy elements such as subsidies or incentives and their effects on the adoption of electric vehicles [49, 50]. In our case, we focus on the interplay of measures as perceived by actors at different points in the sociotechnical system, given our focus on the implementation process. The model of Rogge & Reichardt for policy mixes has been taken up and further developed in various contexts [51, 52]. For example, the extended concept of so-called transformative policy mixes integrates a long-term focus on policy-making and the concrete utilization of instrument mixes [53]. In addition, Kivimaa & Kern proposed a concept that integrates aspects of disruptiveness and the destabilization of established regimes into the policy mix [54]. The framework categorizes policy instruments as either supporting technical innovation and niche development (c-functions) or leading to the decline of carbon-intensive technologies (d-functions) and thus includes both reinforcing and disruptive impacts on the landscape and regime. In the subsequent sections, we use the standard model by Rogge & Reichhardt to illustrate the instruments in place as part of the policy mix, as currently integrated into the national agenda for e-mobility in Germany. On that basis, we document and discuss the perspectives of actors in policy translation and contribute to the analysis of policy implementation with corresponding recommendations, promoting the diffusion of electric vehicles [55]. We do not aspire to analyze the policy mix and its instruments in-depth, as this would be outside the scope of the study undertaken and defeat the purpose of understanding the actors' perspective in the light of the regulatory framework.

2.3. Policy implementation as intermediary action

Policy implementation requires intermediary actors who transform abstract policy concepts and imperatives into practical strategies within specific contexts [56]. In the context of sustainability transitions, the roles and impacts of actors, specifically intermediaries, have gained increasing recognition [57]. Intermediary organizations play an influential role in navigating complex policy landscapes through the acceleration phase of transitions [58]. The understanding of the contributions to public policy, including a pivotal role in policy implementation has further developed in the literature. For example, Boon and Bakker (2016) examine how intermediaries in sustainability transitions interact with and influence public policy [59]. This adds depth to the understanding of intermediary actions, highlighting their importance in facilitating transitions and influencing policy agendas. What these studies have in common is that they highlight the dynamic nature of policy implementation and mediation and show the diverse roles that are mediated between the design tasks of sustainability transitions and public policy and administration. The sociotechnical transitions literature argues that intermediaries are key actors that can catalyze transitions by voicing new concepts [60], commencing novel policy or market procedures [61], and introducing new networks of actors [62]. In the policy process, actors taking the role of intermediaries can be characterized as a) bringing knowledge capacity into policy processes, b) advocating for new policy, and c) building consensus on policy proposals [63]. Intermediaries, though do not act as free agents but within institutional boundaries and arrangements [64]. Here, we connect conceptually to previous studies by drawing on the concepts of intermediaries and policy translation, particularly emphasizing the processes of agency, interpretation, negotiation, and the exercise of judgment.

In addition to the concept of intermediaries, elements of Scott's [65] institutional typology, as detailed further in section 3 are of further relevance to this study. Scott's perspective offers theoretical insight into the embedding of new social structures and hence has been applied in sociotechnical contexts [66]. Offering a framework for understanding the role of institutions in shaping organizational behavior, Scott's approach defines three institutional pillars, each of which is reproduced by actors within organizations: regulative, normative, and cognitive. The interplay of these shapes organizational structure, practices, and strategies. As with policy implementation, actors necessarily mediate these processes, and their experience of this mediation tells us about the pressures that not only they face subjectively, but also about the pressures and tensions within the system. Thus subjective actor experience – the realm of micro-level sociology – has relevance for more structural accounts of social and sociotechnical life.

3. Method

The overall research design is an empirical case study aimed at exploring the diverse perspectives of actors involved in or connected to e-mobility policy and practice. While our study touches upon aspects of policy implementation processes, its primary focus is on exploring actors' perspectives within the e-mobility system, particularly emphasizing their roles and experiences in navigating challenges and opportunities for EVs in the sociotechnical system. To provide context for these perspectives, we begin with a review of the national policy landscape relevant to Germany. The review provided a knowledge base of the overall policy mix, including strategies, objectives, and specific instruments. In addition, we conducted actor interviews as field research. The two-fold approach established linkages between specific and detailed references by the interviewees and the policy elements, improving contextual and situational understanding of the system.

When reviewing and documenting actors' situated assessments of the policy landscape, Germany's pivotal location within the European industrial economy should be borne in mind, as well as its deeply ingrained industrial framework, and its advocacy for environmental and sustainability issues [67,68]. Initially, we began our policy review by identifying the fundamental components of the German policy mix and its constitutive elements [69]. Our data sources for key strategy documents consisted of public reports released during the initial half of the decade following 2010 and updated in the 2020s. We followed a standard review procedure for policy analysis [70]: employing an initial scoping procedure, pertinent sections were marked within each report, and distinct features representative of policy elements were noted. This enabled the identification of policy elements and instruments. In addition, a legislative map for e-mobility was used for orientation [71]. Expert interviews were conducted with actors at different points in the electric vehicle (EV) sociotechnical system. The professional fields represented included public administration, commerce (SME), academic research, engineering, energy, and consumers. Participants were mostly drafted from the Lower Saxony areas and sought to represent each sector field illustratively, not statistically. As such, the interviewees' experience should be treated as illustrative of actor experience, not definitive, in the sense of representing all actors in similar positions. This trade-off between depth and numerical breadth is inherent to qualitative, case study work [72].

For our purposes, engineering refers to the technical arenas of electric drive technology, energy to all aspects related to the grid, and the provision of electricity. As said, the actors are not assumed to be necessarily representative of their roles, but rather illustrative: the issues that they raise are assumed to be within the larger set of issues that a larger group of such actors would raise. Detailed information about the content provided by each respondent and their grouping can be found in Appendix B (*structure and content of the sample*). Seven groups were formed, with two interviewees assigned to each group, enabling comparison across groups. We chose to sample actors primarily from one region to establish a case and improve comparability. The interview questions followed a protocol designed to encourage respondents to provide personal accounts of the policy process – i.e. accounts of their experience, from their standpoint within the EV system. For this reason, a semi-structured approach in the interviews was used, enabling a set of standard inquiries to be made, while allowing the conversation to build

and develop to explore new areas [37]. Semi-structured interviews are particularly useful when the research aims to understand actor perspectives of policy frameworks and underlying factors, which shape the viewpoints of the interviewed actors on policy instruments [73].

In this way, we explored the diverse roles and perspectives of actors in the e-mobility field, including their views on policy and its practical implications [11]. The selection of respondents followed a purposeful sampling approach rather than a random selection, with two interviewees chosen per subfield (part of the system). Additionally, snowballing techniques were utilized to identify potential participants and expand the network of interviewees [74]. All interviews were recorded with the written consent of participants and stored for a finite period on a secure server. Post transcription the material was cataloged using MAXQDA software.

Coding of the transcribed material sought to leverage the important aspects of the material related to our research questions [75]. Figure one summarises the two-round coding process, using high-level codes in the first round and sub-codes in the second round to explore various aspects of policy, including the actors' understanding of problems and challenges to the EV system, plus the institutional categories we explain in the following. Thus the analysis was conducted with a systematic approach while being sensitive to emerging themes. In the first round of coding, we employed concept-driven high-level coding to match individual accounts with policies relevant to their actor roles. For this purpose, we use the categorization provided by Hoffmann et al. [76]: resources, supply, and maintenance; infrastructure; technology and sociotechnical transitions; rules and regulations; cultural aspects; and user practices (further information: coding scheme in Appendix C). As part of the coding process, visual tools were used to review how the codes assigned spread across the sample. Special attention was paid to policy conflicts in the areas of public service, infrastructure, political legislation, political administration, funding, market, and spatial planning. The analytic stage that followed included a selective application of Scott's theory of institutional types. Of particular relevance were normative orientations [65], which refer to the underlying values, beliefs, and norms that individuals or organizations hold and/or enact. Normative orientations help to shape behavior and decision-making within an institutional environment. In essence, they reflect moral and ethical principles, as well as preferred ways of doing things following societal and institutional norms. By categorizing actors based on their normative orientations, we can show how these affect their approaches to implementation, and how this influences their view of policy conflicts. In essence, Scott's theory of institutions facilitates a nuanced exploration of how different actors interact with and respond to both the policy imperatives and the sociotechnical system. While not a primary analytical focus, Scott's institutional typology provided a supplementary framing tool for understanding the pressures and tensions identified in the data, particularly the interplay of regulative, normative, and cognitive elements. In the third stage, we identified meta-themes highlighting structural challenges and points for policy intervention to improve implementation. The individual steps are not to be understood here as definitely distinct from one another but as phases with iterative transitions, which are illustrated more elaborately in Fig. 1.

4. Results of policy review

The first part of our results provides an overview of the policy landscape in which actors operate. We structure the policy agenda in Germany in terms of the conceptual model for policy mixes by Rogge & Reichhardt [41]. We identify fundamental components and constitutive

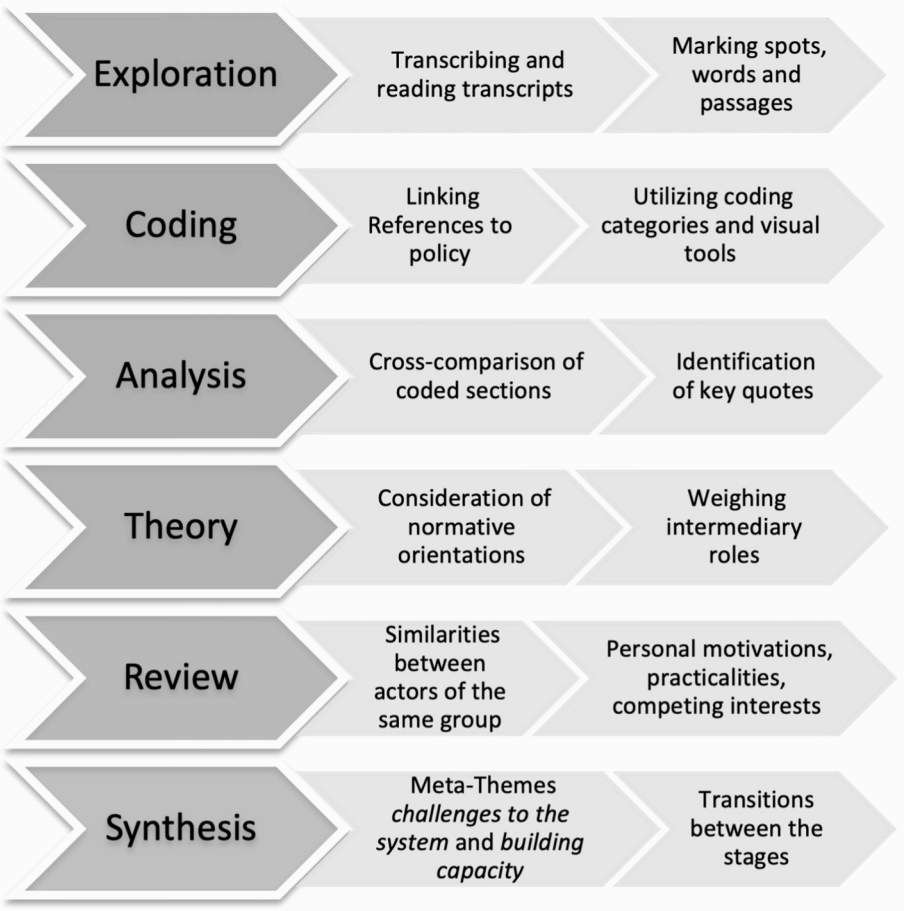

Fig. 1. Process of analysis.

8.2 System capacities and implementation challenges in Germany's electric vehicle policy mix: an actor-centered review of the policy mix (Article 2)

elements [41,69] from data (strategy documents, governmental programs, public reports, laws, funding framework directives) and instruments of the policy mix. The policy landscape for e-mobility has evolved from tentative to comprehensive over the last two decades. The roman numbers indicate the policy documents we revised, listed in appendix C. One note on terminology: if not indicated otherwise, local refers to the level of municipalities and cities.

The foundation for promoting electric mobility in Germany can be traced back to the *Integrated Energy and Climate Program* (IEKP) of 2007 (X). Concrete measures and discussions on electromobility began with the *National Strategy Conference on Electromobility* in late 2008 (IX). Germany's political structure, organized as a federal republic, comprises national, federal state (Bundesländer), and municipal levels, each with distinct responsibilities. At the national level, the federal government sets overarching policies, legal frameworks, and funding programs for e-mobility. Federal states adapt these frameworks to regional contexts, implement state-level initiatives, and may introduce complementary measures. Municipalities are responsible for local infrastructure development, such as establishing charging networks and integrating e-mobility into urban planning. In line with these roles, the first national funding programs were launched in early 2009 as part of the *Fiscal Stimulus Package II* (VIII). In August 2009, the German government presented the *National Development Plan for Electromobility* (VII). To facilitate e-mobility efforts, the *Joint Federal Government Office* (GGEMO) was established in 2010 as a central point of contact [27]. Additionally, the *National Platform for Electromobility* (NPE), formed in 2010, brought together representatives from various sectors to develop concrete proposals for achieving the goals of the *National Development Plan*. The NPE published its first interim report in November 2010 (VI). In the same year, following the release of the *Fiscal Stimulus Package II* (2009), a funding budget of approximately 500 million euros was allocated to several federal ministries, including those responsible for economics, transport, environment, education, and agriculture for e-mobility. Projects across fifteen thematic areas (V) included field trials of electromobility in passenger car traffic, the program model regions electromobility in Germany, and a proposed battery test center to improve European production [77].

That is while the first decade of the 21st century served to form policy strategy and principal plans, during the second decade instruments were further developed and legally refined. The developments resulted in a diversified policy mix as exemplified in Fig. II.

The political strategy for e-mobility includes building institutional, industrial and technological capacities, implementing measures to increase the resilience of transport and mobility systems to energy and climate crises and providing economic drivers and incentives for the development of market structures (see Fig. 3). The principal plans are increasing renewable electricity production (Energy Industry Act, I), promoting the development of charging infrastructure (Masterplan Charging Infrastructure, II), and granting privileges for electric vehicles (E-Mobility Act, III). The instruments for implementation are described in the next section and illustrated by figure three. These initiatives reflect the national commitment to advancing industrial development and technological innovation in electromobility, focusing on improving batteries, charging infrastructure, and market uptake [78,79] Comparatively, limited efforts have been made to regulate and phase out vehicles with internal combustion engines. Germany's initial resistance delayed the EU's adoption of CO_2 fleet limits. However, a compromise was reached, allowing vehicles powered by e-fuels to be registered in the EU beyond 2035, provided they meet stringent climate neutrality criteria [80,81] In addition to national and EU-level legislation, academic advisors have proposed measures such as taxes and charges on combustion vehicles, urban tolls, and mobility management programs in companies and public institutions [82].

As visible in figure two the instruments in the national policy mix aim to promote sales and procurement of electric vehicles, provide tax incentives as benefits, promote the expansion of charging infrastructure and create privileges in traffic and parking. The concept of circular economy is supported through the battery law (BattG) and measures for climate mitigation are coordinated in the Federal Immission Control Act (BIMSchG). Building on our policy review, we identified a gap in the literature: a structured overview of the diverse regulatory instruments shaping the national e-mobility landscape was missing. To address this, we developed the model depicted in figure three.

By providing a systematic overview, the figure serves two purposes: first, it offers a framework to contextualize the diverse references made by stakeholders to existing regulations during our interviews. Second, it highlights the interconnections and thematic overlaps within the policy mix, and enables a comprehensive understanding. As no comparable visualization currently exists, this model aims to fill an important knowledge gap in the field and provide a tool for both academic analysis and practical policymaking. The instruments are incorporated in various legal documents: some in laws, some in directives or administrative regulations, and some in funding framework directives. Gustafson and Anderberg [83] provide an illustrative example of how policy measures at different levels of government affect a developing green technology. Similar to the legislative map of electromobility [71], this illustrates

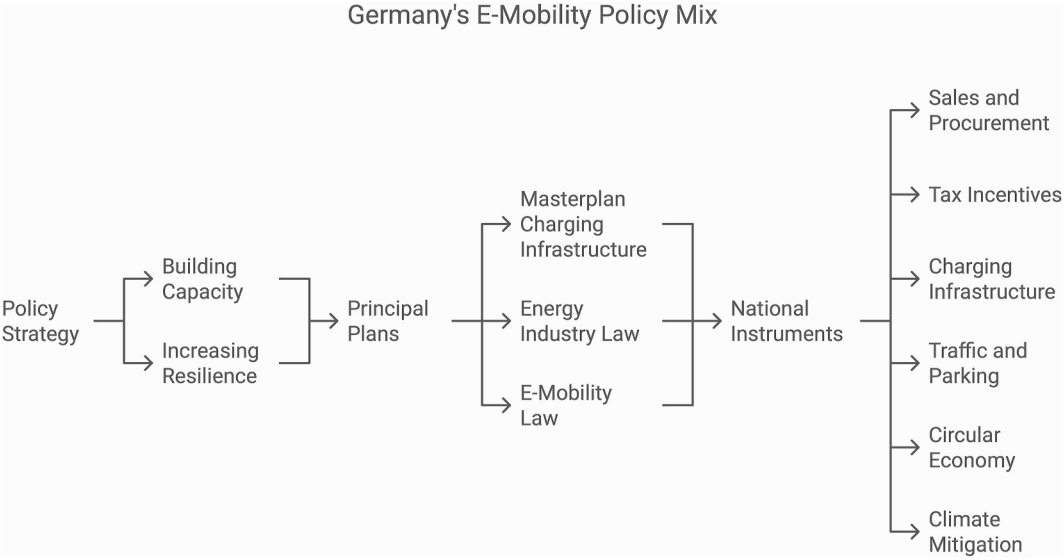

Fig. 2. Elements of the policy mix for e-mobility in Germany.

8.2 System capacities and implementation challenges in Germany's electric vehicle policy mix: an actor-centered review of the policy mix (Article 2)

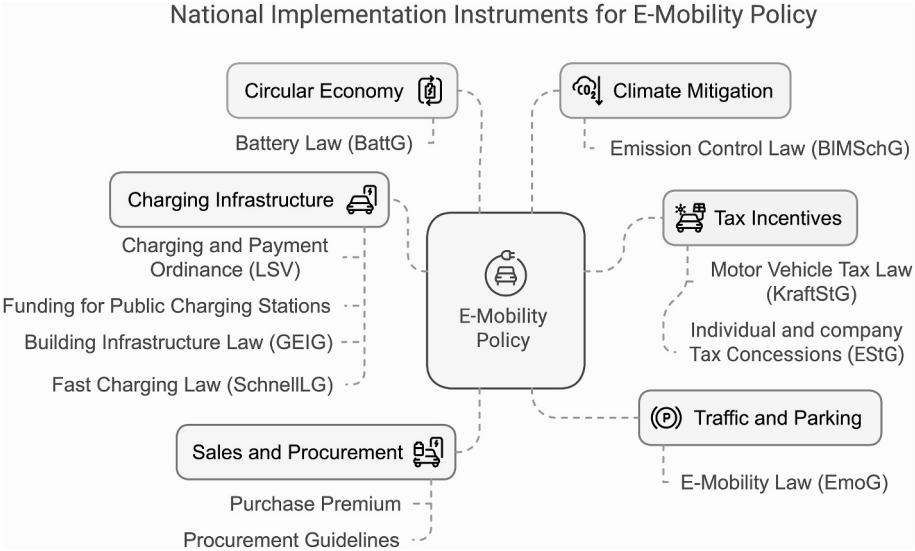

Fig. 3. Implementation instruments for e-mobility policy.

how different policy measures have an impact at different levels. As exemplified, certain legal instances are specifically formulated to facilitate cooperation in governance across levels. The directive on the Funding Framework for the deployment of public charging stations is enacted at the national level, while the responsibility for applying for funding for locally installed charging stations lies with the municipalities. Regarding higher-level European strategy papers, such as the Green New Deal European guidelines and national strategy papers define the objectives for corresponding legislation, such as the building electromobility infrastructure law (GEIG).

One note on governance and responsibilities: At the national level, laws and regulations primarily address overarching issues such as economic policy, energy regulation, and nationwide infrastructure, with a focus on the broader energy and mobility transition. At the level of the federal state (sometimes called regional), state-specific laws aim to implement national policies and address regional needs, particularly in energy policy and transportation systems. Municipalities, in turn, hold responsibility for local governance, including the development of urban transport plans, traffic management, and local charging infrastructure. Most activities at the Lower Saxony level are aligned with federal funding programs, with municipalities primarily focused on practical measures such as parking regulations, charging infrastructure permits, and local incentives (e.g., free parking for electric vehicles). These measures vary widely and have seen notable reversals: for example, both Göttingen and Braunschweig recently discontinued free EV parking, citing the rising number of electric vehicles and a need to reallocate resources for charging infrastructure and parking management. Additionally, some local e-mobility policies are embedded in broader climate strategies or air quality plans, such as restrictions on combustion vehicles in city centers. What we seem is that municipalities hold a transformative potential within the boundaries of their realms of influence.

5. Implementation dynamics and capacity gaps: actor views

Having reviewed the policy landscape, we turn to our results on how actors engage in policy implementation. To understand this, we began by examining the overarching perspectives held by these actors on critical aspects of e-mobility development, encompassing infrastructure,

Table 1
Orientation and perceived challenges by different actor groups (charging infrastructure).

Field of Actor	Themes	Normative orientation	Identified challenges	Options for Policy Intervention
Rural retail, entrepreneurship	Availability of charging	Innovative focus, positive mindset towards shortcomings	Complexity and confusion associated with charging tariffs.	Streamlining payment service (legally)
Public-private partnership & non-profit organization	Charging Capacity	Focus on providing service, establishing effective partnerships, and fostering innovative solutions.	Internal limitations to further development, e.g., conflict of interests and administrative guidelines	Updating administrative guidelines and functions in ordinances (legally)
Municipal administration I and II	Procurement, scheduled drives and charging	Implementing policy, contributing to climate mitigation, providing service to the public	Flexible forms of service and small local solutions for charging spots; Identifying local hotspots for potential charging infrastructure	Adoption of municipal guidelines and concepts by the Council
Government agency	Featured programs, R&D funding, dialogue with public officials, infrastructure, governance	Creating linkages, promoting transfer of knowledge, fostering innovations	Dysfunctional charging spots (for various reasons), confusing references between the responsibilities of federal state and federal republic	Providing advice and mediation in ambiguous or unresolved legal areas, mandating providers to ensure functionality
Engineering	Upscaling and its limitations, charging options	Improving technology and efficiency, solving technological problems	Charging infrastructure in cities, insufficient options for private charging, capacity of the grid (connected load)	Further develop the existing legal basis for charging infrastructure in cities and the upgrading of the electricity grid
Private use	Charging on the road, Payment processing	Pioneering, supporting sustainable development, showcasing green mobility	Denser network of functioning charging stations, unified payment system	Streamlining payment service (legally), mandate providers to ensure functionality
Energy provision	Maps and navigation systems for charging spots	Promoting the e-transition, assisting though advice	Charging stations, unified payment system	Streamlining payment service (legally)

sociocultural factors, and resource availability. We especially explored the interplay between different actor groups and their normative frameworks - given Scott's emphasis on this, and the challenges that they perceive as part of the policy implementation process (Table I). This actor-centric approach to transitions places greater emphasis on the social aspects of transitions, complementing the traditionally technology-oriented focus. It deepens our understanding of individual and collective behaviors as essential components of these transitions, as noted in prior research [9,10]. The accounts of the actors pointed to specific suggestions for strengthening institutional capacity, improving cross-level coordination, and advancing policy integration. In addition, many of these proposals focused on addressing challenges for the infrastructure development of the EV system. However, rather than reflecting abstract or generic notions, these accounts point to a situated, actor-driven process embedded in the e-mobility transition. This process involves adaptive engagement by formal institutions, intermediaries, and local stakeholders facing the concrete complexities of implementation.

We organized our findings into two sections. The first section (5.1) outlines the critical system challenges identified by the actors, while the second section (5.2) looks into their perspectives on the additional capacities needed in the sociotechnical system.

5.1. Challenges in the development of the EV system

From a sociotechnical systems perspective, system challenges are understood as complex and interconnected issues that arise from the interactions between social and technical elements within a system [84]. The sociotechnical systems approach recognizes that changes in one aspect of the system can have ripple effects on other components, leading to potential disruptions, conflicts, or unintended consequences. Addressing system challenges requires a holistic understanding of the sociotechnical context and the interdependencies between various elements to develop effective and sustainable solutions. Our actors viewed system challenges as an interplay between technological components, social practices, cultural norms, and institutional structures. Several actors voiced shortcomings and fundamental shortages for EV technology and the wider system in which it is embedded. These can also be framed as bottlenecks, systemic weaknesses, or initial positions for political intervention [85,86]. As such, what we present is more than a description of system-level challenges as perceived by the actors interviewed; it includes starting points for policy interventions, with a focus limited to charging infrastructure (Table 1). What we find is that the actors' perspectives of system challenges can also be understood as challenges to the institutionalization of EV system elements, which we refer to using Scott's term normative orientation [65]. While our interest was to map policy implementation processes as viewed by situated actors, charging infrastructure emerged as a key concern across actors, and we chose to focus on this aspect due to its centrality in the discussions. In the following table, the first and second columns link the field of the actor to emergent themes of problems in the socio-technical system. The third and fourth columns display the links between the perspective taken for problematization by the actors and their respective normative orientations. For instance, the following actor, serving as the director of a municipal service unit, emphasized quality in service provision:

> And there are internal obstacles. Because as a general contractor, we are obligated to ensure traffic safety […] And we have on-call services. In some cases, these still exclude electric vehicles. Because we must be on duty for longer periods, for example for winter services or unforeseeable events on the roads, accidents, and so on.
>
> (Entrepreneur A2, pos. 19)

The referenced actor identified internal limitations, such as conflicts between development goals and administrative guidelines, as a key challenge. This phenomenon was observed among multiple actors. Table one illustrates the challenges perceived within the actor's field and their associated normative orientations, which often appear to conflict with these challenges. To maintain a clear focus, we highlight one thematic arena common to all actors: charging infrastructure. However, the same analytical framework can also be applied to other areas examined, such as policy, regulation, and technological development.

Different actors in the e-mobility field face unique challenges but also have specific goals. For example, rural retailers struggle with confusing charging tariffs, while public-private partnerships deal with internal conflicts and unclear rules. In the field of administration, tension may arise between normative orientations and implementation practice, exemplified in the quote following. A senior executive at a federal innovation agency linked to car manufacturers and suppliers in the region is primarily tasked with coordinating funding programs and associated projects, as well as promoting dialogue between public and private structures. Normative orientations point to: improvement of cooperative collaboration, promotion of knowledge transfer and further development of innovations. The manager problematises confusing administrative responsibilities:

> 1 How can you bring regenerative energy into the vehicle and make it usable for electric driving? Whether that is a passenger car, an e-bike, or an e-vehicle, that can then certainly become enforced. You can always do a lot, but it's a question of what kind of understanding you have of what the state's mission and responsibility is in this context […]. And I think that this current […] situation shows very clearly, if you want to create incentives there, that there's always somebody who says, 'No.' (Manager C2 A, Item 23).

Despite the officer mentioning the often confusing formal accountabilities, which several respondents raised as an issue, he also emphasizes the lack of a 'progressive' attitude towards innovation and highlights the problem of malfunctioning charging spots not being repaired promptly by the provider. A third example demonstrates the comprehensive considerations that can take place in the background of decision-making processes, even if neglected in direct decision-making.

A municipal officer entrusted with climate protection matters described his thoughts on the question of a potential failure in the context of EVs, the following way:

> 2 Where do we build charging infrastructure? And what energy is generated at the same time as the charging demand arises? Do we want everyone to charge at home in their single-family […] home and we get huge peaks in electricity demand from 5 to 7 pm? Can we get business models that offer flexible electricity tariffs? Can local energy suppliers already do this? What are the follow-up costs? Or wouldn't we prefer employers to be supported in setting up charging infrastructure that charges much more slowly, that charges at the midday peak, when the sun can provide the energy for three-quarters of the year? So there are a lot of technical and organisational questions that offer many opportunities, but you have to recognize them at first. And that is often not the case in reality. Instead, there is a very acute, implementation-oriented focus on what we need to do now and urgently. And then misallocations and wrong decisions are often made because there are no concepts that really look at the future: what do we need by 2030?' (Public Officer B1, pos 132).

In the broader policy landscape, municipal administrations reported difficulties in implementing policy effectively, particularly in adapting national-level strategies to local conditions. Actors from engineering fields emphasized the need for technical support in upgrading the grid and expanding charging infrastructure. Similarly, representatives of public–private partnerships stressed the importance of accessible and flexible administrative frameworks to facilitate collaboration. Rural retailers pointed to challenges in charging tariffs and payment systems, highlighting the need for simplification to support broader accessibility.

In sum, the examples highlight the complex interdependencies between social practices, cultural norms, institutional structures, and technological systems within the e-mobility landscape. The normative orientations of the actors often revealed tensions between their intentions and the systemic barriers they encountered. These contradictions point not only to persistent structural challenges but also to entry points for targeted policy intervention, as outlined in Table 1. Interviewees frequently emphasized the need to improve institutional capacity, ensure more effective cross-level coordination, and accelerate infrastructure development—particularly in addressing the widespread issues surrounding charging infrastructure.

5.2. Supporting systemic capacities for sustainable policy and governance

Recent discussions in sustainability transitions research have moved beyond conventional notions of capacity-building, embracing more multidimensional frameworks such as *transformative capacity* [87], *systemic innovation capacities* [88], and the *functions of innovation systems* [89]. These concepts emphasize that capacities essential for enabling and accelerating socio-technical transitions extend beyond technical domains to include institutional, educational, cultural-cognitive, and infrastructural dimensions. In the context of electric mobility, actor insights pointed to a range of capacity-related challenges that connect

Table 2
Measures to advance capacities in the sociotechnical system.

Field of capacity	Objectives	Suggested improvements	Policy Options
Technological	Expand and improve the charging station network	- Increase public charging spots - Enhance accessibility - Ensure compatibility - Install fast chargers - Set up charging facilities for larger utility vehicles - Streamline maintenance and payment service of charging spots - Improve technical reliability - Create virtual connectivity with software	Further promote development of charging infrastructure according to masterplan, legally mandate technical reliability including sanctions, and promote research for the integration with vehicle-to-grid systems.
	Further develop the technology required for low-carbon electric vehicles	- Expand the range of vehicle models - Adapt available technology to larger utility vehicles - Increase battery range - Optimize thermal management - Propel research, development, and innovation - Enable integration into vehicle-to-grid systems	
Institutional	Advance effective policy-mix	- Balance incentives and regulations. - Support the integration of evolving technology into the landscape. - Administer programs for the diffusion of socio-technical solutions. - Coordinate public invitations to tender. - Endeavor synchronization of collaboration among stakeholders. - Refine public procurement guidelines. - Foster public or public-private collaboration. - Enable the electrification of public transport.	Continue the political work for a balanced policy mix that combines incentives and regulations, supports stakeholder collaboration, and integrates evolving technologies into public procurement and public transport systems.
Cultural-cognitive	Advocate a shift in mobility conceptions	- Cultivate a shift in attitudes, norms, and beliefs toward e− mobility - Heighten awareness about electric vehicle advantages - Dispel and clarify misconceptions - Foster a culture supportive of eco-conscious, localized solutions. - Address mobility behavior to align with vehicle capabilities - Embrace the challenge trio: digitization, electrification, and connectivity - Consider novel usage patterns, emergent business models and innovative mobility services - Foster an overarching trans-formation in mobility paradigms.	Investing in awareness-raising campaigns social perception and behavior towards e-mobility (such as *Schaufenster E-mobilität)*, offering consulting options through funded intermediaries to clarify misconceptions and continue to promote a culture of environmentally conscious mobility, e.g. through municipal offices for climate protection and appointed climate protection managers/officers.
Educational	Strengthen skills and competencies in the field	- Offer trainings to stakeholders in the field - Increase awareness about electric mobility - Disseminate knowledge about the latest developments in the field. - Provide qualifications through training for experts in the field	Support capacity building through co-funding specialized training programs, and encourage transfer of knowledge and training initiatives for stakeholders and professionals in the field.

policy alignment with the dynamics of the sociotechnical system. Strengthening these capacities is not only critical for enhancing system resilience and upscaling but also for enabling actors to effectively navigate transition processes. Interviewees highlighted deficits and needs across multiple domains, stressing that the success of the transition depends on coordinated efforts to address these systemic weaknesses. In addition, the capacity to navigate transition processes can decisively determine their success [90]. The following categorization (Table 2) synthesizes the main capacity types referenced by the actors—technological, institutional, cultural-cognitive, and educational—and situates them within the broader discussion on building governance capabilities for sustainability transitions.

What we can see regarding technological capacity is a two-fold challenge. Research, development, and innovation are viewed to address both charging and vehicle technology, including battery, drive, and thermal management. Hence actors underscore the durability and longevity of the technology (Entrepreneur, Engineer, Researcher), and its commendable power delivery and acceleration (engineer, user, energy provider) as main potentials already developed, but. Still, also note that electrification needs to address larger utility vehicles (Public-Private Entrepreneur). In addition, the grid needs to incorporate mobile power storage units to apply the vehicle-to-grid concept (Engineer, Energy Provider), and various improvements are required to expand and improve the charging station network. A particular request voiced by several actors was streamlining payment services (Entrepreneur, Manager, User, Energy Provider). Lacking transparency in payment processes for charging increases the uncertainty associated with the technology for potential users. All of these factors contribute to building technological capacity for a large-scale transition to e-mobility. A further developed drive and battery technology, that serves different types of vehicles and interacts smartly with the grid would provide all additional functions to the mobility system (Administrative, Entrepreneur, Energy Provider). From an institutional perspective, the main objective of building capacity is to advance an effective policy mix and strengthen capability and competence within the administration and public service agencies, to progress policy, regulation, and governance. The entities involved need to be equipped with appropriate legal authority to enforce the statutes that are in place. This includes incentivizing the adoption of electric vehicles, creating operational structures, and synchronizing collaborative efforts among relevant stakeholders. It is particularly important to promote cooperation between municipalities and local companies (public-private, public-public, and private-private), as exemplified by several actors (public-private entrepreneur, public officer, manager, energy provider). An officer stresses that a trio of present challenges - digitization, electrification, and connectivity - need to be addressed by municipalities. This involves a spectrum of novel usage patterns, emergent business models, innovative mobility services, and an overarching transformation in mobility paradigms as part of strengthening cultural-cognitive capacity. Cultural-cognitive capacity here involves cultivating a societal shift in attitudes, norms, and beliefs to embrace electric mobility. Among the arguments raised within this category was heightening awareness of the advantages of electric vehicles in everyday-life contexts, and dispelling misconceptions, e.g., about range (both Users, Car-sharing Director, both Researchers and Energy Provider). Another partial but essential capacity addressed multiple times is the educational capacity generated by educating professionals, and providing training to strengthen skills and competencies. Building educational capacity can involve programs such as the "*showcase Lower Saxony*" described by a public-private innovation manager. The program seeks to enhance public dialogue and promotes test drives, but also increases the visibility of other electric vehicles such as buses and bicycles. It also includes specific training for professionals already in the field, but not yet familiar with electric drive technology, such as mechanics who need a specific certificate to operate on high voltages. This particular aspect was also raised as a recommendation by engineers and the operator of a local car workshop.

One not on policy process and approach, that leads us to further discussion of the results: In our study, actors primarily focus on identifying what needs to be addressed within their own institutional boundaries, which aligns with the concept of a "policy approach." This emphasis on institutional priorities reflects a limited ability or inclination to engage with the broader "policy process," which involves the interplay between multiple institutions. This observation is critical because it highlights the fragmented nature of policy discourse, where actors may not fully consider the interconnected dynamics inherent in sociotechnical transitions. The absence of substantial discussion on the policy process among actors can be attributed to two key factors. First, understanding the institutional capacities and constraints of other organizations involved in the process requires a broader systems perspective that many actors may lack. Second, actors tend to focus on their immediate institutional goals and roles, making it challenging to "think outside the box" of their organization. This insularity limits the ability to address challenges to the sociotechnical system collaboratively.

6. Discussion

The study raises issues relating to the complexity of policy implementation processes as viewed by different actors intermediating in the field. In particular, it indicates a need to achieve a shared understanding of the challenges and opportunities inherent in the transition, albeit with distinct perspectives shaped by their respective roles, expertise, and normative orientations. These differences highlight the importance of actor-centered analytical perspectives in understanding policy implementation processes, particularly in the context of e-mobility. Scott's institutional typology provides a valuable lens for framing these dynamics, as it highlights how regulative, normative, and cognitive pillars influence the behavior of organizations and individuals and stresses the role of institutional capacity. Some actors emphasized the importance of institutional capacity-building, fostering collaborations, and overcoming regulatory barriers (normative and regulative aspects). Other actors stressed the relevance of technical readiness and innovation, such as improved charging infrastructure or vehicle-to-grid integration (regulative and cognitive aspects). By considering how actors' experiences and normative orientations interact with these institutional pillars, this study offers a more comprehensive view of how policy is enacted and interpreted across different sectors.

Both actor interviews and policy review examined in this study reflect the complexity of the e-mobility transition. Across accounts, actors articulated distinct, field-specific challenges in navigating the e-mobility transition. Their perspectives underscore the need for improvements in institutional capacity, infrastructure development, and cross-sector collaboration through more coherent legal and procedural integration [91]. In line with broader understandings of capacity-building as the development of competencies, resources, and practices that enable collective action and strategic direction, our findings suggest that such capacities emerge across multiple, interrelated dimensions of the electric vehicle (EV) system. This aligns with existing research on transition management, which emphasizes the importance of strengthening systemic capacities—particularly across governance levels—to effectively steer sociotechnical change. [92,93]. Strengthening technological capacity involves not only advancing EV infrastructure—such as charging networks and grid integration—but also supporting continuous innovation in vehicle technology. Institutional capacity, by contrast, depends on improving governance structures and fostering effective cross-level coordination and policy integration. While cultural-cognitive capacity was addressed less frequently, it remains essential for shaping societal norms, user practices, and public acceptance of electric mobility. Educational capacity, meanwhile, is critical for developing a skilled workforce capable of supporting the technical and operational demands of the transition. The interplay of these capacities, when aligned with efforts to resolve the policy challenges

identified in this study, forms the basis for a targeted policy design and future research. Ultimately, the long-term success of the e-mobility transition will depend not only on technological progress but also on the establishment of a coherent policy framework that enables inclusive actor engagement and mobilizes expertise across sectors.

Drawing from the results we see a need for improved coordination, specifically in and between three fields: (i) Technically between research, manufacturing; and (ii) user experiences, infrastructure-wise, between grid operators, municipalities, and user representatives; and (iii) socially between experienced users, potential users, and public organizations. In terms of challenges to the EV sociotechnical system, we described how actors expressed concern about shortcomings and fundamental shortages for EV technology and the system. These can also be framed as bottlenecks or initial positions for political intervention [85]. What we found particularly is that actor perspectives of system challenges are also implied as challenges to the institutionalization of EV system elements. Moreover, the differing commitments of the actors stood out – that is, their differing roles, as expected, shaped their views of policy implementation problems and how they interpreted policy.

In terms of the relationship between actors' normative orientations and the problems identified in the sociotechnical system, however, a repetitive pattern was identified. The pro-EV normative orientations of actors contradict and contrast with the challenges and problems they regard as most disturbing and pressing to the transition of the system, i.e., the system deficits prevent their pro-EV stance from being realized in practice, and that tension also tends to catalyze engagement for change and transition. At the same time, analytically normative policy orientations are shaping the tasks they undertake and their impact on the system's overall functioning. Essentially, as hypothesized, actors' beliefs and policy perspectives interact with challenges to the sociotechnical system and their organizational roles which shape their actions and contributions to the transition to e-mobility. It is noteworthy that, within our set of interviewees, key actors, including administrative officials, project managers, researchers, coordinators, and representatives of lobby organizations, often played dual roles as users. They actively participated in the testing and evaluation of electric vehicle technology on a personal level in parallel with their strategic actions at a professional level. This dual function creates a self-reinforcing process where insights from both their professional and private roles enrich each other, contributing to further developments in the field. From the inferred recommendations for policy and capacity-building, we can infer a willingness on the part of each actor to contribute to the transition toward e-mobility as a whole. In many cases, their narrative content appears to be testimony to innovative and creative problem-solving accounts, particularly when taking the narrow limits of implementation into account.

Methodologically, we employ three foundational concepts to underpin our research: (i) the model for policy mix elements developed by Rogge & Reichhardt [41]; (ii) the dimensions of the automobility regime within the context of a multi-level governance framework presented by Hoffmann et al. [76] and (iii) Scott's model comprising the pillars of institutions [65]. Thus our research also contributes to the analytical discourse of sociotechnical transitions studies by demonstrating the practical utility of these conceptual frameworks per se and when brought together to outline a systematic approach for transferring expert knowledge. Arguably the compilation of instruments in the policy mix merits further research in-depth in transitions studies, focusing on the policy implementation part of the policy cycle, with a view to understanding the intricate and interrelated mechanisms and instruments at play in policy mixes.

Furthermore, there is room for future research to explore additional aspects, including the alignment of strategy with specific instruments, the effectiveness of various instrument types such as the purchase premium, and the evaluation of policy coherence when taking all governmental programs into account. When considering the broader sociotechnical system, assessing causality in transition processes is a formidable task due to their complexity and multidimensionality [84]. This complexity also extends to the analysis of policy implementation processes, which are influenced by the actions of intermediaries. Even with a wealth of data, attributing successes and failures to specific factors in the policy process remains challenging and requires additional methods and data sources such as regression analysis with quantitative data. As a consequence, the question arises as to whether a more transparent legal framework would lead to a denser network of charging stations or whether more funding for programs to promote public awareness and visibility of the technology would lead to higher sales of e-vehicles. Adapted quantitative research method could allow a reliable statement to be made in this regard. Given the exploratory nature of our research and the tentative nature of evidence in a single case study region, further investigations into the effectiveness of policy implementation are necessary. These would ideally take the complexity of policy implementation processes influenced by intermediaries into account and would use systematic assessment, data triangulation, and consultation of policy experts in a similar way.

7. Conclusion

This study has explored the perspectives of diverse actors involved in the e-mobility system in Lower Saxony, Germany, examining how they perceive and navigate challenges within the broader sociotechnical landscape of e-mobility. Based on interview data with actors from seven fields of action within the e-mobility system, and a review of the policy context, the analysis reveals problematic issues in several sub-areas of the sociotechnical system: resources, supply, and maintenance; infrastructure; technology and sociotechnical transitions; rules and regulations; cultural aspects; and user practices. We interpreted our results in terms of a need for a more comprehensive and integrated policy approach that addresses current deficiencies and shortcomings. By highlighting challenges related to infrastructure requirements and usage patterns of electric vehicles from the perspective of key actors we describe conditions, that need to be transformed for a continuing diffusion of electric vehicles. As a result of our analysis, we identified several system challenges to the implementation of e-mobility policies, including the availability and capacity of charging infrastructure, complexity, and confusion associated with charging tariffs, limitations in technological development and upscaling, and conflicts of interest and administrative guidelines within organizations. While these issues are widely recognized, our main contribution lies in emphasizing the need to consider the practical experiences and perspectives of diverse actors within the e-mobility system, who encounter and navigate these challenges in their intermediary roles. Yet, from a top-down perspective, a coordinated approach of adapted and orchestrated policy instruments can add to the improvement of e-mobility governance. Looking from a bottom-up angle the insights of expert knowledge provided specific and applicable recommendations to enhance capacities in the EV system. These include improving technological capacity through research, development, and innovation in EV technology, strengthening institutional capacity through policy coordination and collaboration between stakeholders, enhancing cultural-cognitive capacity by promoting awareness and dispelling misconceptions about electric vehicles, and building educational capacity through training and skill development.

Thus, in short, the research presented here highlights the need for a comprehensive and integrated policy approach, coordinated among the political levels. As shown, policymakers need to address the challenges and deficiencies to improve the adoption and diffusion rates on a pathway to sustainable mobility patterns. In addition to this, our analysis led to further information on the options available to enhance the current policy mix as a basis for future recommendations. Here we aligned with SDG 9 by addressing the development of sustainable and innovative mobility systems. By identifying policy and actor-driven strategies for e-mobility, the study contributes to building resilient infrastructure and promoting inclusive, sustainable industrialization,

key targets of SDG 9.

CRediT authorship contribution statement

Lea Gathen: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Paul Upham:** Conceptualization, Writing – review & editing, Supervision. **Jens Newig:** Software, Resources, Writing – review & editing, Supervision.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used DEEPL in order to improve the linguistic accuracy and correctness of the terms used. Chat GTP was employed to enhance readability and assist in the structural refinement of arguments by providing alternative formulations and suggestions for conceptual consistency. In particular, the tool was used iteratively during the revision process to align terminology and improve coherence across sections. All AI-generated suggestions were critically reviewed, adapted, and edited by the authors, who take full responsibility for the final content of the publication.

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 A. Supplementary data

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Data availability

The authors do not have permission to share data.

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Between Transition and Transformation: Understanding Sustainability Change through Governance, Agency, and Resilience —

A Qualitative Exploration of Complexity in Sustainability Change Discourses

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Abstract

Despite the growing body of research on sustainability transitions and sustainability transformations, conceptual overlaps and distinctions remain contested. This study investigates how leading scholars in these fields understand agency, governance, and resilience in the context of societal change. Drawing on 15 semi-structured interviews with highly cited transition and transformation researchers, we gather insights and make tacit knowledge visible from scholars whose work has significantly shaped the discourse. The findings show that agency centers on actor roles and collaborations, operates through a dynamic interplay between individual initiative, collective mobilization, and structural conditions. Governance ranges from state-led top-down and participatory bottom-up approaches at times combining both. Resilience highlights systems thinking and crises as potential catalysts. Beyond and within these themes, scholars reflect on the blurred boundaries between sustainability transitions and sustainability transformations, and on tensions between process-oriented inclusivity and outcome-oriented directionality as well as roles of researchers in transitions and transformations. By foregrounding the voices of scholars who shape these debates, the study shows that transitions and transformations should not be treated as linear pathways toward predefined outcomes, but as processes unfolding under conditions of uncertainty, where governance must balance directionality with openness. The study demonstrates how complexity-informed perspectives can advance sustainability research and practice.

Keywords: *sustainability transitions, sustainability transformations, system change, sustainability governance*

Author Statement

The order of authors reflects the sequence in which they joined the writing process. E.T. was responsible for the original research design, conducting the interviews, performing the initial phase of data analysis, and writing the original manuscript. J.G. was responsible for the research design of the second phase of data analysis, the conduction of analysis and its interpretation with L.G. supervising the process. The full manuscript was reviewed and edited by E.T., A.S., and L.G. with specific regard to the added theory section, a refined research question and modification of results and discussion. All authors contributed to the conceptual development of the study and its further development as well as writing during the review process. L.G. created the visualizations.

1. Introduction

Research on and for sustainability change processes is on the rise. Sustainability transformations (hereafter transformations) and sustainability transitions (transitions) are two most prominent conceptual approaches emerging in sustainability research fields, which are used to address the growing urgency of fighting present sustainability challenges such as climate change, biodiversity loss, and social inequalities.). The literature suggests that obstacles to sustainability change include governance and politics, structural barriers, cultural discourse, resistance from incumbent firms, and the complexity of multisystem interactions (Hausknost, 2020). The challenges that threaten the long-term security of societal development conditions are addressed by sustainability science at system, target, and transformative level (Brandt et al., 2013). Despite developments in sustainability science, the knowledge required to manage sustainability change processes is not unanimous.

To conceptualize the processes for sustainability change, various terms have emerged. From a top-down perspective, sustainable development has become a major goal and strategy at the UN level and is reflected in the Sustainable Development Goals (Kotzé et al., 2022), while bottom-up small-scale innovations toward sustainability are gaining visibility in politics, businesses, or other institutions. Ideally, the strategies to address and meet these should be informed by robust knowledge about sustainability change processes and driven by aligned efforts across different disciplines and fields (Studer & Pohl, 2024). Many sustainability studies remain focused on isolated elements or technical fixes, without addressing the deeper structural dynamics that sustain unsustainable systems—a challenge that Grin et al. (2010) identify as central to the governance of transitions (De Haan & Rotmans, 2011; Grin et al., 2010, Loorbach et al., 2017) also argue, that such a more fundamental systemic change is needed to facilitate the prevention of the collapse of ecosystems and social structures.

The literature reveals certain inconsistencies and disagreements in conceptualizing agency, governance and resilience within transformation and transition, for example in the role of agency versus systemic factors (Child & Breyer, 2017). While some researchers argue that agency is sufficiently embedded in transition studies, others emphasize the need for greater focus on individual-level agency, behaviors, and motivations (Koistinen & Teerikangas, 2021). Patterson et al (2017) have suggested scholars study sources of agency and roles for both state and non-state actors in enabling and supporting transformations as well as what types of institutions and governance arrangements are needed to enable and shape transformations. In addition, the distinction between process- and outcome-oriented understandings of change within the two frameworks reflects underlying theoretical commitments about how sustainability changes unfold and should be governed (Feola, 2015). Similarly, the frameworks incorporate different understandings of system dynamics and characteristics, which we look through resilience. That is the starting ground of this study, which provides explanatory insights into sustainability change and the conceptual subtleties and differences in terminology and understanding of change. Our guiding research question here is:

> *What do expert perspectives reveal about the theoretical and practical dimensions of sustainability transformations and transitions, particularly regarding agency, governance and resilience?*

Our underlying premise is that transition and transformation are not mutually exclusive but offer nuanced insights into societal change. We hold the assumption that differences between the concepts may arise from their origins and the associated research communities that use each concept. Drawing on and extending existing approaches (Linnér & Wibeck, 2021), we analyze the empirical material to reflect how leading scholars themselves understand the conceptual landscapes, in the light of agency, governance and resilience.

In summary, this article investigates how leading academic experts conceptualize sustainability transitions and transformations, revealing both convergences and tensions in how agency, governance, and resilience are understood. Drawing on Patterson et al. (2017) as an integrative framing, we examine how scholars articulate sources of agency, modes of governance, and system dynamics that shape and sustain transformative change. Through this lens, the study offers insight into how different research traditions approach the steering and emergence of sustainability processes. The following sections outline the theoretical foundations (Section 2), methodological design (Section 3), and main empirical findings (Section 4), before discussing conceptual frictions and opportunities for advancing sustainability change research (Section 5). The paper concludes by reflecting on broader implications for theory and practice (Section 6).

2. Theoretical Background

2.1. Concepts of sustainability transformation and transition

Transformations and transitions are interrelated, but distinct concepts used to analyze and guide large-scale societal change toward sustainability. The theoretical underpinnings of transition and transformation both draw on diverse disciplines and perspectives to address the complex challenges of achieving sustainability in various systems and contexts. Nevertheless, they differ in their disciplinary roots: while transition is connected to the theory of socio-technical transitions and originates in the fields of e.g. technology studies and institutional economics (Geels, 2002; Geels & Schot, 2007; Geels et al., 2017), transformation has more heterogenous origins. Both transformation and transition offer perspectives on how to describe, interpret and support desirable radical and non-linear change (Hölscher et al., 2018, Soininen et al., 2024). Transformation and transition have been used interchangeably and often metaphorically identifying pathways and solutions for sustainability problems and the concepts have moved closer to each other (Hölscher et al., 2018). The differences between the concepts stem to a great degree from the different research communities of origin and using the concepts. Several other conceptual definitions for societal transformation exist (Feola, 2015), but here we pinpoint the key features of the concepts of our focus: transition and transformation (Table 1).

Table I. Key features of sustainability transformations and transitions (adapted from Gathen 2025).

Aspect	**Sustainability Transformations**	**Sustainability Transitions**
Definition	Involves broader, fundamental shifts in societal values, behaviors, and structures to reimagine systems entirely.	Refers to long-term, systemic changes in socio-technical systems (e.g., energy, transport) to address sustainability challenges.
Focus	Aims for radical reconfiguration of systems and paradigms.	Concentrates on the process of change, emphasizing gradual, multi-dimensional shifts in technology, institutions, and culture.
Scope	Encompasses holistic and cross-sectoral changes at larger scales (e.g. international)	Typically addresses specific sectors or domains (e.g., energy systems).
Approach	Disruptive and transformative, often requiring shifts in power dynamics and deep cultural changes.	Often incremental and guided by governance frameworks like Transition Management.

Examples	Transforming societal norms around consumption and equity to create a just and sustainable society.	Transitioning from fossil fuels to renewable energy systems.

Sustainability transformation encompasses a profound, systemic change that fundamentally redefines societal norms, values, and structures (Brand, 2016). Widely used approaches in transformation research are leverage points (Abson et al., 2017; Meadows, 1999), three spheres of transformation (O'Brien, 2018), and heterogenous general references to sustainability goals. Leverage point perspective takes a stance on the depth of change – do the places for intervention allow deep or shallow societal change (Abson et al., 2017; Meadows, 1999). Heterogeneity of origins is reflected in the difficulty of settling how to measure transformation, and the desirable social endpoint is harder to define than the desirable ecological outcome (Salomaa & Juhola, 2020). Transformation requires radical changes rather than simply applying sustainability principles to an existing system (Hammond, 2020). In this context, the term "transformation" typically denotes extensive societal changes spanning global, national, or local levels, and including interactions between human and biophysical system components (Hölscher et al., 2018).

By contrast, transitions focus on systemic, incremental yet radical, shifts within socio-technical systems, such as energy, mobility, or agriculture. The multilevel perspective is an analytical framework that conceptualizes transitions by examining the development of niches that challenge existing unsustainable systems and potentially replace or reconfigure them (Geels, 2002; Temper et al., 2018). Moreover, understanding transitions further benefits from integrating techno-economic, socio-technical, and political perspectives (Cherp et al., 2018; Turnheim & Geels, 2012). In the transition scheme, the existing regime cannot induce transitions by themselves, often they stem from innovations, developed in niches and diffusing the market. This is the reason why transitions research is linked with research on experiments in society, for example on real-world laboratories and pilot projects, which often involve local and participatory elements.

2.2. Agency

Both concepts stress the role of human agency and innovation: transformation perspectives emphasize human agency, collective action, and innovation in driving systemic shifts (Westley et al., 2011), transition research links agency to the capacity derived from individual interests and resources, often contextualized within distinct phases of the change process (Bodenheimer & Dütschke, 2021; Huttunen et al., 2021).

One important dimension of agency within sustainability transitions and transformations is the evolving role of scientists in these processes. Traditionally viewed as external analysts, scientists are increasingly understood as embedded actors who shape, facilitate, and sometimes catalyze change (Scholz, 2017). In response to the growing complexity and normativity of sustainability challenges, research approaches such as transformative science conceptualize scientists as process facilitators and co-creators of change (Schneidewind & Singer-Brodowski, 2015; Wittmayer & Schäpke, 2014). This shift highlights the epistemic transformation underway in sustainability research, whereby knowledge is not only produced for society but co-produced with societal actors through structured, participatory engagement (Jacobi et al., 2022; Seidl et al., 2013). Transdisciplinary methods, including the use of real-world laboratories, institutionalize these interactive learning processes and position science as an integral part of governance frameworks for sustainability transitions (Singer-Brodowski et al., 2018; J. Wittmayer et al., 2021).

These developments underscore that agency in sustainability change is not limited to policymakers or civil society but includes scientists operating within new roles that challenge traditional boundaries between science and practice (Leventon et al., 2021).

2.3. Governance

Both transition and transformation traditions have considered how to analyze, understand and potentially shape the governance of societal change (Chaffin et al., 2016; Lange et al., 2013; Smith et al., 2005)**.** Transition governance sees private and public actors essential for changes and typically focuses on the governance in the various sectors of production and consumption, and it produces especially knowledge on disruptive interventions. A notable line of research for governance is transition management (Rotmans & Loorbach, 2009) and strategic niche management (Kemp et al., 1998). Governance of sustainability transformation is often linked to participation and equality questions, and inner dimensions are seen as important for achieving transformation. Accounting for the political nature of societal change is important for the governance of transitions and transformations (Patterson et al., 2017). Patterson et al. (2017) further encourage scholars to examine the sources of agency and the roles of both state and non-state actors in enabling and supporting transformations, as well as the types of institutions and governance arrangements needed to shape them across multiple scales. This perspective highlights why agency and governance questions are central for comparing how transition and transformation processes are conceptualized and enacted.

2.4. System dynamics and resilience

Transformation and transformation are both systemic approaches which make systems and system dynamics central in their exploration. Transition and transformation define the focus systems differently. Transition has been mainly employed to societal subsystems like energy, mobility or cities whereas transformation is more linked to studying social-ecological interactions and large-scale processes (Hölscher et al., 2018). Building on a socio-technical understanding of change processes, various models have been developed to capture specific aspects of change dynamics—for example, the archetype proposed by Gottschamer and Walters (Gottschamer & Walters, 2023) or frameworks addressing disruption and institutional decline (Newig et al., 2019). Complementing these models, researchers have introduced conceptual perspectives such as the resilience of sustainability transitions, which incorporate progress, stability, and adaptability as key dimensions of transition (Schilling et al., 2018).

Notably, the term resilience originates from the discourse on social-ecological transformations, having emerged within the field of ecology. Resilience refers to the capacity to maintain the central functions of systems following a disruption by absorbing or recovering from it (Holling, 1973; Folke, 2006). Social-ecological resilience has been typically studied within community- or resource-based systems. Nowadays, resilience is treated often as a way of thinking that describes a characteristic of a system (Folke, 2006). Change in the context of resilience of social-ecological systems especially focuses on shifts from one system state to another. In this context, the concept of transformation entails systemic change that, much like transition, involves shifts across ecological, economic, and social structures to promote sustainability and long-term resilience (Walker et al., 2004). In literature resilience is treated as both descriptive property and normative aspiration. Importantly, transformations are frequently associated with resilience, particularly in the sense that systems can shift to more sustainable configurations upon reaching critical thresholds or experiencing crises (Folke et al., 2010).

A further significant theoretical dimension concerns should analytical and practical focus be placed primarily on the processes that drive change, or on the outcomes these processes are intended to produce? This debate is pivotal to both the conceptualization and governance of sustainability transitions and transformations. On the one hand, emphasizing the process highlights the importance of inclusive, participatory, and adaptive approaches that engage

many stakeholders in cocreating solutions. On the other hand, prioritizing outcomes stresses the need for concrete, measurable results that address pressing environmental and social challenges. This dichotomy is not merely academic but has profound implications for how policies are designed, implemented, and assessed. The tension is further compounded by the inherent politicization of transformative processes, the necessity of adopting an anticipatory (ex-ante) perspective, and the challenge of balancing the desire for control with the inherently open-ended and evolving nature of such processes (Patterson et al., 2017).

To conclude, the theoretical exploration of sustainability transitions and transformations reveals a rich interplay of concepts, frameworks, and perspectives that converge on the systemic challenges of achieving sustainability. Both approaches emphasize the complexity and multidimensionality of change processes while stressing the importance of human agency, governance, and resilience in navigating these shifts. Following our research question, we will highlight this and provide examples from discourse and the accounts of academic experts.

3. Methods

3.1 Research Design

To investigate conceptual nuances in depth, the following sections outline the methodological approach adopted for this study. Building on the interpretive epistemological stance, the research design, sampling strategy, and data collection process are presented first, followed by an explanation of the coding and analysis procedures. Together, these methodological steps ensure that the study captures both the individual sense-making of leading scholars and the broader structural patterns shaping the discourse on sustainability transformations and transitions from interviewees' accounts.

Our study adopts an interpretive, social-constructivist approach to explore how transformation and transition are conceptualized within the scientific community. Understanding these concepts is situated within the “lifeworld” (*Lebenswelt*) of academic scholarship, where meanings are co-produced, contested, and refined through scientific discourse. Consequently, this research design focuses on gathering reflective, experience-based insights from scholars whose work has significantly shaped this discourse. The empirical strategy combines a systematic literature search for finding the interviewees with qualitative semi-structured interviews. While the interpretive paradigm emphasizes subjective meaning-making, a systematic sampling process enhances credibility by ensuring that selected participants hold recognized authority within this academic field.

Semi-structured interviews allow for consistency across core topics while accommodating the emergence of new perspectives during the conversation. Unlike a literature review of the same authors’ published work, semi-structured interviews enable the emergence of experiential and contextual knowledge, as well as researchers’ doubts and uncertainties, which are rarely documented in academic publications.
The interview with Leventon (Leventon, May 2023) serves as a good example illustrating this added value. It provided space to reflect on methodological standards and academic practices, such as publication pressures, that would typically remain implicit in written work. The open interview format also created space to address topics the interviewee described as “politically sensitive”, including questions of redistribution of goods and power. These often implicit assumptions underpin scholars’ understandings and uses of transformation and transition. Our aim is to clarify and differentiate the conceptual understanding of sustainability transitions and transformations within the academic discourse itself..As a consequence of this sampling strategy, senior Western scholars are disproportionately represented in the sample. This constitutes a limitation, as it risks reproducing existing epistemic hierarchies and privileging already dominant forms of knowledge. At the same time, these scholars represent an epistemic community whose knowledge production, contestations, and meaning-making practices warrant in-depth

exploration. Examining their perspectives therefore provides insight into how key concepts within this field are articulated, negotiated, and stabilised.

3.2 Sampling and Data Collection

Given the study's aim to analyze the academic use and differentiation of transformation and transition, the sampling strategy intentionally targeted leading scholars whose work has demonstrably influenced the field. The Scopus database served as the basis for identifying potential participants, ensuring transparency and thematic relevance. Two search strings were applied within the 'article title' category on March 17, 2023:

- **Search String I:** *transformati* AND sustainab**
- **Search String II:** *transition* AND sustainab**

To operationalize academic prominence, the inclusion criteria combined the number of publications retrieved with an H-index threshold of **h** ≥ 15. This metric served as a pragmatic proxy for scholarly impact. While acknowledging the known biases of the H-index — including its tendency to favor established researchers — it was preferred over single-number citation counts, which can be even more skewed (Costas & Bordons, 2007). A lower threshold was deliberately set to avoid excluding significant mid-career contributors. No geographic restrictions were applied during selection. However, the resulting sample reflects the predominance of transformation and transition scholarship within European and North American contexts, highlighting an ongoing imbalance in global scholarly visibility. An initial list of 40 potential interviewees was generated and then refined to address duplicate entries. Of all requested, 15 scholars replied positively and were thus interviewed. This sample comprised of six experts identified via the transformati* search and nine via the transition search. We used 13 interviews of the scientists who gave consent to their names to be published as the core sample. The final sample represents a cross-section of highly visible, thematically relevant voices whose reflections offer rich insight into the meanings, overlaps, and boundaries of transformation and transition within academic debate. Importantly, the labels used in Table A (In Supplementary material) should be understood primarily as resulting from the search process and the disciplinary background of the interviewed scholars, rather than as fixed self-ascriptions.

Data collection employed semi-structured interviews, conducted between April and May 2023 via recorded online interviews. An interview guide, developed from a review of relevant literature, included twelve core questions grouped into four thematic areas: *Understanding*, *Success*, *Examples*, and *Outlook* (view Supplementary material C). The design of the interview script was informed by prior literature in the field and aimed at investigating the researchers' subjective understanding about sustainability transformations and transitions. In addition to the interview guide serving as a structure for all the interviews. While the guide structured the conversations, its flexible application allowed for probing emergent lines of thought (Brinkmann, 2014; Sovacool et al., 2017). This approach not only allowed flexibility for emergent themes but also ensured comparability across interviews (Brinkmann & Kvale, 2019; Eagle et al., 2017). It further facilitated the elicitation of subjective theories, making implicit assumptions and individual perspectives accessible for analysis (Helfferich, 2011).. Interviews averaged 30 minutes and were transcribed for analysis. For a detailed list of the academics interviewed view the Supplementary material A and B.

This methodological design reflects the study's commitment to grounding conceptual insights in the lived expertise of the scientific community. By focusing on the perspectives of leading scholars, the study provides an interpretively robust basis for understanding how transformations and transitions are framed and differentiated in academic discourse — an essential precursor to any operationalization or application in practice.

3.3 Coding and Analysis

To guide the systematic analysis of the interview material, the study employed a two-phase coding strategy that integrates both inductive and deductive elements, consistent with a flexible qualitative approach (Saldaña, 2016; Thomas, 2006). Figure I shows the two-phase qualitative analysis procedure employed in this study. To further mitigate interviewer bias, the coding and analysis of the data was conducted by multiple people. In the firstphase, the general inductive approach (Thomas, 2006) allowed key themes to emerge directly from the data without being constrained by a rigid a priori framework. Through repeated readings and open coding in MAXQDA, recurring statements, shared meanings, and contrasting perspectives were clustered into preliminary themes, ensuring alignment with the interpretivist lens (Braun & Clarke, 2006).

Figure 1. Two-phase qualitative analysis procedure illustrating the different phases.

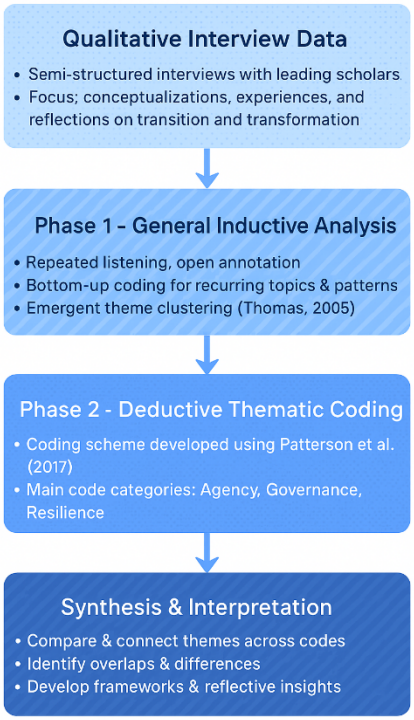

Figure I: Two-phase qualitative analysis procedure (illustrating the inductive and deductive stages of data analysis, including coding, interpretation, and synthesis steps).

To further deepen the analysis and sharpen the conceptual focus, a second, more deductive phase was introduced, drawing on established frameworks for studying transformations and transitions. In phase two, coding structured by the categories of *Agency, Governance, and Resilience*. We developed our coding scheme with inspiration from Patterson et al (2017), using their framing to guide the identification of agency, governance, and institutional dimensions in the interview material. As we were interested in comparing the views on dynamics and characteristics of a system, we chose to operationalize this through resilience. To further systematize this stage, elements of Kuckartz & Rädiker (2022) structured content analysis were applied. This involved iterative steps such as case summaries, memo writing, and the use of MAXQDA functions (e.g. code-relation browser, summary grids) to refine category development and ensure analytical transparency (Supplementary material D-F). The final coding scheme comprises three main thematic areas each with a set of analytical subcodes. An additional meta-reflection category was used to capture cross-cutting reflections on conceptual ambiguity, epistemological positioning, and scholarly self-understanding (Charmaz & Belgrave, 2014; Flick, 2019). During coding the codes were systematically organized and coded segments compared, enabling the tracing of both converging and diverging interpretations across the expert interviews.

Most of the coded segments related to agency were assigned to either actor types and roles, collective agency or individual agency. The most frequently mentioned category was governance with 114 coded segments addressing at least four of the five subcodes. The emerging themes from each code (for codebook view Supplementary material E) are grouped in two directionalities or modes of governance for summary: Regime and policy-driven governance (top-down mode) and polycentric and participatory governance (bottom-up). To add another layer of depth to the analysis, the interview material was reviewed to search for recurring themes of each governance code: Institutional Arrangements, Types of Influence, Power & Politics and Participation & Inclusion. Here the motivation was to capture the role governance was assigned to in sustainability transitions and transformations.

For transparency, the Supplementary material G provides a complementary table that links each dimension more explicitly to individual expert perspectives, ensuring traceability. For the category of resilience, coding focused on how interviewees conceptualized system stability and adaptability across ecological, social, and technological dimensions, including reactions to stress, the role of crises and tipping points, and the links between resilience, transition, and transformation.
We don't compare these results to the literature the same authors have written but rather aim to capture the content of discussions. We also made remarks on roles of scientists and epistemological tensions during the coding process; these results we discuss in interplay with literature on these topics.

Our two-phase coding design represents a robust approach: the inductive phase ensured openness to the participants' perspectives, allowing nuanced views to surface freely, while the deductive phase added analytical focus on theoretically significant aspects of agency, governance, and resilience. Together, these phases ensured a transparent, systematic, and theoretically grounded analysis of how experts conceptualize sustainability transition and transformation. This reflects a reflexive, interpretivist process of knowledge co-production, in which scholars' perspectives, particularly regarding agency, resilience and governance are engaged as part of the evolving discourse (Patterson et al., 2017) and reveal theoretical and practical dimensions of sustainability transformations and transitions.

4. Results

4.1. Expert perspectives on agency, governance and resilience

The interviews revealed diverse perspectives on how sustainability transitions and transformations are conceptualized and operationalized. While the experts acknowledged overlaps between the two discourses, their accounts showed different characteristics in terms of agency, governance, and resilience, as well as broader reflections on conceptual clarity. Rather than producing a unified definition, the interviews highlight a spectrum of positions rooted in professional experiences and disciplinary traditions. The interdisciplinary nature of the field is highlighted by academic Florian Kern as moving across *"very different schools of thought from sociology to political science to economics, evolutionary economics and international relations, institutional theories, [and] consumption studies"* (Kern, May 2023). The following subsections outline key themes that emerged across the interviews, framed by Patterson et al.'s (2017) emphasis on agency and governance, and in addition resilience.

4.2 Agency: Sources and Roles

Across the interviews, agency was a critical element of how sustainability change is conceptualized. Yet, the ways in which experts described its sources and roles varied, reflecting disciplinary backgrounds and professional orientations. Most of the discussion related to agency were on either *actor types and roles, collective agency or individual agency*. We will follow this scheme. Several participants framed central actor roles in terms of innovators, niche actors, and local communities, who can experiment with new practices and technologies and gradually scale them into broader societal uptake. This perspective aligns closely with the transitions discourse, which emphasizes incremental, bottom-up processes of change driven by actors working within protected spaces. For instance, Raven (Raven, May 2023) gave a practical example of the energy movements for renewable energy in Denmark and Germany as initial bottom-up initiatives, which were able to scale up. Another typical actor's roles framed and referred to in the material were the powerful: incumbent actors, elites, politicians and economic actors. Politicians can enable both sustainable and unsustainable pathways. A little less frequently mentioned were the marginalized actors: indigenous or marginalized groups as well as activists and media. Also inherent were institutions, institutionalized actors, government agencies, as well as small businesses and NGOs.

Secondly, agency was referred to as a collective and systemic phenomenon, emphasizing mobilization across wider segments of society. Here, agency was seen as the capacity to deliberately reorient societal priorities, norms, and values, a framing more consistent with transformations. In this view, movements, coalitions, and citizen groups were often positioned as crucial agents, rather than individual innovators or organizations:

> *"I think […] that people don't talk enough about are social movements and transformative change from the bottom up that aren't driven by technology or policy, and they're driven by coalitions of people […]. They started from the ground up with the social problem."*
>
> Benjamin Sovacool, April 2023

It was emphasized that agency is not an individual attribute but a relational and contextual phenomenon, becoming particularly visible in moments of disruption or crisis. When established systems are disrupted, agency can be mobilized through crisis and opportunity but whether this leads to incremental adjustment or deeper transformation depends on the surrounding governance arrangements, on policy and structures for political opportunity (Kern, May 2023). Agency was viewed as very much influenced by institutional structures, political opportunity spaces, and the ability of actors to form alliances across scales. Some scholars drew attention to the tensions between individual and collective agency, noting that while individuals may act as catalysts, enduring transformation requires broader networks and coalitions to sustain momentum. Yet, the two scales are interlinked with *individual agency* mostly viewed as an enabler for *collective agency.* Here, two operational modes could be identified: relationship-building between actors and cross-sectoral collaboration. The significant references to shared visions and narratives by transformation scholars aligns more with relationship mode. While scaling-up bottom-up alliances (as brought up by some transition scholars) aligns stronger with the cross-sector collaboration.

Taken together, these perspectives suggest that agency in sustainability change processes cannot be reduced to a single source or level. Rather, it operates through a dynamic interplay between individual initiative, collective mobilization, and structural conditions. Recognizing this plurality highlights both the complementarity and tensions between transition-oriented and transformation-oriented understandings of agency.

4.3 Governance: policy, institutions and arrangements

Governance was the most frequently coded term and was addressed by each interviewee, approximately half of the sample engaged substantively with governance. Across the interviews, governance was conceptualized primarily in democratic terms, grounded in parliamentary representation, shared power distribution, civic participation, and reflexivity of governance. Two directionalities or modes of governance were apparent.

In the first mode, top-down governance, comparatively more weight was placed on the role of the state, policy and regulatory interventions. Policies may take the form of legislation (including directives), guidelines, distribution of information and financial incentives (Raven, May 2023). A recurring objective through the perspective of transition studies here is to foster niches and innovations as a seed for changes to the system that can be potentially scaled (Kern, Raven, both May 2023). When analyzed in more detail, this policy-driven governance is seen to unfold through specific mechanisms of actor involvement and institutional design. Kern highlights how public policy can act as both a supportive and destabilizing force, influencing incumbents and newcomers alike:

> *"Public policy can support such transitions through policies, through policy mixes, through governance approaches, […] but even the most powerful government in the world cannot change it alone […]. There are a lot of different actors involved, and the interplay between them is crucial."*
>
> Florian Kern, May 2023

Building on this perspective, several experts further emphasized the role of institutional arrangements, including formal guidelines, economic conditions, international agreements, financing models, and intermediary actors. The top-down mode portrays governance in relatively hierarchical terms, with the state and its policy instruments in a position of authority. While the available steering mechanisms are diverse, their sustainability impact ultimately hinges on the orientation and resolve of political actors. At a structural level, Coenen (Coenen, April 2023) underscores this by arguing that the climate crisis should be addressed with the same urgency and state-led measures as inflation.

In the second mode, polycentric and participatory governance perspective, the government holds power but delegates and distributes it. Top-down processes are viewed critically, as they have often failed historically (Kemp, May2023) and generated resistance among those being told what to do (Abson, April2023). Instead, responsibilities should be shared and solutions co-created rather than imposed (highlighted by Abson; Sovacool, both April 2023). While this mode of governance is collective, interventions should include small-scale experimentation and be experience-based. Such processes require ongoing deliberation and need to be connected to collective agency and shared visions. As stated before, inclusion is treated as a foundational design principle by several researchers. The ethical and moral guideline stated here, is identify who is most vulnerable and ensure these groups are substantively represented in agenda-setting, decision-making, implementation, and evaluation. Without such democratic inclusion, change processes are at risk to backlash and reverse (Wibeck, May 2023). The visible modes of governance included a range from top-down to bottom-up, at times combining both referring to networked and heterarchical arrangements with discursive spaces.

Table 2 presents a synthesized overview of the governance-related challenges and sometimes prerequisites for changes towards sustainability, as viewed by the experts. This condensed representation also highlights cross-cutting issues that emerged consistently across interviews. For example, a prevalent aspect was that balancing power is an essential and should be accompanied by *fundamental questioning* of "*who holds power, where does it sit, how is it facilitated"* and an ongoing reflection (Leventon, April2023). This discussion is linked with decolonial orientation. The experts also described governance modes that combine state-led top-down steering with participatory bottom-up elements, alongside networked/heterarchical arrangements and discursive spaces. Detailed case summaries of expert views on governance are found in the Supplementary material F.

Table II: Governance of sustainability change processes, synthesized across key dimensions, emerging themes and interpretive synthesis.

Dimension	Emerging Themes	Interpretive Synthesis
Institutional Arrangements	Formal policies, economic frameworks, international agreements, funding schemes, and mediating roles.	Institutions shape pathways to change but risk reinforcing incumbency unless inclusivity and adaptability are ensured.
Modes of Governance	State-led top-down and participatory bottom-up governance, networked/heterarchical arrangements, discursive spaces.	Effective governance requires pluralistic, participatory modes that balance experimentation with legitimacy.
Types of Influence	Policy incentives, bans, subsidies, information provision, vision-building, narratives.	Influence operates through both material instruments (policies, technologies) and immaterial means (stories, discourse).
Power & Politics	Distribution of power, elite capture, vested interests, media-driven polarization, short-termism.	Addressing power imbalances is essential; without reckoning whose voices count, governance risks losing legitimacy.
Participation & Inclusion	Engaging vulnerable groups, fostering trust, creating collective visions, education, equity.	Inclusion is a prerequisite for legitimacy and durability of change; exclusion risks backlash and failure.

Beyond these normative considerations, the interviews also reveal disciplinary distinctions in how governance itself is framed. Contrasting the use of “governance” between transformation and transition scholars reveals tendencies, though less clear-cut than for agency. The role of technological innovation in change processes is addressed exclusively within transition research (Coenen, April 2023; Kern, Linner and Raven, all May2023). Polycentric and participatory elements are emphasized in both streams; however, among transformation scholars they appear more deeply embedded in the underlying architecture of governance (Leventon and Horcea-Milcu, both April 2023; Pereira, May 2023).

4.4 Resilience and Dynamics of Change

A small number of interviewees explicitly referred to resilience thinking, most notably Abson (Abson, April 2023) and Pereira (Pereira, May 2023), both of whom are closely associated with transformation research. This is unsurprising given the conceptual proximity between transformation and resilience (as noted by Pereira, May 2023). Where resilience was directly invoked, it served to highlight factors that strengthen systems against disruption. The boundaries of the systems were defined differently, but primarily in relation to social systems. Leventon (Leventon, April 2023), for example, employed the notion of a “social tipping point” to describe the dynamics of political polarization, while Kern (Kern, May 2023) examined the social security system. He argued that increasing independence and decoupling of the social system from economic growth could reduce systemic vulnerability and enhance the resilience of the social system to potential dysfunctions. To describe a state of stability reached after a phase of change slows down, he used the concept-specific term “equilibrium.” Kemp (Kemp, April2023) offered a different perspective on strengthening systems, emphasizing the importance of experience-based learning processes as a means of maintaining stability. Although resilience was rarely mentioned explicitly, many experts implicitly adopted a resilience perspective through a broader systems-thinking lens. Intent was seen as particularly crucial system characteristic for enabling fundamental change (Abson, April 2023). However, it is also inherently ambivalent, as systems may simultaneously pursue multiple, competing objectives, which can easily generate contradictions or hinder transformation and similar tensions arise in relation to system stability (Abson, April 2023). Ecological systems may require accelerated change to adapt and remain resilient, whereas social systems often need to slow down change processes to maintain stability (Coenen, April 2023). Interviewees' arguments often pointed toward the capacity of social or institutional structures to adapt, reorganize, and persist amid disruption, even if not framed with resilience terminology. The disparity between direct and indirect mentions illustrates that although resilience language is not dominant in academic discussions of transition and transformation, its principles continue to inform how scholars conceptualize sustainability change processes. Tensions emerged between seeing resilience as maintaining function versus as enabling deep structural change, underscoring the complexity of operationalizing the term across contexts.

4.5 Concluding reflection on agency, governance and system dynamics

Taken together, the empirical results show themes across the three analytical lenses. Unsurprisingly, our results aligned with transitions and transformation discourses. Quantitatively, governance emerges as the dominant theme, followed by agency, while resilience appears more specialized and less frequently foregrounded. We followed Patterson et al (2017) in studying understandings of sources of agency and roles for actors in enabling and supporting transformations as well as governance arrangements which are needed to enable and shape transformations. *Agency* discussions cluster around actor roles, inner capacities, and the importance of cross-actor collaboration, which is similar to the findings by Fischer & Newig (2016). The diversity of perspectives on agency reflects its central function in system theories, where change is understood as emerging from the interplay between structure and human action. *Governance* debates range from state-led policy interventions to polycentric participation, complemented by perspectives that foreground power-critical or decolonial orientations. Here it could be interesting to have a closer look as causal mechanisms in the future (Newig et al., 2017).

The relative visibility of governance might be surprising, but it reflects that balancing power is crucial for achieving transformations and that leading scholars believe in the capabilities of governance to enable and steer such change (Patterson et al., 2017). The frequencies of the themes can be partly due to our research design. Our reflections on system dynamics, through understandings of *resilience* emphasizing intent, interdependence, and nonlinear dynamics, likewise align with Patterson et al. (2017) in recognizing the catalytic role of crises as moments that can destabilize existing regimes and open windows for transformation. While acknowledging these, the importance of stability and independence within systems was likewise highlighted, especially in relation to social systems. The frequent adoption of resilience through a broader systems-thinking lens indicates that resilience functions less as an explicitly articulated framework and more as an underlying conceptual lens in academic discussions of transformation.

The findings also demonstrate the interweaving of themes: for instance, governance discussions frequently touch on questions of agency, and resilience perspectives often depend on governance arrangements to unfold. It also opens space for broader reflection: how do these conceptual strands converge or diverge when seen through the lenses of transition and transformation? And what does this mean for the role of scholars, the epistemological underpinnings of the field, and the balance between process- and outcome-oriented framings?

5. Transitions ≠ Transformations - Exploring conceptual frictions and opportunities in system understandings

5.1. Conceptual boundaries

Beyond specific debates on agency, governance, and resilience, many experts reflected on the general conceptual fuzziness between transitions and transformations in systems thinking. Some resisted drawing sharp distinctions, instead viewing the concepts as complementary lenses for understanding different dimensions of societal change or as a vital element of democracy:

> *One interesting thing about this field of research is that there is no […] consensus, and maybe there shouldn't be. […] In a democratic society, we also need to have this constant discussion about priorities and politics and what the goals and the outcomes would be. […] there is this constant discussion about what transformation needs and what are the pathways, who are the actors, the drivers. […] that in itself, it's important […].*
>
> Victoria Wibeck, May 2023

Other researchers expressed concern that the proliferation of frameworks risks fragmentation and conceptual inflation, potentially confusing both scholarship and practice. Looking at whether interviewees distinguish between the two concepts, the findings suggest a spectrum of positions rather than a clear divide. Some interviewees explicitly articulated distinctions, often along lines of scope and depth: transitions were frequently described as changes within socio-technical systems or sectors, whereas transformations were framed as more comprehensive, cross-sectoral, and structural changes affecting entire societal systems. Others conceptualised the two as relational, for example by viewing transitions as pathways or components within broader transformation processes, with transformation representing a more fundamental end state. At the same time, a considerable number of interviewees reported using the terms interchangeably or without a strong commitment to distinguishing them. In contrast, a few interviewees reversed or blurred commonly assumed definitions, for example by describing transformations as changes within existing systems or as synonymous with transitions. This ambivalence resonates with the multidisciplinary roots of both traditions, as highlighted in our theoretical review. Importantly, several interviewees highlighted that the distinction between transitions and transformations may be as much a matter of language and disciplinary background as of substantive conceptual disagreement. The two terms were frequently associated with different epistemological traditions and research communities—transitions with socio-technical and

multi-level perspective approaches, and transformations with socio-ecological and resilience-oriented frameworks. In this sense, differences in terminology often reflect “different coexisting tribes with different conceptual approaches” (*Kern, May 2023*), rather than fundamentally incompatible understandings of societal change. This also explains why some scholars perceive increasing blurriness between the terms over time.

Overall, the interviews suggest that while a subset of scholars does draw relatively clear conceptual distinctions, a significant proportion either treats the terms as overlapping or views their differentiation as context-dependent and normative. Based on our results, we can confirm the description of Hölscher et al. (2018) that both conceptualizations offer valuable perspectives, and transition has more focus on subsystems whereas transformation is more linked to interactions and large-scale processes (Hölscher et al., 2018). More specific use of the concepts might be useful for the research field, but seems unlikely given the broadness of the field.

5.2 System Understandings: Between Steering and Emergence

These epistemological tensions between concepts are also visible in how interviewees relate the two concepts to process and outcome dimensions. Transitions are often associated with pathways, mechanisms, and sectoral change processes, whereas transformations are more frequently linked to systemic outcomes, paradigm shifts, and broader societal reconfigurations. However, this distinction is not consistently upheld across the sample, further reinforcing the notion that conceptual boundaries remain fluid and contested.

A recurring theme across interviews concerned the question of how sustainability change can be understood, guided, and evaluated. The distinction between process and outcome, discussed in both transition and transformation research, reflects a deeper epistemological tension about the nature of systems themselves. Scholars differ in whether they view sustainability change as something that can be steered toward defined goals or as an inherently emergent, evolving process that resists precise prediction or control.

Central to these reflections was the question of how sustainability change should be understood, guided and evaluated – through the ‘processes’ it unfolds or the ‘outcomes’ it achieves. Many interviewees leaned toward process-oriented perspectives, pointing to the inclusiveness, legitimacy, and adaptability of change as critical to ensuring durable sustainability outcomes. For these scholars, focusing prematurely on outcomes risks overlooking the deep system characteristics—such as intent or design—that must be challenged for transformation to take root. This very much aligns with an understanding of systems as complex, adaptive, and continuously unfolding, where interventions can only create conditions for transformation rather than determine its results. Scholars of transformation actively argue for this systems perspective (Feola, 2015; Feola et al., 2021; Turnhout et al., 2020). Several experts highlighted that measurable outcomes are important for legitimacy and accountability, yet difficult to capture when transformations are ongoing and dynamic. Other interviewees insisted that the measurability of outcomes is necessary, as transitions and transformations ultimately aim at achieving more sustainable configurations, and without assessing directionality, progress remains uncertain. Some advocated combined approaches that connect process indicators with outcome benchmarks, for example, comparing system performance at different points in time to evaluate whether change leads to genuine sustainability gains.

In all of this, steering remains a central aspiration of sustainability governance. As Patterson et al. (2017) note, deep societal change requires both anticipatory policy frameworks and an acknowledgment of unpredictability. This duality was echoed by our interviewees, who spoke of the need to balance structure with openness, direction with flexibility. Salomaa and Juhola (2020) point out that focusing on outcomes is often linked to operational issues of assessment and evaluation. While process-oriented approaches foreground learning and inclusion. Yet both perspectives share the aim of fostering systemic resilience and directionality amid uncertainty.

Taken together, these insights suggest that sustainability transitions and transformations are characterized by a persistent negotiation between steering and emergence—between the desire for control and the recognition of complexity (Stirling, 2010). Understanding systems in this way means accepting that sustainable change unfolds through iterative, contested, and co-evolutionary pathways rather than linear trajectories—an understanding that calls for reflexive governance and adaptive evaluation approaches capable of navigating this tension.

5.3 Academia as mediating form of agency

Variations in understanding the role of science from descriptive-analytical to process oriented offer various roles for scientists (Wittmayer & Schäpke, 2014). Illustrating the increasingly recognized embeddedness of scientists in sustainability change processes, we briefly discuss actor roles of scientists here. By reflecting on the concepts of transition and transformation, scholars do not simply analyze social realities from a distance; they actively shape the discourses that inform governance, policy, and practice. This dual role of scientists as both observers and participants depicts and shows an epistemic transformation underway in sustainability research (Scholz, 2017; Wittmayer & Schäpke, 2014).

From an agency perspective, academia represents a mediating form of agency—linking analytical observation with transformative practice. Rather than acting solely as external commentators or activist drivers, scientists navigate between these poles, shaping how sustainability transformations are conceptualized and enacted. Within this spectrum, more traditional transition scholars tend to maintain clearer boundaries between academic analysis and activist engagement, emphasizing that conceptual clarity and cumulative knowledge themselves contribute to systemic change. Several transformation scholars emphasized the continued need for knowledge generation—particularly target knowledge, transformative knowledge of inner dimensions, and deeper process-oriented insights (for example, Abson, April 2023; Horcea-Milcu, April 2023; Linnér, May 2023). Others argued that the challenge lies less in producing new knowledge than in mobilizing and transmitting existing insights into societal action. This view aligns with calls for problem-oriented, transdisciplinary research that bridges academic discourse and societal application (Jacobi et al., 2022; Singer-Brodowski et al., 2018; Wittmayer & Schäpke, 2014).

While navigating between attempts to produce knowledge and action, scientists face multiple conflicts of interest including within university practises and career incentives. Academia needs also to address the power imbalances alike the broader society. At the same time, the broader literature and expert perspectives highlight the multifaceted role of scientists as knowledge generators, transmitters, and facilitators, as well as other intermediary forms of agency (Gliedt et al., 2018; Kanda et al., 2020; Kivimaa, et al., 2019a; 2019b). Such pluralism within the academic community is not necessarily a weakness but may instead foster the democratic contestation needed for sustainability debates to remain open, legitimate, and adaptive (Linnér & Wibeck, 2021).

6. Conclusion

This paper examined how leading scholars conceptualize sustainability transitions and transformations through the lenses of agency, governance, and resilience. Agency operates at multiple levels, governance is central to the discourse on transition and transformation, and resilience remains an undercurrent. Our research approach enabled the emergence of tacit knowledge from the scholars who shape the discourse. These are visible for example on the emphasis on collective agency over individual agency and the self-critical reflections on conceptual fuzziness. Rather than converging toward a unified understanding, the findings reveal a field characterized by conceptual plurality and ongoing negotiation. Importantly, the interviews show that these differences are not merely semantic but reflect deeper assumptions about how complex systems change—whether through steering, emergence, or their interplay. In this sense, sustainability scholarship operates not around stable definitions, but around productive tensions that shape both analysis and action.

What emerges from the empirical material is a more explicit articulation of sustainability change as a complex, adaptive, and co-evolutionary process in complex systems. Experts consistently emphasized interdependence, nonlinearity, and the catalytic role of crises, while also highlighting the limits of prediction and control. This suggests that transitions and transformations should not be treated as linear pathways toward predefined outcomes, but as processes unfolding under conditions of uncertainty, where governance must balance directionality with openness. The distinction between process and outcome, as well as between steering and emergence, thus reflects a broader systems understanding that is central to both research and practice. The academic themself have a role of mediating agency in these transformations and transitions.

These insights carry implications for sustainability scholarship. Rather than seeking conceptual closure, future work should engage more explicitly with the tensions inherent in complex systems and develop approaches that integrate process-oriented and outcome-oriented perspectives. This includes rethinking how concepts are operationalized, moving beyond static indicators toward more adaptive and context-sensitive forms of evaluation. For governance and policy, the findings underline the need for approaches that combine strategic direction with flexibility, and that acknowledge uncertainty as a structural condition rather than a temporary limitation.

At the same time, the study is limited by its focus on academic expert perspectives, which reflect particular epistemic communities, Western established scientists, and may not fully capture how concepts are enacted in practice. In addition, the short duration of interviews gives only a partial image of the thinking of the interviewees. Future research should therefore extend this work by synthetizing and linking conceptual debates more closely to empirical cases, exploring how systems thinking can be operationalized in concrete governance settings, and further developing integrated approaches to facilitate and monitor sustainability change, extended to countries beyond the Western hemisphere.

Declaration of generative AI in scientific writing

The authors declare that they used the software tools ChatGTP and DeepL to improve the structure and flow of the language in specific parts. After using the service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Data availability statement

The authors do not have permission to share data. All data has been stored anonymised on appropriately secured servers provided for this purpose according to the guidelines of the Leuphana University and will be deleted after a finite period of time.

Informed consent to participate statement

All interview participants provided oral informed consent prior to participation. The researchers named in the article have additionally given written consent for their mention and were fully informed about the purpose and objectives of the study. All consent forms are securely stored in digital form and can be made available to the editors upon request.

Ethical compliancy statement

The research conducted in this study is in accordance with the ethical standards of the Leuphana University and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Competing interest and funding statement

The authors have no relevant financial or non-financial interests to declare.

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