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Research article

Home field advantage: examining incumbency reorientation dynamics in low-carbon transitions

Sophie-Marie Ertelt [a,*], Johan Kask [b]

[a] *Center for Sustainable Business, School of Business, Örebro University, Fakultetsgatan 1, 702 81 Örebro, Sweden*
[b] *Center for Research on Digitalization and Sustainability (CREDS), Inland Norway University of Applied Sciences, Strandvegen 3, 2212 Kongsvinger, Norway*

A R T I C L E I N F O

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A B S T R A C T

Recent work has offered a more nuanced view of incumbent actors' roles in transitions, yet a comprehensive understanding of how reorientation activities and subsequent interaction patterns *among different* incumbent *actor types* shape the direction of system reconfigurations remains underexplored. This paper proposes a framework for empirically assessing actors' relational dynamics in response to low-carbon transitions and conceptualises actor interaction types and the nature of their interaction. Through a case study of the low-carbon transition of road freight transport in Sweden, we examine how reorientation dynamics, e.g., coalitions, competition, and contestations, can facilitate and hinder system reconfigurations by creating regime tensions. Our study highlights that incumbency reorientations are multi-dimensional, with actor involvement and strategies varying, leading to divergent actor positions and role constellations as actors attempt to reconfigure the focal regime. Extending beyond the Swedish case, five avenues for future research are outlined.

1. Introduction

Phasing out fossil fuels across all industry sectors globally will be necessary to reach net-zero targets and limit warming to 1.5°C. With the growing urgency of such low-carbon transitions — aimed at reconfiguring current socio-technical systems (hereafter: systems) that fulfil societal functions, like mobility or energy, to mitigate climate change (Geels et al., 2017; Geels and Turnheim, 2022) — the role of incumbent actors in these transitions has become an important topic (Mori, 2021; Steen and Weaver, 2017; Turnheim and Sovacool, 2020). Compared to historical transitions, research on ongoing transitions often challenges the stereotype of incumbents — established actors in state, market, or civil society — as transition opponents and resistant to change. In response, recent transition literature has proposed a more pluralistic view on incumbencies in transitions (Apajalahti et al., 2018; Berggren et al., 2015; Markard and Rosenbloom, 2022; Turnheim and Sovacool, 2020) and developed system reconfiguration approaches (Geels, 2018a; Geels and Turnheim, 2022; McMeekin et al., 2019). These contributions provide an analytical perspective on how existing structures and rules that orient established actors and coordinate activities of vital societal functions can be altered endogenously. System reconfigurations thus occur through incumbent actor reorientation activities — a shift in focus, support, or resources from stabilising existing systems to low-carbon innovations (Geels and Turnheim, 2022) — which changes the elements and architecture of an existing system (Geels et al., 2017; Geels, 2018).

* Corresponding author.
E-mail addresses: sophie-marie.ertelt@oru.se (S.-M. Ertelt), johan.kask@inn.no (J. Kask).

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However, even though established actors' reorientations are crucial for the diffusion of low-carbon innovation (Geels, 2021; Kump, 2023), incumbency reorientations — the changes in interaction patterns among incumbents as they reorientate their activities in transitions toward net-zero societies — are still not well-understood in transition studies (Farla et al., 2012; Mori, 2021; Steen and Weaver, 2017). Research on how different interests and strategies of established actors and the resulting interaction among them may contribute to regime stability or change is especially scarce (Mori, 2021; Stirling, 2019; van Mossel et al., 2018). Even though transition scholars already use organisational field approaches (Fligstein and McAdam, 2012; Hoffman, 1999; Scott, 1995) to conceptualise a socio-technical regime (hereafter: regime) as the system's path-dependent but dynamic "grammar" that orients actors' interactions (Fuenfschilling and Truffer, 2014; Geels, 2020; Schot and Geels, 2007), this dynamism remains largely black-boxed (Steen and Weaver, 2017). Too often, this results in a congruent and confined portrayal of regimes with established actors aligned over one pathway (Stirling, 2019; Turnheim and Sovacool, 2020). We argue that this frequent disregard for the heterogeneous nature of incumbency exposes a gap in the literature on how diverse actor interaction patterns amongst actors, such as coalitions, competition, or conflictual relations and the potentially resulting tensions, may contribute to (or hinder) system reconfigurations.

Against this backdrop, this paper aims to add to the conceptual understanding of incumbency pluralism and the possibilities of regime tensions in low-carbon transitions. It examines reorientations of established actors, the resulting changes in interactions amongst these actors, and their aggregated impact on system-level reconfigurations. In doing so, this study addresses the following research question: *How do incumbency reorientations and the resulting relational changes actively contribute to (or hinder) system reconfigurations?* To answer this question, we use organisational fields as a theoretical and methodological construct (Wooten and Hoffman, 2017). Rather than focusing solely on actors *per se*, our analysis emphasizes actor interconnectedness and interdependencies (Darnhofer et al., 2019; Stirling, 2019) and the varying nature of the resulting interactions (Konrad et al., 2008; Raven and Verbong, 2007) may impact reconfiguration processes.

Empirically, we draw from a case study of the Swedish road freight sector, analysing a governmental initiative referred to as the Electrification Pledges — formal commitments made by 252 public and private actors specifying concrete activities to accelerate electrification (Regeringskansliet, 2021). This concerted effort aligns with Sweden's goal of net-zero freight transport by 2045 (Regeringskansliet, 2020), making the pledges a significant step toward that goal. These pledges are characterised by a variety of reorientation activities aimed at promoting electrification and decarbonisation, including planning and locating charging infrastructure, connecting charging services to grid-related services to mitigate costly grid peaks, ensuring robust electricity grid capacity, and updating procurement processes to facilitate electric goods transport services. Automotive manufacturers, utility and grid operators, charging and hydrogen infrastructure providers, fuel suppliers, freight companies, transport service purchasers, regional authorities, municipalities, and state agencies are involved. These pledges show high collaborative engagement among these stakeholders to lead, participate in, or coordinate electrification projects. Sweden can be considered a frontrunner in the electrification of freight transport due to its vision of a fossil-free economy, strong heavy vehicle manufacturing industry, and high numbers of newly registered battery-electric trucks (Volvo, 2022a). Thus, with the dominant presence of automotive incumbents and their documented engagement in transition processes (Berggren et al., 2015; Werner et al., 2022), this case is particularly apt for studying incumbency reorientations. Previous research has shown that electrification might require interactions and reconfigurations extending beyond the transport system (Andersen and Markard, 2020; Geels, 2018b; Rosenbloom, 2019). In response to such calls for system boundary-spanning changes to realise transitions and a focus on multi-system interaction (Andersen and Gulbrandsen, 2020; Kanger et al., 2021; Rosenbloom, 2020), our analysis covers incumbency reorientations within and across three systems: freight transport, energy, and communication.

This study contributes to theory and research practice. First, we propose a conceptual framework for assessing incumbency reorientations in response to low-carbon transitions, including six actor interaction types and three different interaction natures. This allows us to uncover how heterogeneous incumbency reorientations dynamics across different regime dimensions result in changes to the focal system trajectory. Second, we present a multi-system analysis of activities and interactions in the selected case to outline five future research avenues to better understand the role and influence of incumbency reorientation dynamics in low-carbon transitions. Third, the lessons from the case have implications for practice on its own merits.

The following section presents the theoretical background and the conceptual framework for analysing incumbency reorientations in system reconfigurations. Section 3 details the research methods, case, and data collection. Section 4 presents the case findings, followed by an analytical discussion based on these in Section 5. Section 6 concludes the paper by outlining implications for future research, limitations of the study and policy recommendations.

2. Theoretical background

This study analyses actor reorientations in an ongoing low-carbon transition using a system reconfiguration approach drawn from socio-technical transition research (Geels, 2018b; Geels and Turnheim, 2022; McMeekin et al., 2019). This perspective highlights the role of internal regime processes inside existing systems and the potential for endogenous change driven by reorientation activities in the form of gradual shifts of incumbent actors' strategies, resources, and/or political support toward niche innovation (Geels et al., 2017; Geels and Turnheim, 2022). It also acknowledges that deep decarbonisation of existing systems generally entails interactions across multiple regimes and systems (Geels, 2018b; Markard and Rosenbloom, 2022; Zhang and Fujimori, 2020), emphasizing the need to understand broader multi-system dynamics (Andersen et al., 2020; Rosenbloom, 2020). The remainder of this section covers these aspects and develops a conceptual framework to guide our analysis and interpretation of results.

2.1. Endogenous change

Transition research initially focused on how exogenous sources of change, like radical innovations, affect a system. However, recent studies have shifted focus toward endogenous change, which comes from actors within a regime (Friedrich et al., 2023; Runhaar et al., 2020). Using institutional theory, numerous scholars have improved our understanding of the regime[1] and the potential for endogenous regime change (Brodnik and Brown, 2017; Fuenfschilling and Binz, 2018; Ghosh, 2019; Smink et al., 2015). This literature has yielded an important insight: regimes are semi-coherent sets of rules (normative, cognitive, and regulative) rather than monolithic and homogeneous incumbent structures (Runhaar et al., 2020). In this context, semi-coherence refers to a regime containing a wide range of rules that evolve along five *dimensions*: technology, science, policy, market and user preference, and socio-cultural meaning (Geels, 2004). The complexity and diversity of the regime concept and its various interacting components (e.g., technical artefacts, scientific knowledge, and regulations), thus, are reflected in the multiplicity of these regime dimensions (Geels, 2002; 2004). Each of these regime dimensions is governed by its own set of rules; nevertheless, they are linked, and their alignment is coordinated through the regime that serves as the shared "deep structure" that directs the behaviour of actors in a system (Fuenfschilling and Truffer, 2014; Geels, 2004, 2011; Schot and Kanger, 2018). However, different actor groups' varying interests, values, and objectives along the five regime dimensions are never fully aligned, resulting in the semi-coherent characterisation of the regime and the possibility of regime *tensions*, defined here as mismatches between rule sets (Geels, 2004).

An analytical understanding of how such tensions may arise during *reconfiguration processes* benefits from zooming in on the dynamics of the five regime dimensions by conceptualising them as *organisational fields* (Fligstein and McAdam, 2012; Hoffman, 1999; Scott, 1995). Organisational field refers to a set of actors (e.g., organisations, government, special interest groups, and the public) whose interrelated activities form a web of interactions (Scott, 1991; McAdam and Scott, 2005; Scott, 1991). Examples include competition for resources, influence, market share, collaborations on joint projects, and negotiation and conflict over resources and field rules (Fligstein, 1997; Fligstein and McAdam, 2012). Previous transition research (Fuenfschilling and Truffer, 2014; Geels, 2020) has frequently used organisation fields, and building on this work, we argue that the five dimensions of a regime are best understood as organizational fields, each characterised by its specific rules and interacting actors. These *regime fields* are technology, market and user practices, policy, socio-culture, and science (cf. Geels, 2004). Within each regime field, specific actors — such as companies, government agencies, cultural organizations, and academic institutions — engage according to evolved field rules. These rules may include technical standards, legal regulations, social norms, and scientific methods. The dynamics within these regime fields are crucial for endogenous change as actors interact, whether in agreement or conflict. Through these interactions, they either stabilise or change the existing regime or pose tensions to it, which, in the aggregate, may reconfigure a system. In other words, we view the five regime fields as relational spaces where sets of actors interact to (re-)produce rules and develop a common meaning system (Scott, 2001) to either stabilise or change the evolutionary trajectories of an existing system (see Fig. 1). These common meaning systems are continuously contested (Fligstein and McAdam, 2012; Hoffman, 1999) and result from the regime fields members' actions and tactics (Oliver, 1991).

In line with established theorisations of regime stability (Geels, 2004; Geels, 2011), even stable regime fields are dynamic in the sense that gradual restructuring can be observed as a result of its actors continuously working on reproducing the status quo (Fligstein and McAdam, 2012; Lounsbury and Glynn, 2001). This process, however, is not driven solely by established actors but rather by the interplay among a broad and diverse spectrum of actors, as peripheral and niche actors may also significantly contribute to the reproduction of existing rules (Geels, 2011; Smith et al., 2010). As a result, only incremental adjustments are made, and the regime is "dynamically stable" (Geels, 2004; Geels and Turnheim, 2022). Factors that lead to such field-level stability may include fixed regulative structures (Fligstein, 2001), institutionalised norms, technological stability (Scott, 2008), as well as interdependence and cohesion among field actors (Davis and Marquis, 2005). Under this perspective, endogenous regime change, as Fig. 1 illustrates, results from significant restructuring processes in the regime fields. These radical changes are produced by field-level activities like the exit or entry of a powerful actor (Barnett and Carroll, 1993; Hoffman, 1999; Scott et al., 2000), as well as the creation of new field rules through reorientation activities that alter existing — or create novel — interaction patterns (Brint and Karabel, 1991) both between incumbents and across incumbents and niche actors.

Novel field rules that have been stabilised, such as shared technological standards (van Wijk et al., 2013) or legal frameworks (Reusswig et al., 2018), play an important role in legitimising these restructured regime fields (Kungl and Hess, 2021). However, tensions such as competing ideas among field actors about how to decarbonise a specific sector (Köhrsen, 2018), different interpretations of the future (Neukirch, 2016), or incompatible technological visions (Schmid et al., 2017) may impede such stabilisation. Consequently, from the standpoint of system reconfiguration, such tension may hinder endogenous change processes, necessitating analytical attention.

[1] Applying the regime concept in the transition literature has been diverse and incoherent (Markard and Truffer, 2008). To detangle the regime, incumbency, and system concepts, this work adopts the interpretation of a regime as a "set of rules" and actor interactions (Geels, 2004; Geels and Turnheim, 2022; Schot and Kanger, 2018), making a conceptual differentiation between (1) the whole system configured of a material, relational, and institutional dimension, (2) the five interdependent regime fields that together represent the regime of such a system, and (3) the incumbent actors that through field-level activities stabilise or restructure regime fields to shape the trajectories of a system.

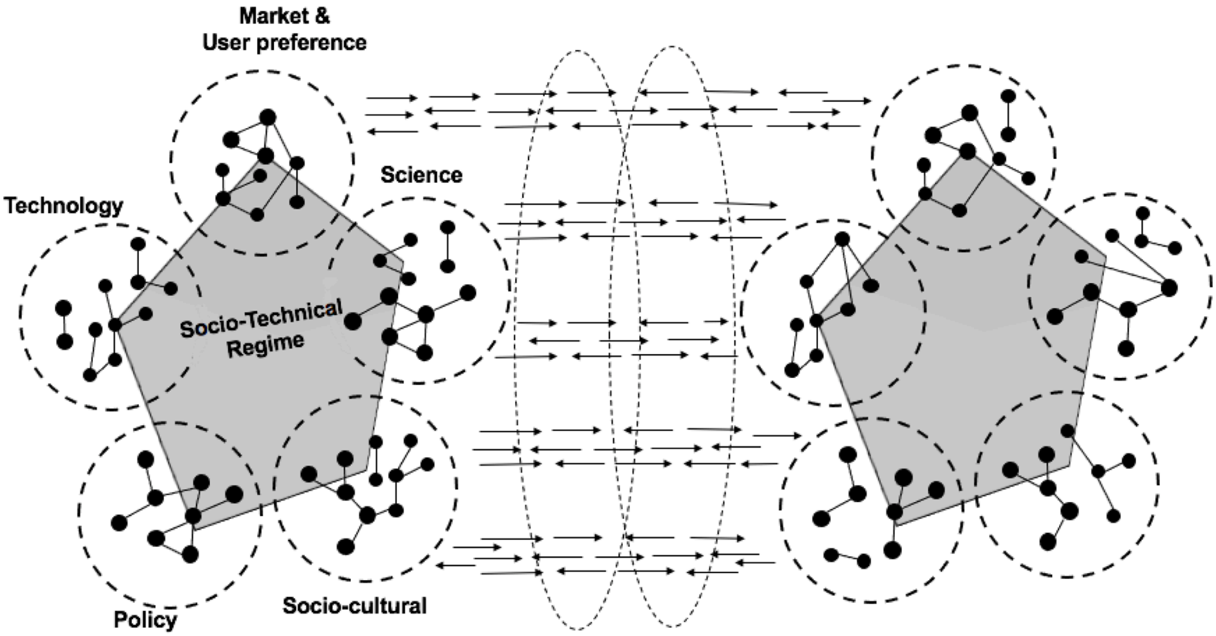

Fig. 1. Dynamically evolving regime fields (black dots represent actors, lines represent interactions) that form a regime. Arrows pointing in different directions represent field-level contestation about a common meaning system, while changes in actors and interactions lead to changes in the regime fields (substantially adapted from Geels 2004; 2011).

2.2. A relational perspective on incumbent reorientations

Incumbent actors can exhibit a range of reactions and play different roles in transitions (Kungl, 2015; Mori, 2021; Steen and Weaver, 2017). While some incumbents may resist reorienting to maintain the status quo (Johnstone et al., 2017), others can drive and facilitate endogenous change through diverse activities such as proposing new regulations, developing niche alternatives, political lobbying or diverging from a dominant technological trajectory (Apajalahti et al., 2018; Berggren et al., 2015; Heinze and Weber, 2016; Strambach and Pflitsch, 2020). Recent work has emphasised the latter's importance as an essential aspect for accelerating low-carbon transitions (Geels and Turnheim, 2022; Kump, 2023). Regarding their agency, incumbents are entrenched in the structures of existing systems, but they also have accumulated intangible resources and a strong network position that allows them to influence political processes (Galvan et al., 2020). Their ability to act or effect change is thus "embedded" in the sense that it is constrained and shaped by the rules of a regime (Grin et al., 2010). Hence, on the one hand, the field rules that actors follow inform their activities to a high degree (Hoffman, 2013) . However, conversely, incumbents also engage in activities to restructure the rules (Apajalahti et al., 2018). Such activities are embedded in complex networks of interactions (Hoffman, 2013), and actors anticipate each other's behaviour as they engage in interrelated activities to influence change and stability within a field (McAdam and Scott, 2005; Scott, 1995).

These interdependent dynamics, which reproduce rules but also produce new rules in some circumstances due to actor reorientation, may be challenging to capture solely by focusing on (incumbent) actors in isolation (Darnhofer et al., 2019; Turnheim and Sovacool, 2020). Instead, a relational perspective (Darnhofer et al., 2019; Stirling, 2019) emphasizes the interconnectedness and interdependencies of actors and the intricate web of interactions within the different regime fields. Thus, to better understand the dynamic stability of a regime, our analytical perspective examines how regimes are reproduced through relational processes among many actors in various fields (Stirling, 2019). Building upon Hoffmann's (1999) definition of fields as relational spaces that "bring together various field constituents with disparate purposes" (p. 4), we analyse how actors relate to one another within the regime fields. This aids in bridging the gap between actor interactions, aggregated field restructuring, and the possible tensions emerging from this process.

2.3. Multi-system interactions

Recent research has emphasised that drastic decarbonisation of entire industries broadens the scope of transition dynamics from single systems to interactions and reconfiguration processes between multiple systems (Andersen and Geels, 2023; Andersen and Gulbrandsen, 2020; Geels, 2018a; Rosenbloom, 2019, 2020). Drawing again on the organisational field literature, it is clear that as actors from an adjacent system enter a focal system, like energy companies entering the transport system, their interpretation of the focal systems' dynamics is shaped significantly by rules from their original fields (Kungl and Hess, 2021; Wassermann et al., 2015), which prompts questions about how actors from different systems interact and the nature of these interactions.

Previous work has conceptualised interactions of actors within a given system (Dijk, 2014; Geels, 2007; Lin and Sovacool, 2020; Smith, 2007) and *across* systems (Rosenbloom, 2019; Sutherland et al., 2015; Ulmanen et al., 2009). Both within and across systems, interactions can occur between actors of regimes and niches (Geels 2006), between actors of two regimes (Konrad et al., 2008; Raven and Verbong, 2007) or two niches (Bakker et al., 2012). In previous transition studies, conceptualisations of different interaction natures can also be found. *Symbiosis* is when two interacting parties' benefit from cooperation and may become mutually dependent (Konrad et al., 2008; Raven and Verbong, 2007; Rosenbloom, 2019). *Competition* refers to interacting actors actively competing for markets and resources because they serve the same or similar societal function (Raven and Verbong, 2007; Sandén and Hillman, 2011). *Antagonism* refers to asymmetric interactions, such as predator-prey interactions or power imbalances, in which one actor benefits more and the other may be adversely affected (Dijk, 2014; Sandén and Hillman, 2011).

2.4. Conceptual framework

Drawing upon these three conceptual building blocks elaborated above, this section synthesizes these elements to develop a conceptual framework. It makes it possible to analyse endogenous regime change processes across five regime fields to study incumbency reorientation for a system reconfiguration. Each regime dimension is understood as a distinct organisational field in this framework. Moreover, it emphasizes the importance of a relational perspective on incumbency to uncover potential regime tensions, zooming in on actor interactions and their varying natures in these fields. Acknowledging the multi-system interactions at play in reconfiguration processes, we propose two over-arching categories for a more precise categorisation of actor interactions within and across systems: *Intra-system interactions* are those in which actors within the same system interact, resulting in changes to the fields of a focal regime. *Inter-system interactions* are those in which actors from different systems interact with each other, precipitating changes that span across multiple systems and restructuring the fields of a focal regime. This distinction is necessary when adopting a multi-system transition perspective to pinpoint those interactions that bring actors from multiple systems into contact. Hence, it enables understanding how the reorientation dynamics of various actors and social groups between existing systems can lead to novel couplings. Recognizing the heterogeneity of interactions, we argue further that the nature of the interaction must also be considered in the framework, and we build on the previously conceptualised interaction natures, including competition, symbiosis, and antagonism. This allows for a more nuanced understanding of the multi-actor dynamics of transitions, where interactions of different systems are not limited to one kind of interaction (Rosenbloom, 2020) but are shaped by many micro-level interactions of varying natures.

Fig. 2 shows our conceptual framework for study analysis and interpretations. This framework allows a system to have multiple regimes, each comprising five regime fields and multiple niches at its periphery. As actors in these fields reorient, aggregated restructuring occurs through 6 types of interactions: *Intra-system interactions*, taking place within the same system, between (1) two regime actors of the same or different regimes, (2) a regime actor and a niche actor, or (3) two niche actors of the same or different niches. *Inter-system interactions* take place across two different systems, between (4) actors from regimes, (5) regime and niche actors, or (6) niche actors in different systems. The nature of these interactions may be competitive, symbiotic, or antagonistic. We apply this framework to analyse relational patterns of actors from multiple systems to increase our understanding of how restructuring processes and the tensions that may arise in this process at an aggregated level contribute to or hinder low-carbon system reconfigurations.

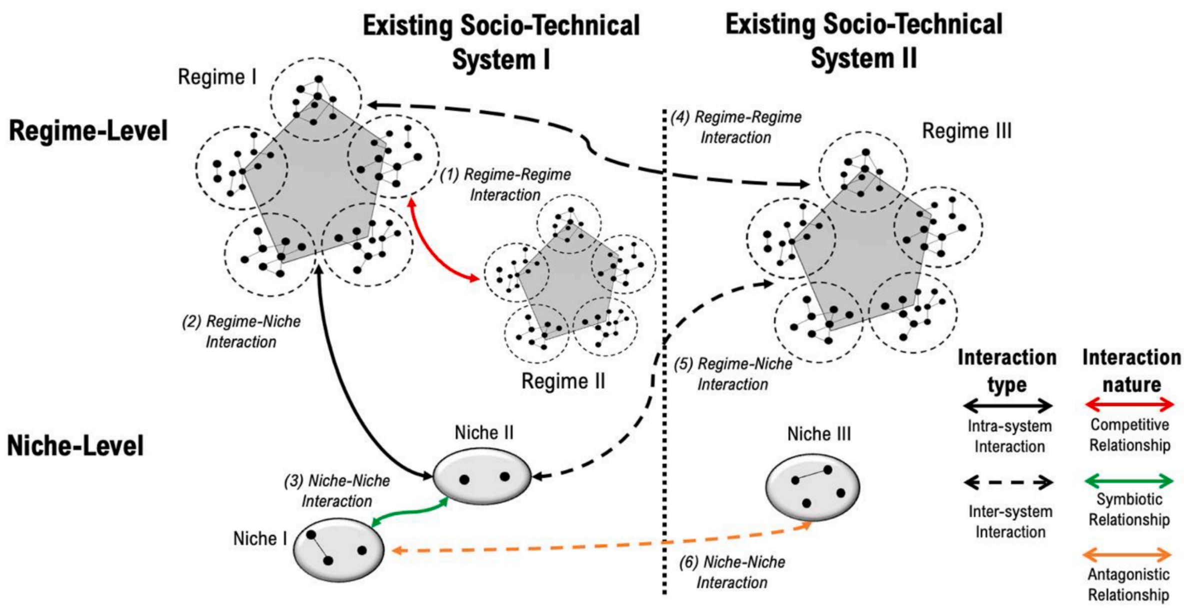

Fig. 2. Multi-system reorientation framework (substantially adapted from Rosenbloom, 2020).

3. Methods

3.1. Case selection

The framework is used to analyse actor-level interactions in the Swedish road freight transport sector to assess interaction patterns within the regime fields of the low-carbon transition toward electrification. Sweden frequently ranks among the top three countries in the world for logistics (World Bank, 2018), and the road freight transport industry has generated over EUR 9 billion per year on average in the last decade (Statista, 2022). For the largest Nordic economy to remain competitively integrated with the world market, efficient road transport of goods is vital. Heavy commercial vehicle manufacturers represent two of the largest companies by annual revenue. These companies are some of Sweden's largest employers and exporters, making them a pillar of the country's economy (Pohl, 2017). Nevertheless, road freight transport today accounts for approximately 90% of Sweden's transport-related CO2 emissions, with heavy trucks contributing the most. Given the expected rise in transport demand, decarbonising the sector by 2030 will be crucial to meeting national climate goals (Fossilfritt Sverige, 2017). In the last seven years, increased awareness of the sector's contribution to climate change and its negative impact on global warming through air pollution and resource depletion have put pressure on governments and freight transport value chain actors. In response, Swedish heavy truck manufacturers are investing multiple hundred million euros in R&D for zero-emission vehicles (ZEVs) and production facilities (Volvo Trucks, 2022b; Scania, 2021), entering strategic joint ventures to finance adequate charging infrastructure (Volvo Trucks, 2022c), and scaling back combustion engine investments (Traton, 2022).

To accelerate the decarbonisation of this sector, the Swedish Government established the Commission for Electrification in 2020 (Regeringskansliet, 2020). This commission's initial plans outlined large-scale electrification of road freight transport to meet the national climate target of cutting the transport sector's CO2 emissions by 70% by 2030 (Regeringskansliet, 2020). Since most Swedish domestic goods are transported regionally (Transport Analys, 2022), the commission has focused on coordinating regional activities to accelerate the transition to fossil-free regional road freight transport. In 2021, this led to 17 Electrification Pledges across 16 Swedish regions (Regeringskansliet, 2021). In the broader European context, the Swedish Electrification Pledges stand out as a unique initiative due to their collaborative approach, engaging a diverse set of stakeholders from the public and private sectors toward a common goal of electrification. Unlike some initiatives with abstract goals, the Electrification Pledges mostly outline actionable activities, providing a clear roadmap for accelerating road freight electrification. Moreover, they involve a sector coupling strategy that aims to electrify the freight transport industry while also increasing the efficiency of the energy systems by, for example, harmonising transport and energy systems through smart charging.

Three interrelated factors motivate the case selection: first, previous studies (Scherrer et al., 2020; Werner et al., 2021) have shown that the electrification of road freight transport involves many different incumbent actors, so studying this transition provides an illustrative case of how established actors reorient their operations in interaction with other actors. Second, Sweden is investigating battery-electric (BEV) and fuel-cell-electric (FCEV) commercial vehicles simultaneously. Accordingly, parallel investments in electric road systems demonstration pilots, stationary mega-watt charging systems, and hydrogen solutions have been made (Regeringskansliet, 2020). Therefore, this case will aid the understanding of the role of regime tensions in system reconfigurations by shedding light on struggles and disputes between actors promoting different technological solutions for electrification. Third, as previously acknowledged (see, e.g., Andersen and Markard, 2020; Geels, 2018b; Rosenbloom, 2019), the reconfiguration of the fossil fuel- and combustion engine-dependent transport sector toward electrification cannot be achieved solely through interactions and reconfigurations within the transport system. Instead, it can be considered a multi-system transition as linkages with other systems, such as the energy system, are needed. Thus, this case is especially prominent for applying our framework because it allows for analysing actors' reorientation activities and the resulting interaction patterns across multiple regimes and systems.

3.2. Data collection and analysis procedure

We employ social network analysis (SNA) to map and analyse actor interactions that result from reorientation activities and contribute to field restructuring processes in the focal regime of analysis, road freight transport (see Table 2). Recently, SNA has gained popularity among scholars studying actors and their interactions in transition (Giurca and Metz, 2018; Scherrer et al., 2020; Song et al., 2023). SNA, an application of graph theory, uses nodes to represent network members like organisations and edges to represent their connections, forming a network that can be visualised in maps (Scott and Carrington, 2011). SNA is an appropriate and warranted method for this study because it aids us in mapping actor networks and interactions, thereby revealing the sets of actors that comprise our regime fields and revealing, in the aggregate, structures and change dynamics. SNA, thus, provides insights into actors' network positions, the interactions, and their effect on the network's overall structure (Prell et al., 2009; Scott, 2000). It also enables the production of graphic representations that allow a holistic visualisation of actor interactions at a network level. (Christopoulos, 2006; Prell, 2012). These qualities make the method especially suited for multi-system transition studies, as it allows researchers to capture ongoing developments in detail even when zooming out to study connected transition dynamics across multiple systems.

Our SNA utilised primary and secondary data: We conducted 32 semi-structured expert interviews[2] with stakeholders from the transport, energy, and communication sectors, selected through a snowball sampling technique (Biernacki and Waldorf, 1981). Experts

[2] A list of the interviewed experts, including which system they were categorised as, actor type, and position of those interviewed, can be found in Appendix C.

Table 1
Data sources that informed the SNA.

Type of data	Number
Interviews	32
Industry event observations	21
Policy documents	28
Company reports & press releases	41
Media Clippings	72
Scientific publications & research project reports	24

were initially recruited via email or industry events, and they referred us to additional experts. During the interviews, experts supplemented our data with additional resources such as membership lists, unpublished project reports, relevant publications, and presentation slides, which were incorporated into our analysis. We also attended 21 industry events — both online and offline — where actors, policymakers, and researchers discussed the sector's electrification initiatives. Considering the risk of bias in responses during interviews and events (Fisher, 1993), we used secondary sources to triangulate and contextualise our primary data, enhancing the study's reliability (Flick, 2018). To this end, we sourced publicly available reports, individual electrification pledges, press statements (of the Commission for Electrification on road freight transport), annual company reports, industry analyses, media clippings, academic literature, and international research collaboration publications through web-based research. Table 1 provides a comprehensive overview of all data sources used to construct the SNA datasets.

Next, we conducted a directed content analysis on interview transcripts, observation notes, and secondary sources to identify actors and their activities (Hsieh and Shannon, 2005; Potter and Levine-Donnerstein, 1999).[3] Our initial coding categories, formed from the five regime dimensions (technology, science, policy, market and user preference, and culture) and associated rules for each dimension (Geels, 2002; 2004), served as a coding framework for the identified pledge activities. In the first step, all identified activities were categorised based on which regime dimension the activity related to and in the second step, the activities were coded based on which rule of a given dimension they are associated with (see, e.g., Ghosh, 2019 for a similar approach).[4] The identified actors performing these activities were grouped into different systems and regimes based on what societal need each actor fulfilled (Papachristos et al., 2013). To represent the plurality of incumbency in the analysis, not only large companies with significant market shares were classified as incumbent actors, but also a variety of other established actor types, such as intuitional, governmental, or societal (cf. Stirling, 2019; Turnheim and Sovacool, 2020) that actively contribute to the stabilisation of existing systems[5]. The remaining actors were grouped into six niche categories, which emerged through coding the interview transcripts, observations and documents based on their primary business models and activities.[6] Table 2 lists the actors for each regime and niche included in the analysis. The connections in the SNA (i.e., actor interactions) were derived from the previously categorised activities of actors within specific regime fields (dimensions). Based on categories of interaction nature from our conceptual framework (symbiosis, competition, and antagonism), these interactions were categorised as symbiotic when activities necessitated collaboration, resulting in mutual benefit. When actors performed activities in parallel, vying for similar resources or market share, these were classified under "competition." Additionally, when actors engaged in cooperative activities, but the benefits or contributions were skewed, leading to power imbalances, these interactions were termed antagonistic (Table 2).[7]

Throughout the analysis, we refined those categories and combined the science and culture regime fields due to the following three reasons (1) significant overlaps between the regime fields, (2) maintaining separate regime fields for both science and culture added unnecessary complexity to the analysis without providing additional insight and (3) improved visual data representation in the SNA. This approach produced four node and undirected edge datasets labelled *hereafter Technology and Infrastructure, User Practices and Markets, Policy and Regulations, and Socio-culture and Science*, listing all identified actors for each regime field, containing actors, actor interactions, their nature, and type. We visualised these datasets in *Kumu*, an open-source software that allowed us to analyse and compare the dynamics of individual nodes in regime field networks using advanced metrics algorithms. Table 3 offers a synopsis of the SNA metrics used in this study and their interpretations.

[3] All data sources were manually coded using the qualitative data analysis software MAXQDA.

[4] Appendix A outlines the coding framework for the categorisation of activities including a description of each regime dimensions and associated rules.

[5] As illustrated in previous transition studies on the electrification of the transport system (Berggren et al., 2015; Scherrer et al. 2020; Werner et al., 2021) also this analysis showed incumbent actors that are active at a niche level. For example, two identified vehicle manufacturers were actively involved in niche development by supplying electric vehicles to commercial demonstration projects around Sweden. We consider this as an example of a reorientation activity. Yet, because the main product offering and the way that these organizations make their largest profit today is through the sale of ICEVs, contributing firmly to the stability of the existing socio-technical system, we classified them as incumbent actors in this study.

[6] A decision tree for actor classifications can be found in Appendix B.

[7] A decision tree for the interaction classifications based on our framework can be found in Appendix D.

Table 2
Existing socio-technical systems, regimes, niches, and their actor groups are included in the SNA.

System	Freight Transport S1	Electricity S2	Communication S3
Regimes	***Road freight transport*** Vehicle Manufacturers; Carriers; Shippers; Gas Station Franchises; Transport Associations; Road Administration Bodies; Transport Terminals	***Power generation*** Energy Generators; Power Distributors ***Grid infrastructure*** Energy Transmission Operators; Energy Safety Agencies ***Electricity consumption*** Electricity Network Operators; Electricity Suppliers; Energy Market Regulators	***Telecommunication*** Telecommunication Service Providers; Network Providers
Niches	***Electric freight mobility N1*** Autonomous Electric Transport Solution Developers; EV Manufactures; Vehicle Converters ***EV battery technology N2*** Vehicle Battery Technology; Battery Storage; Battery Recycling Solutions Developers ***EV charging N3*** Dynamic & Static Charging Infrastructure Providers ***Hydrogen-powered vehicles N4*** Hydrogen Fuel-Cell Vehicle Manufactures	***Hydrogen Energy N5*** Green Hydrogen Producers; Storage & Refuelling Infrastructure Providers ***Smart-grids N6*** Smart-grid Charging Solution Developers	

Table 3
SNA metrics employed and their interpretations in this study.

Network level metrics	Interpretation	Node level metrics	Interpretation
Network Density ($DEN = \frac{2E}{n(n-1)}$)	Level of the interconnectedness of actors in a regime field.	Betweenness centrality $\left(g(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}\right)$	Identify the actors that fall on the shortest pathway between other pairs of actors thus, have a positional advantage. Following Hanneman and Riddle (2005), actors situated "between" others, hence serving as essential intermediaries for facilitating exchanges, are likely to leverage this brokerage role to wield influence within a regime field.
Average degree ($AD = \frac{2E}{n}$)	The average number of reorientation interactions present in a regime field.		
Average path length ($l = \frac{1}{N(N-1)} \sum_{i \neq j}^{d} ij$)	Level of separation between actors in a regime field.		

4. Results

4.1. Actors in Sweden's reconfiguration of road freight transport

The analysis of Electrification Pledges and additional material on Sweden's low-carbon system reconfiguration identified 324 relevant actors. As shown in Fig. 3, many incumbents from three existing systems (Freight Transport, Electricity, and Communication) are driving this transition. Freight Transport (S1) incumbents consistently made up more than half of the total actors in every regime field. Transport carriers, shippers, and regional authorities were this regime field`s most identified actor types. Many actors are embedded in all four regime fields. However, actor involvement varied, with most actors being engaged in activities supporting a low-carbon transition within the *Socio-Cultural and Science* and *Policy and Regulations* regime field.

Three interrelated factors influence actor participation in the regime field differently: (1) low availability of heavy commercial BEVs and FCEVs, (2) lack of public charging infrastructure, and (3) operational costs and functional suitability uncertainties. These barriers to actor reorientations have led to lower involvement of transport carriers in the *Technology and Infrastructure* and the *User Practices* and *Markets* regimes. Electricity system (S2) actors, including electricity suppliers, energy generators, and power distributors, constitute the second largest group of stakeholders. Like road freight incumbents, their participation varies across the different regime fields. The lower contribution of energy incumbents to reconfiguration processes within the *Technology and Infrastructure* and *User Practices* and *Markets* regime fields compared to the other two regime fields can, on the one hand, be attributed to this actor group's expressed difficulties in finding strategic partners. On the other hand, while E-mobility represented a new business opportunity for most of these incumbents, their core business, such as generating and selling energy, remained unchanged. A few Communication (S3) incumbents are also actively involved in reconfiguration processes across all regime fields. Like the S2 actors, they see e-mobility as a new business opportunity. Their digital technologies contribute to a more efficient BEV and charging station operation and management by ensuring seamless connectivity and data transmission.

Moreover, it shows a consistent involvement across all four regime fields of new entrants housed in six different niches. These

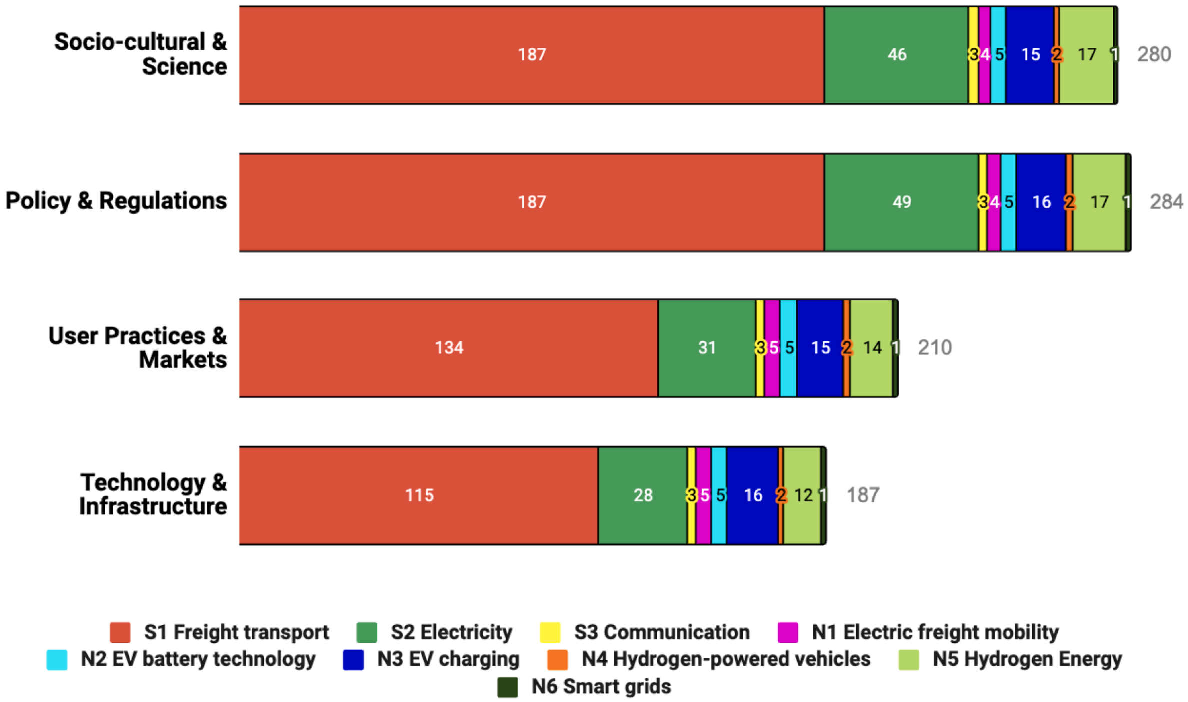

Fig. 3. Amount and types of actors contributing to the reconfiguration processes of the four regime fields.

niches represent low-carbon alternatives to the prevailing internal combustion engine vehicles (ICEVs) and fuelling infrastructure. The two largest identified niches, N3 and N5, include novel actors pioneering technological innovations related to dynamic or stationary charging of BEVs, as well as hydrogen production and refuelling infrastructure. In comparison, both N1 and N4, in which new entrants develop BEVs and FCEVs, are relatively small in actor size, which can be explained by the fact that established vehicle manufacturers in Sweden represent first-mover incumbents in the sense that they not only hold strong positions in the existing market and have already started to substantially reorientate their activities and business strategies toward the manufacturing of zero-emission vehicles (ZEVs). Two additional niches, small in actor size, were identified: N2 includes actors developing battery technology for electric vehicles, and

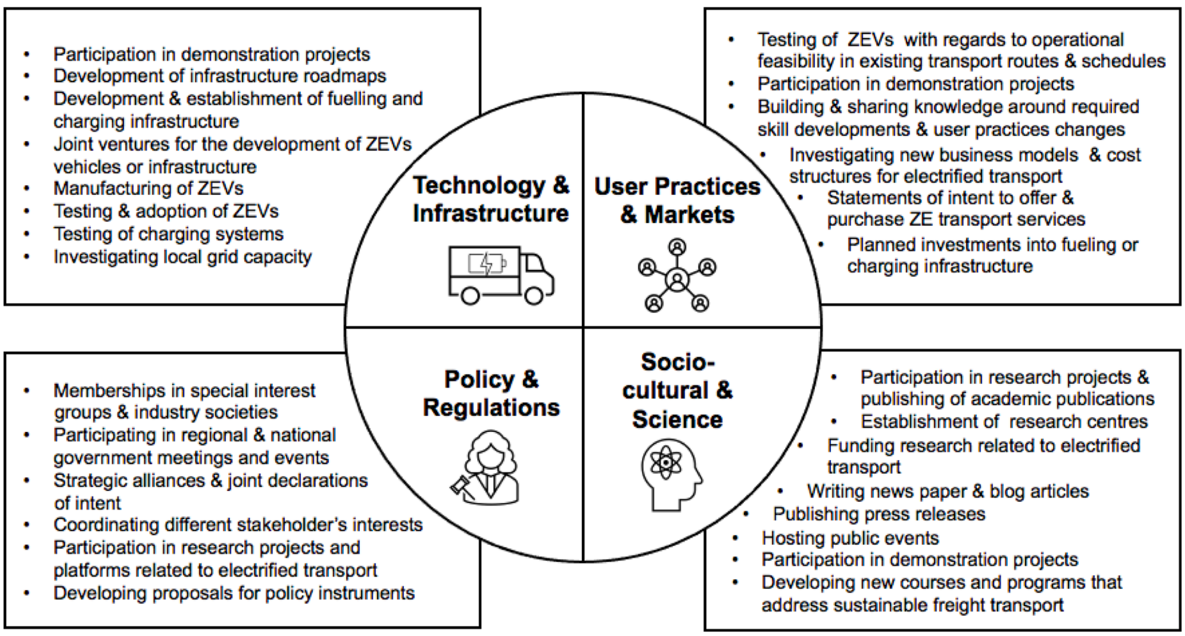

Fig. 4. Examples of different reorientation activities in support of a low-carbon transition within the four regime fields.

N6 houses a start-up offering smart charging solutions to reduce expensive grid peaks. Both can be considered critical complementary technologies for a low-carbon transition.

The stakeholders in all the electrification pledges examined are committed to a wide range of reorientation activities currently underway in the Swedish road freight sector. The actors' activities were divided into two categories across the four regime fields. The first represented already ongoing activities, such as investments into charging infrastructure and measurable actions with concrete targets, such as shippers committing to convert a portion of their ICEV fleets to ZEVs. They outline substantive reorientation that is already taking place and include quantifiable goals for ongoing and planned activities, thus allowing for a measurable assessment of actor reorientations over the next few years. Fig. 4 depicts examples of such concrete reorientation activities organised by regime fields.

Pledges covering joint measures by S1, S2 and S3 actors indicate that the decarbonisation through electrification may cause sector coupling, bringing formally independent systems together. In relation to this, the need for a sufficient amount of charging infrastructure was identified, and S2 actors (e.g., electricity providers) are working jointly with S1 to develop it. To optimise and control charging processes and collect user payments, S3 actors (e.g., telecommunication service providers) collaborate with niche actors and incumbents from S1, providing them with required internet connections and Inter-of-Things platforms. Additionally, several regions entail actor pledges outlining current investments in infrastructure for green hydrogen production and FCEV refuelling. This shows that actors still debate about whether battery- or hydrogen-powered vehicles can achieve fossil-free road freight transport. Only one region focused solely on hydrogen for road freight transport, and few transport operators have ordered or already adopted FCEVs. Instead, most actor activities focus on adopting and accelerating BEVs and their complementary technologies (i.e., charging systems, vehicle batteries, and payment services). Lastly, a substantial amount of the identified reorientation activities included participation in research projects, investigations into required electricity grid capacity, developing roadmaps outlining optimal charging locations, and feasibility studies of ZEVs for various transport assignments (i.e., urban deliveries, long-distance or waste collection). This indicates knowledge gaps about, for example, the functional suitability of ZEVs, required fuelling infrastructure, and ways to handle potentially increased grid loads that must be addressed to accelerate the low-carbon transition.

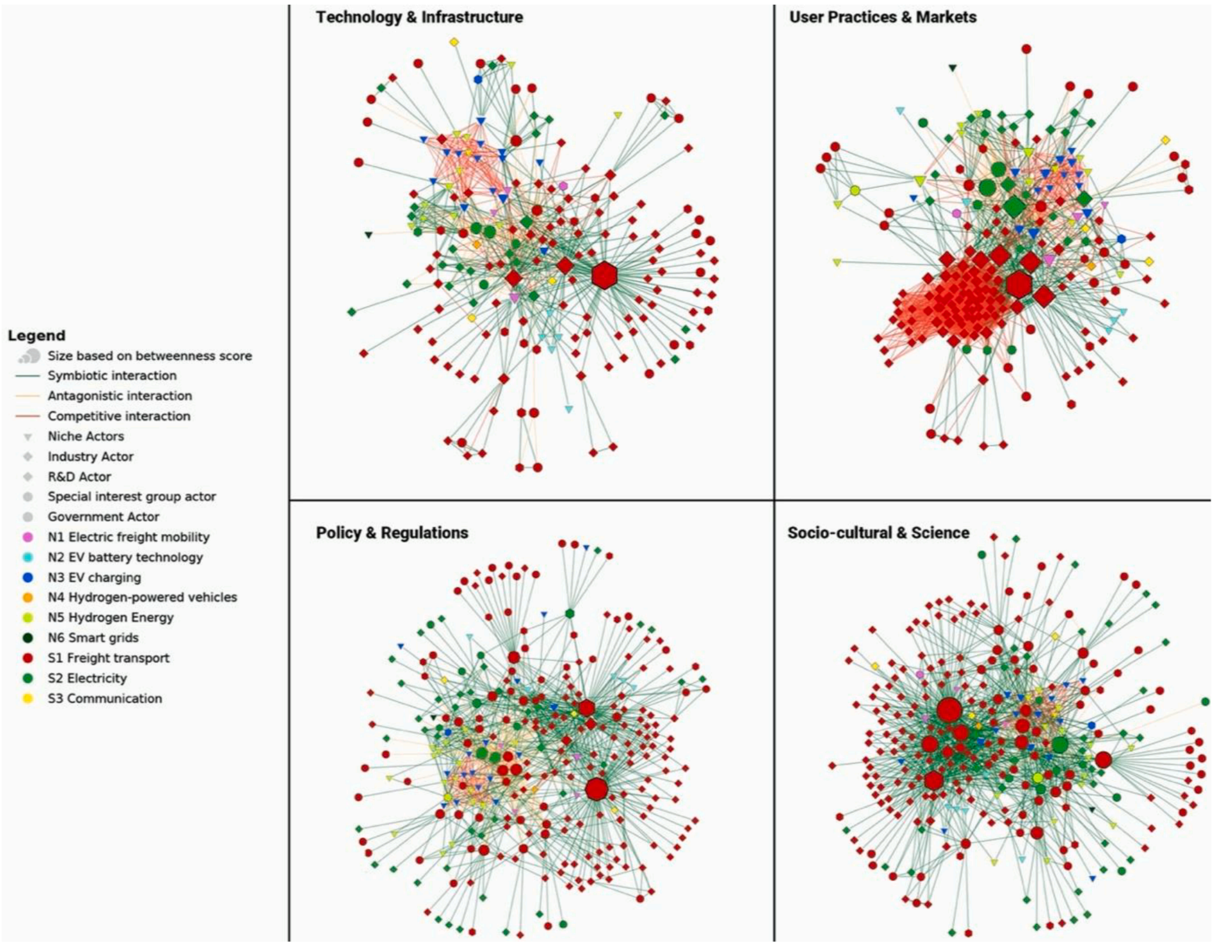

Fig. 5. Interactions within the four regime field networks, illustrated as binary, undirected network graphs; edge colour represents the interaction nature, and node size indicates the betweenness score.

Table 4
Network metrics scores within the four regime fields.

	Technology & Infrastructure	User Practices & Markets	Policy & Regulations	Socio-cultural & Science
Total number of actors (Nodes)	187	210	284	280
Total number of interactions (Edges)	713	2697	1085	1239
Intra-system	478	2431	746	902
(Symbiotic/Antagonistic/Competitive)	(307/62/109)	(300/46/2085)	(611/102/33)	(841/28/33)
Inter-system	235	266	339	337
(Symbiotic/Antagonistic/Competitive)	(120/46/69)	(135/48/82)	(212/64/63)	(251/23/63)
Density	4%	12%	3%	3%
Average degree	7.62	25.68	7.63	8.81
Average path length	2.74	2.42	2.9	2.79

To contextualise these results regarding their counterpart, it is crucial to highlight that the incumbents included in this analysis do not currently dedicate themselves solely to substantial actor reorientations. For example, heavy commercial vehicle manufacturers, despite expanding their market share in ZEVs continuously (Volvo Trucks, 2023), still predominantly produce and sell ICE-powered vehicles (Volvo Group, 2023; Scania, 2023). Similarly, many shipping companies have begun offering electric goods transport services, yet it still represents only a modest, albeit growing, share of their total offerings (Postnord, 2023).

The analysis also identified intentional reorientation activities without clear goals, timelines, or other details that indicate a readiness to change and a desire to help the low-carbon transition. In line with the Swedish word for pledge (*löfte* {neut.} promise), actors promised to reorient to low-carbon technologies and invest in electric transport. These forward-looking reorientation statements frequently ended with "if the feasibility allows for it" and used words like "intent" or "anticipate." To avoid conflating the reorientation dynamics, our SNA excluded these intended activities. It is unclear if and to what extent actor change and reorientation will follow these promises.

4.2. Interactions that give rise to field restructuring

The ongoing reorientation activities of incumbents in support of a low-carbon transition and the entry of novel niche actors have allowed actors from multiple systems to interact and engage in field restructuring processes. Fig. 5 presents four network graphs of actor types interacting within the four regime fields of the focal regime. Table 5 compares the four networks in terms of the total number of actors and interactions and network metrics.

4.2.1. Technology and Infrastructure regime field network

As seen in Table 4, the *Technology and Infrastructure* regime field network had the fewest interactions of the four. While it had the second highest network density (4%) among all regime fields, this network showed a minor average degree but not a smaller average path length. This shows that actors, on average, had fewer field restructuring interactions but no greater separation between actors. In this network, the highest percentage of inter-system interactions (33%) were found: predominantly symbiotic interactions between established actors of S1 and S2, highlighting the importance of strategic partnerships between incumbents of the two existing systems for reconfiguring the dominant design of ICEVs and fossil fuel infrastructure toward low-carbon alternatives. Table 5 shows examples of inter-system interactions in this regime field network.

There are many symbiotic inter-system interactions between incumbents in the same system and between established actors and niche actors that operate at the edges of S1 and S2 and between niche actors. The highest number of competitive interactions was observed between niche actors of N3 and N5, illustrated through the tight web of red interactions at the top right of the *Technology and Infrastructure* graph (see Fig. 5). Actors in these two niches develop dynamic and static charging and hydrogen refuelling infrastructure. Thus, they are in direct competition for governmental subsidies and industry partnerships. The dense interactions and competition between N3 and N5 highlight a critical stage of technology development where electric and hydrogen solutions compete to set future industry standards. As shown in Table 4, antagonistic interactions are the most common in this regime field network. Examples (see Table 5) include actors' asymmetric dependence on government fund agencies and regulatory bodies.

The *Technology and Infrastructure* regime field network's most central actor was a national research platform (seen at the lower left side in the graph of Fig. 5). No other actor in any of the four regime field networks scored such a high betweenness number (see Table 6), indicating the national research platform's influence in connecting different types of actors and orchestrating reorientation activities within this regime field. Looking at the following nine actors based on betweenness centrality, we can see that incumbents from the Freight Transport (S1) and Electricity (S2) systems act as key bridges within this regime field and influence restructuring processes (Table 6).

4.2.2. User practices and Markets regime field network

The *User practices and Markets* regime field network has the most restructuring interactions and the shortest average paths. With

Table 5
Illustrative examples of different types of interactions present in the *Technology & Infrastructure* regime field network derived through our analytical framework.

	Intra-system			Inter-system		
	Regime-Regime	Regime-Niche	Niche-Niche	Regime-Regime	Regime-Niche	Niche-Niche
Symbiotic	Interactions between energy generators & electrical infrastructure companies to develop charging systems for BEVs.	Interactions between shippers & vehicle converters to refit ICEVs with batteries.	Interactions between vehicle battery technology developers & battery recycling companies to advance battery recycling schemes.	Interactions between vehicle manufacturers & power companies to develop charging systems for BEVs.	Interactions between shippers & hydrogen refuelling infrastructure providers to build refuelling stations.	Interactions between FCEV manufactures & hydrogen refuelling infrastructure providers to offer integrated vehicle + refuelling solutions.
Antagonistic	Interactions between vehicle manufacturers & transport administration to find technological standards.	Interactions between transport administration & dynamic charging companies to decide on dominant technology.	—	Interactions between transport administration & energy transmission operators for charging station permits.	Interactions between energy safety agencies & green hydrogen producers to develop product safety standards.	—
Competitive	Interactions between vehicle manufacturers to develop superior BEV technology.	Interactions between vehicle manufacturers & BEV manufacturers to develop superior BEV technology.	Interactions between stationary & dynamic charging providers to develop superior charging solutions.	Interactions between energy generators & vehicle manufacturers to develop superior charging solutions.	Interactions between vehicle manufacturers & FCEV manufacturers to develop superior FCEV technology.	Interactions between stationary charging providers & hydrogen refuelling infrastructure providers to develop superior technological solutions.

Table 6
Top 10 actors ranked by betweenness scores within each regime field.

Betweenness centrality rank	Technology & Infrastructure	User Practices & Markets	Policy & Regulations	Socio-cultural & Science
#1	Research Platform (0.334)	Research Platform (0.101)	Special Interest Group (0.257)	Media Outlet (0.188)
#2	Vehicle Manufacturer (0.167)	Electricity generator, supplier & power distribution network operator (0.078)	Research Platform (0.17)	Research Platform (0.142)
#3	Vehicle Manufacturer (0.156)	Vehicle Manufacturer (0.074)	Vehicle Manufacturer (0.093)	Media Outlet (0.097)
#4	Electricity generator, supplier & power distribution network operator (0.091)	Shipper (0.072)	Freight Transport Consortium (0.083)	Media Outlet (0.092)
#5	Autonomous Electrified Transport Service Provider (0.072)	Vehicle Manufacturer (0.070)	National Energy Agency (0.076)	National Energy Agency (0.092)
#6	National Energy Agency (0.061)	Carrier (0.048)	National Transport Administration (0.074)	Freight Transport Consortium (0.091)
#7	Stationary Charging Solution Developer (0.061)	National Energy Agency (0.039)	Vehicle Manufacturer (0.065)	Vehicle Manufacturer (0.076)
#8	Shipper (0.042)	Electricity generator, supplier & power distribution network operator (0.038)	National Transport Research Institute (0.063)	National Transport Administration (0.074)
#9	Energy Safety Agency (0.042)	Carrier (0.038)	Energy Safety Agency (0.061)	National Commission for electrification (0.066)
#10	Electricity generator, supplier & power distribution network operator (0.042)	Electricity generator, supplier & power distribution network operator (0.035)	Regional Authority (0.051)	Vehicle Manufacturer (0.052)

fewer actors than *Policy and Regulations* and *Socio-cultural and Science*, this regime field network has the highest average degree and network density (12%). Inter-system interactions within S1 of competitive nature contribute significantly to these scores, as shown by the red interaction webs in Fig. 5. These actor clusters represent interaction patterns between transport carriers and shippers, fiercely competing to adopt ZEVs cost-effectively to offer sustainable, low-emission transport. Moreover, Table 7 shows how symbiotic intra-system interactions help legitimise the new technology. The prevailing symbiotic interactions within the intra-system category reveal a high-level cooperation amongst actors to address shared regulatory challenges related to electrification.

Table 7
Illustrative examples of different types of interactions present in the *User practices & Market* regime field network derived through our analytical framework.

	Intra-system			Inter-system		
	Regime-Regime	Regime-Niche	Niche-Niche	Regime-Regime	Regime-Niche	Niche-Niche
Symbiotic	Interactions between vehicle manufacturers to co-create proposals for changes to weight requirements regulations for BEVs.	Interactions between research institutes & BEV manufacturers to develop favourable policy instruments, e.g., direct user insensitive.	Interactions between green hydrogen producers & refuelling infrastructure providers to influence favourable policy developments for hydrogen solutions.	Interactions between vehicle manufacturers & power companies to co-create proposals for regulatory changes.	Interactions between transport administration & smart-grid charging solution providers to co-create proposals for BEV smart-charging regulations.	Interactions between FCEV manufacturers & green hydrogen producers to influence favourable policy developments for hydrogen solutions.
Antagonistic	Interactions between special interest groups & transport administration to influence favourable policy developments for transport operators.	Interactions between transport administration & autonomous electric transport solution developers over required road regulations.	—	Interactions between energy market regulators & special interest groups to influence favourable policy instruments for reliable electricity pricing for transport operators.	Interactions between energy market regulators & stationary charging providers over needed electricity regulatory frameworks for the deployment of high-power charging Infrastructure.	—
Competitive	—	—	Interactions between stationary & dynamic charging providers to influence policy in favour of their technological solution.	—	—	Interactions between FCEV manufacturers & BEV manufacturers to influence policy in favour of their technological solution.

Inter-system interactions within this regime field network are predominantly symbiotic, but like the *Technology and Infrastructure* regime field network, new entrants from N3 and N5 stand in direct competition. Both market formation and understanding of user practices such as travel behaviours and vehicle charging times are essential for developing charging standards, infrastructure deployment best practices, optimal charging locations, and payment solutions. Industry actors and regulatory bodies from S1 and S2 also have antagonistic interactions in this network (see Table 7). This antagonism represents a barrier to the swift implementation of BEVs, as it points to currently unresolved issues in regulatory frameworks related to vehicle standards, charging infrastructure and energy requirements.

The node with the highest betweenness centrality (see Table 6), representing the actors with the most influence over ongoing regime field restructuring processes, is once again a national research platform that connects industry actors and public agencies from S1 and S2 in pilot projects directly aimed at co-creating favourable market conditions for BEVs.

4.2.3. Policy and Regulations regime field network

Policy and Regulations has the second-lowest number of interactions and network density (3%) (Table 4). This regime field had the lowest average degree and longest average path length. The top and bottom actors from S1 cluster around special interest groups in Fig. 5. These groups allow actors to express their concerns, voice opinions, and build common future visions, attempting to influence public policy. Consequently, Table 6 lists a special interest group of freight transport as the actor with the highest betweenness scores in the *Policy and Regulations* regime field network. Over a third of all interactions were inter-system interactions, and most were symbiotic (see Table 4). Table 8's left side shows examples of inter-system interactions within this regime field. Within and across systems, competitive interactions between new entrants to niches with non-complementary technological solutions were mainly observed. Inter- and intra-system antagonistic interactions mostly occurred between influential actors (higher betweenness scores) of S1 and S2 and governmental authorities like the transport administration and the energy market inspectorate. This influence of governmental authorities in this regime field network is also reflected by their four appearances in the top ten actors with the highest betweenness scores (see Table 6).

4.2.4. Socio-cultural and Science regime field network

The *Socio-cultural and Science* regime field network had the most actors and was the second-largest network for detected interactions. Actors in this network also showed the second-highest average degree. Despite a low network density (3%), actors were not less (or more) closely connected than within the other regime fields (Table 5). Intra-system interactions of a symbiotic nature were the most common and mostly revolved around established actors from S1 reconfiguring together the storylines and dominant cultural

Table 8
Illustrative examples of different types of interactions present in the *Policy & Regulations* regime field network derived through our analytical framework.

	Intra-system			Inter-system		
	Regime-Regime	Regime-Niche	Niche-Niche	Regime-Regime	Regime-Niche	Niche-Niche
Symbiotic	Interactions between carriers & vehicle manufacturers to understand the total operating costs of BEVs.	Interactions between shippers & autonomous electric transport solution developers to understand the skills development required for the terminal personnel.	Interactions between green hydrogen producers & refuelling infrastructure providers to develop integrated business economics models.	Interactions between vehicle manufacturers & power companies to understand the profitability of charging systems for BEVs.	Interactions between energy generators & EV battery developers to showcase the functionality of their battery solutions for trucks.	Interactions between FCEV manufactures & hydrogen refuelling infrastructure developers to generate financing models.
Antagonistic	Interactions between gas stations & transport administration to develop a road network for charging stations.	Interactions between transport administration & FCEV manufactures to legitimise the application of their technology for trucks.	Interactions between vehicle converters & vehicle battery technology providers to scale up modular battery pack developments.	Interactions between transport administration & electrical infrastructure providers to legitimise their technological solutions through funding.	Interactions between energy market regulators & dynamic charging infrastructure developers to legitimise their technological solution through funding.	Interactions between FCEV manufacturers & green hydrogen producers to secure an upscaling of hydrogen fuel production.
Competitive	Interactions between energy generators to locate optimal charging locations.	Interactions between vehicle manufacturers & BEV manufacturers to understand travel behaviours & vehicle charging times.	Interactions between stationary & dynamic charging providers to understand infrastructure deployment best practices.	Interactions between energy generators & vehicle manufacturers over the development of charging standards.	Interactions between gas stations and refuelling infrastructure providers over favourable locations for optimal infrastructure locations.	Interactions between battery & hydrogen storage providers over the lowest cost of energy storage.

discourse around road freight transport. Table 9 lists examples.

Transport media outlets' influence over the reconfiguration process is reflected in how this actor type scored the highest, third highest, and fourth highest betweenness values of all network actors in this regime field (see Table 7). Actors in N1 compete with one another to shape norms and beliefs about the best technological solution, and they also compete across the niches with N5 actors. Overall, this regime field network had the fewest inter-system interactions of the analysed networks, which were mainly symbiotic (Table 4). Fig. 5 shows how research platforms, the electrification commission, and universities clustered S1, S2, and S3 actors together, facilitating inter-system interactions. These actors simultaneously contribute to restructuring socio-cultural and science regime fields through publications, events, and new research that creates scientific programs that ultimately change the discourse around freight transport.

5. Discussion

5.1. Toward a dynamically evolving view of regime field restructuring

Examining the relational dynamics across different regime fields, our findings uncovered a range of disagreements and conflicts among actors concerning potential system reconfiguration pathways. These conflicts primarily arose from divergent views on technological adoption, infrastructure development, and regulatory requirements and have created tensions rather than alignment. In Sweden, ambitious decarbonisation goals for the road freight sector provide an impetus to shift regime fields from dynamic stability to more radical field restructuring processes. These result from the entrance of new actors, including energy service providers, charging infrastructure developers, zero-emission truck start-ups and novel interaction patterns of varying natures among field members. Our analysis, therefore, revealed a more dynamic view of regime change processes, in line with a non-static theorisation of organisational fields (Wooten and Hoffman, 2017). Fig. 5 depicts dynamic sites of conflict, competition, and collaboration where actors come together to develop new field rules and a common meaning system, encompassing shared beliefs, norms, and expectations about how electrification should proceed, what the benefits are, how challenges should be addressed, and what roles various stakeholders play in this low-carbon transition. Thus, our study's results show that regime fields are dynamically evolving in the context of a low-carbon transition as actors try to make sense of required field restructuring processes and re-establish a common meaning system. Endogenous change mechanisms include strategic activities of field members, novel multi-actor interaction patterns, and the formation of new coalitions between formerly independent systems.

Nevertheless, our results disclose that the stabilisation of field rules is currently challenged by various regime tensions, as

Table 9
Illustrative examples of different types of interactions present in the *Socio-cultural & Science* regime field network derived through our analytical framework.

	Intra-system			Inter-system		
	Regime-Regime	Regime-Niche	Niche-Niche	Regime-Regime	Regime-Niche	Niche-Niche
Symbiotic	Interactions between transport operators & media outlets to produce articles on their sustainability efforts.	Interactions between universities & autonomous electric transport solution developers to collaborate on research projects.	Interactions between vehicle battery technology producers & battery recycling solutions providers to co-fund research projects.	Interactions between (transport) media outlets & power companies to produce articles on their charging system offerings for transport operators.	Interactions between power companies & stationary charging solution providers to produce press releases on their heavy vehicle charging solutions.	Interactions between FCEV manufacturers & green hydrogen producers to influence the dominant cultural discourse around the application of hydrogen for heavy vehicles.
Antagonistic	Interactions between universities & transport administration to obtain funding for research projects.	Interactions between the energy agency & green hydrogen producers to obtain funding for system demonstrators.	—	Interactions between the transport agency & power companies to obtain funding for pilot projects.	Interactions between energy agency & battery storage developers for research around battery energy storage systems for transport terminals.	—
Competitive	Interactions between vehicle manufacturers to alter the dominant cultural discourse around commercial applications for BEVs in their favour.	Interactions between vehicle manufacturers & stationary charging providers to shape norms and beliefs around who can provide charging systems to transport operators.	Interactions between stationary & dynamic charging providers to shape norms and beliefs around which technological solution is the best.	—	Interactions between gas stations and refuelling infrastructure providers to influence the cultural discourse around the future of truck fuelling infrastructure.	Interactions between FCEV manufacturers & BEV manufacturers to shape norms and beliefs around which technological solution is the best.

represented through competitive and antagonistic interactions within the different regime fields. These include disputes and competitions over which ZEV drivetrain will be the leading technology for sector decarbonisation, rivalry over technological standards for electricity payment and charging solutions, asymmetrical dependencies on energy transmission operators for providing adequate grid capacity, and reliance on policymakers for drafting a consistent regulatory framework for electrification. Moreover, our analysis found differences in incumbent actors' involvement in restructuring processes across regime fields. The type and number of actors and their strategic positionings across the different regime fields may naturally vary because different sets of rules (e.g., dominant technological designs, regulations, or user practices) are produced by different actors (e.g., engineers and lawmakers). Nevertheless, we identified barriers to entry and a lack of involvement of relevant incumbent actors from the road freight regime in the *Technology and Infrastructure* and *User practices and Markets* regime fields.

For both regime fields, transport operators, who represented the actor group with the most significant discrepancy in regime field involvement, face high initial capital costs when considering the adoption of electric trucks. The limited availability of charging infrastructure and concerns about grid connections further represented barriers to the reorientation of transport operators. Additionally, participation in funded research projects is often not feasible for smaller hauliers due to limited resources and expertise, hindering their ability to partake in the ongoing low-carbon transition actively.

5.2. *Plurality of incumbency and their influence over system reconfigurations*

As our results show, once one moves past a constraint analytical scope on established actors, like large companies, toward a more relational perspective that examines interactions and dependencies between different actors in the various regime fields as they reorientate toward low-carbon innovations, it becomes possible to investigate a multiplicity of different forms of incumbency (Stirling, 2019; Turnheim and Sovacool, 2020). In the case of the Swedish road freight sector, additionally to established companies, such as vehicle manufacturers, universities, special interest groups and end users – through their (inter) actions – reproduce the stability of prevailing regime fields and influence the directionality of system reconfigurations. For example, the nation's internationally recognised engineering institutions, as of today, still run specialized programs producing a steady stream of engineers with expertise in ICEVs. While strengthening Sweden's prowess in traditional automotive engineering, this educational orientation inadvertently stabilises the existing regimes. The deep entrenchment of such educational and professional pathways exemplifies the intricate layers of incumbency within the studied context. Our results, thus, illustrate the interconnected nature of incumbency in the sense that it is deeply embedded in the social and material realms that guide an industry sector. It will, therefore, not be enough for individual incumbent actors to be "overthrown" by new entries to decarbonise the sector drastically. Instead, reconfiguring existing systems requires radical restructuring and the creation of new field rules. This would enable a shift in the common meaning system of incumbency, triggering rhizomatic change from within.

In this study, incumbent actors held strong positions across all regime field networks, with heavy vehicle manufacturers having the highest betweenness scores, making them the most influential actors with a home field advantage. Acknowledging this central role of established actors raises questions about their power and influence (cf. Turnheim and Sovacool, 2020) over the pace and direction of low-carbon system reconfigurations: These vehicle manufacturers understood that change would occur with or without them. Interviewees described a reorientation toward electrification as a way to actively shape the future of a fossil-free freight transport sector and maintain industry competitiveness. This may lead to new forms of undesirable lock-in by influencing the directionality of reconfiguration, e.g., by shaping the market for commercial ZEVs through their product offerings. Presently, manufacturers develop BEVs with increasingly large batteries to match the driving range of ICEVs, allowing transport operators to switch with fewer changes to transport management practices. BEVs with large batteries have higher vehicle life-cycle emissions compared to those with smaller batteries (Morfeldt et al., 2022), so if manufacturers continue this trend without considerations for second-life solutions for these big batteries, they may promote a drive-train substitution and inhibit more radical system reconfigurations needed for effective and fast decarbonisation of the sector. Actor reorientation activities, thus, should not be viewed as inherently positive, but their motives and activities must be critically evaluated case by case.

5.3. Inhibitors and enablers of a low-carbon system reconfiguration

Through the application of our framework, many competitive interactions between transport operators in the nascent market of sustainable low-emission transport were revealed in the *User practices and Markets* regime field network, which currently hinders an accelerated reconfiguration. Both carriers and shippers perceive a switch to ZEVs as a way to increase customer value and gain a competitive edge in today's low-margin freight market. The reconfiguration toward fully electrified transport raises questions about logistic flows around charging networks, operational costs, fleet characteristics, and the overall work environment. Individual organisations must address these knowledge gaps while running their day-to-day business. Several research initiatives are underway in Sweden to help transport operators electrify their operations, but collaboration and data sharing are rare. Transport operators recognise the role that shared data can play in accelerating system reconfigurations (e.g., sharing data on vehicle routes would enable a better understanding of both charging network locations and power requirements) but fear losing their competitive edge. This reluctance to share data, driven by competitive concerns, stagnates the development of a common meaning system and thus acts as an inhibitor of broader reconfigurations essential for a low-carbon transition in the road transport system.

In addition, the electrification of road freight transport in Sweden requires integration with the energy system, and the findings across all regime field networks showed a broad involvement of actors from there. Hence, this study corroborates prior findings (Andersen and Markard, 2020; Geels, 2018b; Rosenbloom, 2019) that decarbonisation of entire industry sectors cannot be achieved merely by reconfiguring one system. Instead, it involves establishing new field rules that emerge from symbiotic interactions between actors across multiple systems. For example, energy companies have formed strategic collaborations with incumbents and niche actors in freight transport based on common interests. Such novel ties between actors from formally separate systems shape the directionality of reconfiguration processes yet establishing them is challenging for many organisations. Our analysis also highlights the role and influence of research projects and initiatives in addressing this challenge by bringing stakeholders of multiple systems together. These projects and initiatives serve as multi-system intermediaries, enabling actors of different systems to connect, coordinate their interests, and develop a common meaning system within regime fields.

6. Conclusion

In this study, we have explored the complex dynamics of incumbency reorientations in ongoing low-carbon transition. While recent reconfiguration approaches (Geels, 2020; Geels and Turnheim, 2022) have developed an analytical perspective that emphasises the importance of incumbent reorientations, our paper has complemented such approaches by enhancing our conceptual understanding of *how* such incumbency reorientation dynamics - the changes in interaction patterns among incumbents as they reorientate - unfold. By focusing on actor reorientation activities and the nature of actors' interactions within the different dimensions of a regime, our work thus highlights that i) incumbency reorientations do not happen in isolation but through novel interaction and interaction patterns within and across multiple systems and that ii) actor involvement and interactions may vary across regime fields, so incumbency reorientation dynamics are multi-dimensional. These interaction patterns vary strategically for each regime field, resulting in divergent actor positions and role constellations across the different regime fields as actors restructure fields, produce new field rules, and, at an aggregated level, shape system reconfiguration processes. By applying our conceptual framework, we were, therefore, able to better understand the multi-actor dynamics of unfolding low-carbon transitions by showing how changes to field-level interactions shape system reconfigurations.

In addition, while previous work acknowledged internal regime tension (Geels, 2004), our study underscores the potential of these tensions to hinder system reconfigurations by using organisational fields as a methodological construct to explore the dynamics of incumbency reorientations. Therefore, future research should explore how to overcome such tensions to allow for the stabilisation of field rules within different regime fields. This presents an important area of future work that can enhance the understanding of how to accelerate system reconfigurations. This paper introduced a novel analytical lens focusing on emerging reconfiguration processes that lead to multi-system interactions by differentiating actor interactions within and across existing systems. While this study is a first attempt to gain a better understanding of the role of reorientation dynamics of incumbent actors from multiple systems, the cascading effects of transitions across multiple systems and bi-directionality of interactions — how one system's reconfiguration can affect another — also need more research.

We further revealed three aspects that have the potential to inhibit ongoing reconfigurations: First, a lack of involvement of actors may slow the development of new common rationalities in any regime fields and hinder the reconfiguration of the dominant system trajectories. This raises questions about the inclusion and exclusion of stakeholders in reorientation activities and suggests a third future research direction on how missing actor participation affects the pace and scope of system reconfigurations. Second, given the strong influence of incumbent in our studied context, a decline in their reorientation commitments may also slow down the low-carbon transition and instead stabilise existing systems. This highlights the potential pitfalls of a dominant involvement of incumbency in system reconfigurations. Therefore, understanding how to manage these challenges effectively constitutes a fourth warranted direction for future research where more attention is needed. Third, although market competition can force organisations to innovate and become more efficient and cost-effective, in the studied case, these competing issues between transport operators are slowing the BEV adoption, inhibiting a low-carbon transition. In Sweden's road freight sector, platforms for anonymous data sharing may be a solution. However, our findings highlight that revisiting axiomatic market principles as a fifth route for future research could be worthwhile to understand their effects on low-carbon innovation adoption and diffusion.

The presented research has limitations that could inform further research. First, our study should be viewed as an initial attempt to capture the heterogeneous dynamics of incumbency reorientations in low-carbon transitions by empirically focusing on an industry transition in a technologically advanced country. Future studies could apply our framework to analyse actors, activities, and field-level interactions in other industries to explore their system reconfiguration and build a comparative research portfolio. Moreover, this study examined how incumbency reorientation dynamics contribute to system reconfigurations by analysing incumbents' responses to a low-carbon transition. However, investigating actor activities that contribute to the stability of existing regime fields is beyond the scope of this paper. Previous studies have highlighted that incumbents may continue to carry out stabilising activities (Steen and Weaver, 2017). Still, we call for future research to address how incumbent actor strategies can simultaneously overcome the dualism of stabilising and reconfiguring. Without an integrated analysis of reorientation and stabilisation actor activities, it is difficult to assess whether regime field restructurings can lead to radical system reconfiguration. Therefore, it is warranted for research to explore this by focusing on developing frameworks and methodologies that allow a comparative analysis of change and stability. Furthermore, despite the efforts to include only tangible, ongoing reorientation activities in our analysis, minor discrepancies may persist between interviews, pledges, and actual practices. At present, the reorientation dynamics in the Swedish road freight sector are beginning to emerge, and our analysis can thus only provide insights into a temporal window of system reconfiguration. Given the unfolding nature of these dynamics, outcomes are still unclear. Therefore, further long-term studies are needed as more data becomes available.

Lastly, this work has important policy implications. Our analysis of the pledges highlights that many actors currently merely *intend to* reorientate to low-carbon practices. Thus, policymakers must create measures and instruments that encourage actors to fulfil their pledges, allowing intended change to occur. Our findings can also help policymakers understand the influence and interdependence between actors from multiple systems in a transition. In the studied case, the lack of a coherent regulatory framework across industries hindered actor reorientations. Therefore, a successful system reconfiguration will require a shift from today's single-system-focused policy instruments to a multi-system transition governance approach that can solve regulatory issues that emerge through interactions and couplings between formerly separate systems.

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.

Data availability

Data will be made available on request.

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Appendix A

Regime Dimension and Rule Classifications

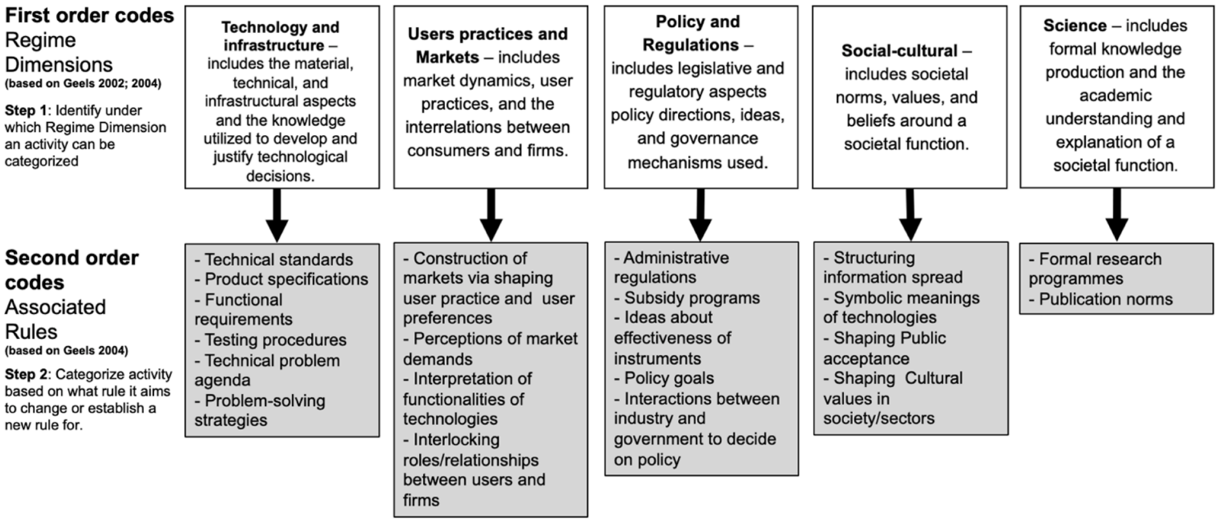

Fig. A1. Coding framework for identified activities in the pledges.

Appendix B

Actor Classification

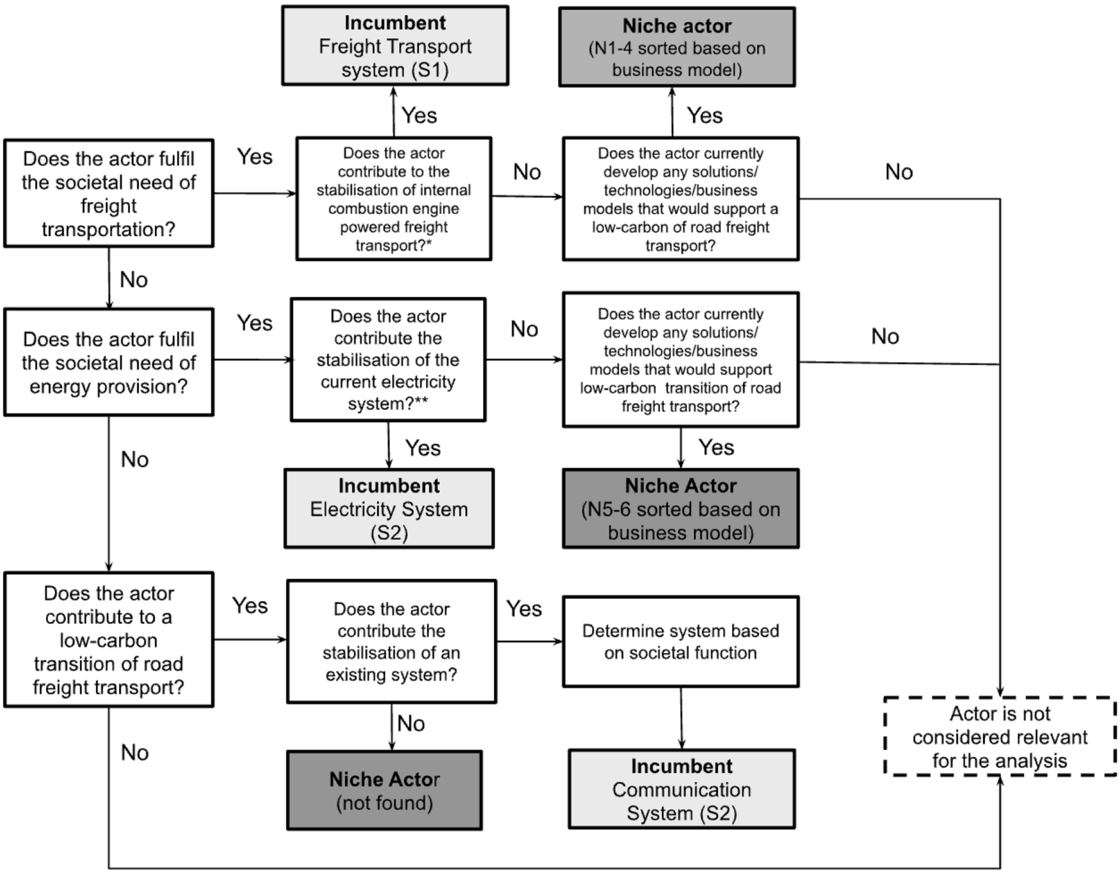

Fig. A2. Coding tree for incumbent and niche actor classifications in the SNA.

* Examples of possible stabilisation activities (Freight Transport):

- Manufacturing fossil-fuel-powered commercial vehicles or related vehicle parts
- Carrying out transport assignments with fossil-fuel-powered commercial vehicle
- Construction and maintenance of road infrastructure
- Supplying and selling fossil fuels for commercial vehicles
- Running engineering programs with profiles on the efficient design of internal combustion engine-based powertrain technologies

**Examples of possible stabilisation activities (Electricity):

- Extracting, refining, or producing both renewable and non-renewable sources of energy
- Maintaining and regulating the national transmission network
- Operating local distribution networks
- Providing electricity to businesses and homes
- Owning and maintaining infrastructure that delivers electricity to businesses and homes
- Overseeing and regulating the electricity market

Appendix C

Interviewee list

Table A1
System categorisation, actor type, and position of interviewed experts.

#	System Categorisation	Actor Type	Interviewee Title	Format	Duration
1	Freight Transport S1	Municipal Authority	Business Director	Face-to-face	62min
2	Freight Transport S1	Regional Authority	Community planning and infrastructure	Face-to-face	86min
3	Freight Transport S1	Regional Authority	Regional development	Face-to-face	72min
4	Freight Transport S1	Regional Chamber of Commerce	Inward investment Manager	Face-to-face	48min
5	Freight Transport S1	Carrier	CEO	Face-to-face	92min
6	Electricity S2	Power and Electricity company	E-Mobility Business Manager	Digitally	66min
7	Electricity S2	Special interest group	Vice CEO	Digitally	78min
8	Freight Transport S1	National research centre	Electric vehicle specialist	Digitally	96min
9	Freight Transport S1	University	Program Leader	Digitally	63min
10	Electricity S2	Electrical infrastructure provider	Technology Leader	Digitally	67min
11	Freight Transport S1	Governmental commission	Transport decarbonisation specialist	Partially	57min
12	Freight Transport S1	National research initiative	Project Manager	Digitally	54min
13	Freight Transport S1	National research initiative	Project Manager	Digitally	51min
14	Electric freight mobility N1	Autonomous electric transport solution developers	R&I Project coordinator	Digitally	68min
15	Freight Transport S1	Vehicle Manufacturer	Head of E-mobility	Digitally	63min
16	Communication S3	Network provider	Head of System Concepts	Digitally	57min
17	Electricity S2	Senior R&D Engineer	Senior R&D Engineer	Digitally	78min
18	Electricity S2	E-Mobility Programme Manager	E-Mobility Programme Manager	Digitally	64min
19	Freight Transport S1	Transport Administration	Senior Advisor	Digitally	92min
20	Freight Transport S1	Transport Administration	Senior Advisor	Face-to-face	80min
21	EV charging N3	Stationary Charging Developers	Manager E-Truck	Digitally	48min
22	EV charging N3	Dynamic Charging Developers	Project Manager	Digitally	78min
23	EV charging N3	Dynamic Charging Developers	CTO	Digitally	67min
24	EV charging N3	Dynamic Charging Developers	Regional Director of the Nordic Countries	Digitally	57min
25	Freight Transport S1	Research Institute	Dynamic Charging Project Leader	Digitally	69min
26	Freight Transport S1	Shipper	Quality and Environmental Manager	Digitally	60min
27	Hydrogen Energy N5	Special interest group	Chairman of the board	Digitally	52min
28	Hydrogen-powered vehicles N4	Carrier	Environmental Coordinator	Digitally	48min
29	Hydrogen Energy N5	Hydrogen infrastructure developer	Business Development Manager	Digitally	67min
30	Freight Transport S1	Shipper	Logistics developer	Digitally	62min
31	Freight Transport S1	Special interest group	University Professor	Digitally	77min
32	Freight Transport S1	Vehicle Manufacturer	Technology Leader Electrification	Face-to-face	57min

Appendix D

Interaction classifications coding framework.

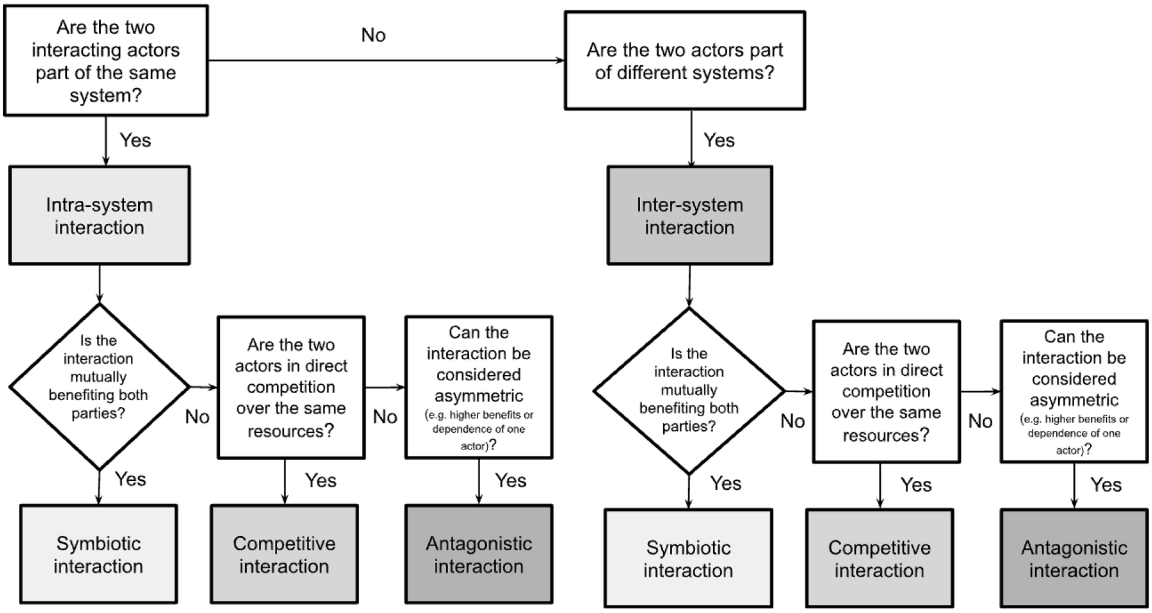

Fig. A3. Decision tree for the classification of interaction type and nature.

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