Mapping Multi-System Interactions in Urban Contexts—A Study of the Energy, Transport, and Food Systems in the Municipality of Gothenburg

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Introduction

Recognizing the relevance of a multi-system perspective, a growing body of work within sustainability transitions studies has begun to employ multi-system analyses (Andersen & Geels, 2023; Andersen et al., 2023; Ohlendorf et al., 2023; Rosenbloom, 2019), promoting a closer examination of the fluidity and permeability of system boundaries, thereby fostering a more dynamic view of system development in relation to other systems (Konrad et al., 2008). For instance, previous studies have investigated the system interactions between the electricity and waste management system (Raven, 2007), and between the electricity and electric transport systems (Haley, 2015). While the broader sustainability transitions literature has emphasized urban contexts as key nodes for socio-technical transitions, functioning as sites where multiple socio-technical systems converge, interact, and evolve (Frantzeskaki & Rok,

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2018), most existing research on multi-system interactions has largely focused on the national level, leaving localized contexts comparatively underexplored. This represents a missed opportunity, as municipal-level analyses provide rich empirical settings to engage simultaneously with multiple socio-technical systems, offering explanations beyond those grounded in isolated systems (Grin et al., 2017).

Another notable limitation of existing multi-system analyses lies in their predominant focus on dual interactions, i.e., mapping and explaining interconnections between two systems. This narrow approach becomes increasingly problematic as transitions accelerate, triggering simultaneous changes across multiple systems. The resulting effects of emerging and evolving cross-system interactions go beyond dual relationships, spanning a broad range of socio-technical systems and their corresponding societal functions. Hence, recent studies have called for "a shift in research from focusing on single system transitions plus wider interactions towards investigating a 'patchwork' of interacting transitions" (Andersen & Geels, 2023, p. 10). In order to begin investigating such "patchworks" of interconnected transitions across multiple systems, the level of municipalities provides an appropriate context.

Accordingly, this chapter goes beyond the typical focus on dual interactions by considering mutual interconnections across three systems, i.e., the food, energy, and transport systems. A transition is urgently required in each one of these systems. The food system is widely recognized as environmentally and socially unsustainable (Hebinck et al., 2021; Meynard et al., 2017), scaling up the diffusion of clean energy production is necessary to limit climate change (Mignon & Bergek, 2016), and the transport system needs to shift from fossil fuels to renewable alternatives (ER, 2017). However, none of these systems exists in isolation and must be considered within their broader socio-technical context, including neighbouring systems with which they interact (Andersen & Geels, 2023; Andersen et al., 2023; Kanger et al., 2021; Sutherland et al., 2015). Earlier studies have highlighted the interconnections between food, energy, and transport systems at the national level (Huttunen et al., 2014; Sutherland et al., 2015). In this chapter, we chose to study the interactions linking these three systems in the urban context of Gothenburg municipality.

Specifically, we perform an in-depth review of policy documents to map the interactions between key actors, infrastructures/technologies, and institutions across these systems in Gothenburg municipality. In doing so, we identify the strengths and weaknesses of the structures (e.g., projects, plans, networks) put in place by municipal actors to foster interactions between these systems and formulate policy recommendations on how to navigate imbalances and asymmetries inherent to urban multi-system transitions.

Following, we present the analytical framework, focusing on the concept of inter-system couplings and connecting it to the urban context. We then elaborate on the methodology and present the study findings in accordance with the theoretical framework. Finally, we discuss the key insights and summarize the contributions, along with suggestions for further research.

Analytical Framework

Multi-System Interactions and Couplings

Interactions across systems result in the reshaping of system boundaries, affecting actor possibilities for achieving their goals (Rosenbloom, 2020). Therefore, previous studies have paid significant attention to explore sites of interactions (Rosenbloom, 2019), their types, intensity, and impact on the involved systems (Breitschopf et al., 2023). Two systems can be involved in different types of interactions simultaneously, ranging from competitive to symbiotic, and the type of interactions can change over time (Geels, 2007; Raven & Verbong, 2009). In this chapter we focus particularly on the interfaces, or couplings that link different systems and are key to achieving compatibility between them (Andersen et al., 2023).

Literature distinguishes between two primary types of couplings, structural and functional (Konrad et al., 2008). Structural couplings are defined as system elements such as technologies (including physical infrastructure), actors, and institutions that connect multiple systems (Konrad et al., 2008). For instance, the installation of harbour charging stations can be understood as a technology-related structural coupling that connects the maritime transport sector with the electricity system (Andersen et al., 2023). This coupling is fundamental as it provides the physical and organizational framework necessary for interaction. Technology-related couplings represent interactions between supply chains and upstream systems during technology development and diffusion, as well as complementary technologies in use contexts. Actor-related couplings emerge when business actors diversify into other systems or when users interact with and transfer learning and experiences across systems. Institution-related couplings emerge when actors address institutional mismatches or when common meta-rules develop across multiple systems (Andersen & Geels, 2023).

Functional couplings refer to the flow of resources between systems (Konrad et al., 2008), which are facilitated by the structural couplings (Andersen & Geels, 2023). For example, the electrical energy flowing through the charging stations at the harbour constitutes a functional coupling between the maritime transport and electricity systems, creating a functional interdependency (Andersen et al., 2023). Ongoing transitions can result in the emergence of new functional couplings across systems. For example, Huttunen et al. (2014) showed how biogas production can enhance new resource flows between transport, agri-food, and energy systems: municipal food waste, among other input materials, undergoes anaerobic digestion and hence serves as an input resource to produce energy or, after additional refining, to produce transport fuels; in turn, the rest products from anaerobic digestion can flow back into the agri-food system in the form of nutrients and fertilizers. However, the feasibility of functional couplings can be hampered by a lack of corresponding structural couplings, e.g., in terms of incoherent policies across different involved systems (Andersen & Geels, 2023; Huttunen et al., 2014).

Building on the foundational work of Konrad et al. (2008), Andersen et al. (2023) proposed a dynamic and processual nexus building perspective elaborating how inter-system couplings are created across the four dimensions of technology, institutions, actors, and resources. They show that the process of building couplings involves tensions, conflicts and can result in asymmetric adjustments where one system has to undergo larger changes than the other due to power imbalances between actors from different systems. Developing technical and institutional compatibility can be a politically fraught process with disagreements on which solutions are most desirable, sometimes leading to the implementation of sub-optimal workarounds (Andersen et al., 2023). Furthermore, as transitions develop from early phases towards acceleration, multi-system interactions become more intense and complex (Markard et al., 2020), which can be seen in a form of knock-on effects from diffusion of individual innovations on wider systems (McMeekin et al., 2019) or in a form of increasingly interconnected transitions in parallel systems, driven by the same factors and competing for the same resources. For example, Nykamp et al. (2023) showed how grid connection challenges were a common constraint in the electrification of both ferry transportation, construction sites, and ammonia production.

Inter-System Couplings in the Urban Context

Multi-system interactions as well as transitions in general are spatially embedded (Ferloni, 2022). Hence, urban environments serve as important contexts where different types of multi-system interactions are created (Frantzeskaki et al., 2017). In terms of technology couplings, cities serve as test beds for developing, testing, and upscaling new technological solutions (Sharp et al., 2024). In one and the same place, different innovations are combined with different existing urban systems (Hodson et al., 2024). Such processes of experimentation and reconfiguration involve competitive as well as complementary interactions across technologies and systems (Hodson et al., 2017). During contemporary transitions where outcomes are still evolving and remain uncertain, urban contexts can support unexpected connections between previously separate elements and systems (Grin et al., 2017; Rohracher & Späth, 2017).

Regarding institutional couplings, in the localized contexts such as municipalities, understandings of sustainability transition goals are often contested. Actors from different systems are driven by different visions, leading to institutional environments that are sometimes contradictory and sometimes mutually reinforcing (Hodson et al., 2017). As multiple interpretations of visions and goals open for multiple development directions, governance of urban transitions requires integrative approaches across different systems, considering conflicts between different solutions and systems along with synergies (Grin et al., 2017; Rohracher & Späth, 2017).

As for the actor couplings, urban studies highlight the roles of various types of actors, including local governments, companies, networks, community groups, etc. (Huang & Broto, 2018). In particular, local governments can take a central role in driving and intermediating urban transitions, with support and engagement of other actors (Broto, 2017; Fudge et al., 2016; Holscher et al., 2019). Through this role, local governments can intermediate between and within different scales of governance (i.e., local, national, and international), hence linking actors, practices, and policies of different scales (Gustafsson & Mignon, 2020).

Method

Case Motivation

Earlier transition research has highlighted the interconnections between food, energy, and transport systems, despite these systems not typically being considered together (Huttunen et al., 2014). For instance, biogas from agricultural byproducts and the co-location of renewable energy technologies on agricultural land demonstrate the potential for systemic sustainability transitions across these sectors (Sutherland et al., 2015). While previous studies have addressed such interconnections at the national level, our study shifts the focus to the municipal level, examining how key actors, infrastructures/technologies, and institutions interact across the food, energy, and transport systems in Gothenburg.

Gothenburg, located on the southwest coast of Sweden at the mouth of the Göta River, provides a suitable setting for studying these multisystem interactions. As Sweden's second-largest city, with a population of 600,000 and over 1 million in the greater metropolitan area, Gothenburg experiences substantial resource flows across these critical systems, providing a rich environment for analysing their interconnections. From a transport system perspective, Gothenburg stands out as a major hub in Sweden, housing key infrastructure such as the municipally owned Port of Gothenburg—the largest in Scandinavia, an airport, extensive rail and road networks, and global vehicle manufacturers, including Volvo Cars and Volvo Trucks that are heavily involved in urban testbeds. The energy system in Gothenburg is similarly noteworthy, with the city owning its own energy company, Göteborg Energi, and operating a vast district heating system. It also has Sweden's largest installed solar power capacity, emphasizing its focus on energy resilience and sustainability. Gothenburg's influence on the food system is notable as well, with the city managing large-scale school meal programmes and 3000 hectares of agricultural land. This is particularly relevant in the context of Sweden's low national food self-sufficiency, which adds pressure on Gothenburg to enhance food system resilience. Overall, the populous urban context of Gothenburg, coupled with the specific characteristics of each system, makes it a promising case for studying multi-system interactions.

Data Collection

This study was conducted through an in-depth review of policy documents from Gothenburg municipality, which serve as a crucial data source for understanding the municipality's role in shaping the interactions between the food, energy, and transport systems. Policy documents are particularly valuable as they capture the municipality's strategic intentions, plans, and priorities, offering insights into how these systems are managed and interconnected within the urban context.

The documents were purposively sampled based on their potential to illuminate inter-system interactions. This targeted approach helped to ensure that the most relevant and informative documents were included in the analysis. Table 4.1 offers an overview of the selected documents, highlighting the primary system for which they were selected.

Although not formally part of the data collection and analysis process, the researchers involved in this study bring with them prior experience and insights gained from their previous research on the food (e.g.,

Table 4.1 Overview of documents selected for analysis

Document	Type of Document	Reviewed by author focusing on		
		Food	Energy	Transport
Circular food system report	Policy recommendations	X		
Energy Plan 2022–2030	Action plan		X	
Electrification Plan 2022–2030	Action plan			X
Waste Management Plan 2021–2030	Program	X		
Environment and Climate Programme 2021–2030	Program	X		
Procurement guidelines	Guidelines	X		
Business program	Program		X	
Traffic Strategy 2035	Strategy			X
Västra Götaland County food system transformation agenda	Strategy	X		

Thomson, 2022), energy (e.g., Mignon et al., 2023), and transport systems in Gothenburg (e.g., Werner & Onufrey, 2022; Werner et al., 2021). The researchers' background knowledge enriched the current analysis, allowing for a more informed and nuanced interpretation of the multi-system interactions within the urban context of Gothenburg.

Data Analysis

The data analysis was conducted in two phases. In the first phase, each author independently analysed the empirical material related to their respective system (food, energy, or transport). This involved an iterative process of reading and re-reading the material, with a focus on identifying key statements that related to the theme of multi-system interactions. These statements were coded according to their relevance to structural or functional couplings and were further categorized based on the specific dimension of socio-technical systems they pertained to (actors, infrastructure/technologies, or institutions). Additionally, each author preliminarily identified the system or systems to which each coded section was related (food, energy, transport).

Following the initial independent coding, a collaborative discussion was conducted to consolidate and refine the findings. In this joint session, each author presented the coded segments from their analysis for collective review. The goal was to develop a cohesive understanding by comparing and integrating the independent analyses. This collaborative process allowed for a more comprehensive cross-system analysis, where structural and functional couplings identified in one system (e.g., food) were examined in the context of findings from the other systems (e.g., energy and transport). This integrative approach facilitated the identification of connections and interdependencies across the systems, thereby deepening the understanding of how these systems interact. By collectively leveraging the insights and perspectives of the researchers, this phase ensured a more thorough examination of the cross-system interactions.

Findings and Analysis

Technology Couplings

Analysis of the strategic planning documents from the municipality of Gothenburg reveals several key established, emerging and planned technology couplings across the energy, transport, and food systems (see Table 4.2). Among the established couplings, the connection of food waste with the energy and transport systems stands out. For instance, waste food is processed and incinerated at municipal co-generation plants (e.g., Sävenäs), providing electricity and district heating. Biogas production from waste slurry, transported to various biogas facilities in the region, reflects how the need for more local renewable energy can create new operational dependencies (e.g., on large fleets of trucks for waste transport). However, these couplings also highlight potential tensions. For example, the intensified use of transport to move slurry (involving around 30 trucks per week) potentially decreases the benefits of biogas. This tension underscores how multi-system interactions can generate unintended knock-on effects if the necessary supporting infrastructure (e.g., pipelines or local treatment plants) is underdeveloped.

Among the emerging technology couplings, notable examples include a pilot project for indoor food production and initiatives focused on alternative charging methods for electric vehicles. The indoor food production pilot, which links the energy, transport, and food systems, involves the development of a food production facility that utilizes excess heat from a data centre owned by the municipal energy company. Due to its urban location, the transportation required to deliver produce to customers is significantly reduced. The municipality's focus on alternative charging (e.g., wireless systems, high-powered stations) indicates the broader electrification drive in the region. Yet, these initiatives remain in pilot or early roll-out phases, highlighting the risk of fragmented implementation if city-wide coordination lags behind technological advances.

Finally, among the planned technology couplings are the ongoing evaluations of a future carbon capture and storage (CCS) and hydrogen production plant, which point to a strategy to transform local industry and transport networks. Documents indicate that such a plant would have the potential to capture emissions from the local industry (including refineries and other manufacturing industries), to transform and store it within and outside of the municipality's boundaries. However, the technical viability of this would require extensive inter-system coordination on how carbon is stored and transported.

Table 4.2 Overview of couplings identified in the data (E stands for electricity, T for transport, F for food)

Document	Structural couplings			Functional couplings
	Technology couplings	*Institutional couplings*	*Actor couplings*	
Energy documents	- electricity grid E+T+F - district heating grid E+T+F - waste-to-energy plants E+T+F - hydrogen production plant E+T - carbon capture and storage plant E+T+F - smart control systems/batteries E+T - charging stations for heavy transport E+T - biocarbon production E+T+F	- action plan for energy E+T+F - environment and climate strategy E+T+F - arenas for dialogues among transport & energy actors E+T - explicit goals to influence policies outside the boundaries of the cities E+T+F - explicit goals to influence citizens and local organizations' practices. E+T+F	- Göteborg Energi AB - Göteborg Energi Nät AB - Vattenfall and Svenska Kraftnät - Renova AB - Gryaab AB - Preem AB and St1 AB - Göteborgs Hamn AB - business region Göteborg - Förvaltning AB Framtiden - Higab - Älvstranden Utveckling AB - Göteborg municipality	- electricity production based on various inputs (e.g., solar, wind, (bio)gas, waste incineration) ⇒ grid ⇒ batteries, charging stations. - electricity generation and waste incineration (including food) Þ district heating - food (or other organic) residue ⇒ electricity generation (and district heating) or slurry ⇒ biogas production (and transport fuel) - CO2 from various industries ⇒ CCS plant ⇒ storage areas - food (or other organic) residue ⇒ biocarbon (will be used locally or transported).

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Document	Structural couplings			Functional couplings
	Technology couplings	*Institutional couplings*	*Actor couplings*	
Transport documents	- charging infrastructure for electric personal cars and heavy vehicles E+T -wireless charging infrastructure for personal cars, via charging plates integrated into the asphalt E+T - electric road systems for goods transport E+T - charging infrastructure for hydrogen cars E+T - energy services related to electric charging E+T - technologies for electricity grid improvements: Capacity enhancements, load/power control, local electricity production, V2G, battery storage E+T+F	- electrification plan E+T+F - transport strategy E+T - strategic programme for business development E+T - business region Göteborg coordinates the implementation of the electrification plan E+T+F - explicit ambition for coordination at the system level to avoid possible goal conflicts/sub-optimizations E+T+F - explicit ambition to have an overall strategy and plan for charging infrastructure and cross-sector electrified transport and energy supply E+T - policy goal for availability of charging options matching societal needs E+T	- business region Gothenburg - Volvo cars & Volvo AB - Chalmers, RISE, Lindholmen Science Park - Renova AB - Göteborg Energi - Vattenfall and Svenska Kraftnät - Göteborg Hamn - Göteborg municipality	- electricity ⇔ electric vehicles E+T - City's purchased transport services include transportation of food, e.g., to schools. T+F - within urban goods transport, food waste collection is one of the primary functions T+F

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Document	Structural couplings			Functional couplings
	Technology couplings	*Institutional couplings*	*Actor couplings*	
Food documents	- water treatment plant E+F - multi-functional greenhouse concept E+F -waste-to-energy plant E+T+F - Gothenburg harbour E+T+F	- City plan E+T+F - waste management plan E+F - Gbg City guidelines for procurement E+T+F - Gbg City report on circular food production E+T+F - public meals policy E+T+F	- Göteborg municipality - Göteborg energi AB - Renova AB - St1 AB - business region Göteborg - Gryaab AB	- food waste Þ processing facility Þ slurry transported around the west coast of Sweden for biogas production E+T+F - waste water and sewage ⇒ biogas and fertilizer ⇒ food production. E+F - data Centre residual heat ⇒ indoor growing E+F - food waste ⇒ waste-to-energy plant ⇒ electricity E+T+F - Most of the food consumed in Gothenburg imported from abroad, much arrives through Gothenburg harbour, as well as the majority of food produced in Gothenburg being exported to the rest of the world T+F

Institutional Couplings

The data highlights both explicit and implicit institutional couplings that shape multi-system interactions. Explicit institutional couplings stem from formal policy documents, such as the Action Plan for Energy and the Electrification Plan, where couplings between systems are described, planned, and framed. For instance, the Action Plan for Energy, a document setting the agenda for the period 2022 to 2030, states that:

> "The *energy system in Gothenburg consists of several interconnected systems…It is necessary to see the connections between the systems to understand the whole and to avoid suboptimization when a single goal is to be*

> *reached. To focus on the connections between the subsystems will be necessary to create synergies and achieve the municipality's energy and climate goals".*

(Göteborg Stads Energiplan 2022–2030, p9).[1]

These documents explicitly establish goals, visions, responsibilities, budgets, and targets that often shape multiple systems. For instance, the action plan for energy sets objectives for electricity production that also support the electrification of the transport sector, defining responsibilities and mandates for actors operating at the intersection of the energy, food, and transport systems. Each document also specifies whether the policies are binding or non-binding and whether the objectives fall within the direct or indirect influence of the municipality. In some cases, such as the municipality's procurement guidelines, the policies are binding, while in others, such as the municipality's infrastructure planning document, the policies are non-binding and serve as long-term strategic guidance.

Implicit institutional couplings involve less formalized objectives and ambitions, where influence is exerted indirectly, often without quantified targets or direct enforcement. These concern institutional influences that the municipality intends to have on actors or decision-makers outside its geographic boundaries. For instance, the action plan for energy indicates that the municipality intends to influence the government and the European Commission's decisions and policies related to biogas. Likewise, in the report on circular food production, the municipality indicates that although its direct influence on sustainable consumption and production is limited (to its own organization), it aims to indirectly influence actors (such as citizens) in choosing more sustainable food alternatives. However, the existence of both explicit and implicit couplings exposes the potential for institutional tensions that can result in fragmented or uneven implementation where some goals are fully enforced (e.g., waste collection) while others remain advisory (e.g., circular consumption and production).

[1] Quotes were translated by the authors.

Actor Couplings

Actor couplings emerge as a principal driver of multi-system interactions, with substantial overlaps visible between the focal system documents. Central actors linking the three systems include, for instance, Gothenburg municipality (encompassing various departments), which serves as a central actor overseeing the food, energy, and transport systems.[2] Gothenburg municipality is the main owner for a number of key companies, including the municipal energy company Göteborg Energi AB, the resource management and recycling company Renova AB, the port of Gothenburg Göteborgs Hamn AB, and the municipal economic development agency Business Region Göteborg. Each of these companies are local nodes between systems. For example, Göteborg Energy AB supplies electricity, district heating, and energy services, and has a growing role in electric vehicle infrastructure. Likewise, Renova AB, besides being a key player in the resource management of the municipality, also operates 70% of the city's own heavy vehicles, tying transport to energy through waste incineration and biogas.

In addition to these multi-system actors, there are also actors that have strong couplings between two systems. For example, Gryaab AB is the wastewater handling and treatment plant owned by Gothenburg municipality; it links the food and energy systems through the treatment of sludge (from food waste) which is used for both fertilizer and biogas production. Likewise, the municipal real estate companies Förvaltning AB Framtiden, Higab, Älvstranden Utveckling AB connect the energy and transport systems through their use of electricity and vehicle charging infrastructure, and in some cases, installation of solar cells on their buildings.

Functional Couplings

The analysis identifies multiple functional couplings among energy, transport, and food. Electricity, produced from waste incineration and

[2] It should however be noted that the lack of a comprehensive food perspective has led to calls for an official collaboration function focusing on food system transformation.

biogas digestion, is fed into the transport system, powering electric vehicles. Conversely, discarded food and wastewater become inputs for energy production, illustrating a circular approach, but also revealing conflicts if food waste is valued primarily as an energy feedstock rather than being prevented or redistributed.

The transport system not only demands energy (electricity, biofuels) but enables resource flows (e.g., delivering imported food, collecting food residuals). Transport ensures that goods, such as food produced outside municipal boundaries, can reach their destination. Moreover, collection of discarded food, which is an important input for electricity production, is also possible only if it can be transported. In turn, transportation of urban waste is among the first electrified applications of urban goods transport in Gothenburg. Future plans for carbon capture systems and hydrogen production will also hinge on the ability of the transport system to support these resource flows.

Finally, the food system is often portrayed as a downstream user of energy and transport, with emphasis on waste disposal over production inputs. The municipal documents note an aspiration to reduce external dependencies (e.g., imports) but lack detail on how local production will scale. This imbalance suggests a power dynamic where energy and transport systems dominate municipal planning, leaving food somewhat peripheral except as a source of residuals for energy generation.

Discussion

When drawing on the results of the mapping of interactions presented above, several notable patterns emerged that allow for the identification of interaction weaknesses and the drawing of empirical and theoretical implications for a sustainable transition in the urban context involving multiple systems.

Firstly, it is interesting to note that the municipality of Gothenburg explicitly recognizes the interdependence of transition processes and systems, advocating that they must be considered collectively rather than independently. Yet, despite this understanding, the mapping of couplings shows that dual system couplings between the energy and transport systems remain the most prevalent ones. While some couplings involving the food system do exist, they tend to be more implicit. Notably, among actor and functional couplings, key actors from the food system were absent. As a consequence, it is fair to stress that there is a mismatch between the ambitions of the municipality, and the structures put into place to facilitate and organize such interactions.

From a policy perspective, this means that awareness and ambition alone are not sufficient to foster multi-system interactions. Instead, it is important for governing bodies such as municipalities (1) to keep track of the interactions taking place and the structures put into place for these interactions (2) to identify weaknesses in the interactions and in the structures put in place, and (3) to adjust the structures to remedy for the lack of interactions. To exemplify, through the mapping of technological, institutional, actor, and functional couplings (Table 2), it appears that the food system is not explicitly mentioned in some strategic documents, plans, or policy goals, despite it being impacted by these policies. Likewise, several projects and dialogue arenas have been created, where representatives of one system are missing. The next step would then be for the municipality to adjust this lack of couplings to facilitate interactions.

From a theoretical perspective, the prevalence of dual interactions (i.e., rather than multi-system interactions) presented in the mapping reflects rather well the current state of the literature on multi-system interactions. It shows that while scholars and practitioners understand the need to consider multiple systems together, it is seldom done in practice. Urban environments, while being sites for multi-system interactions (Frantzeskaki et al., 2017), appear insufficient by themselves to foster meaningful attention to these interactions. This calls for future research to develop new methods to study multi-system interactions that can be used for both researchers and practitioners. A further development of coupling mapping, which was performed in this study, may be a way forward for increased awareness of multi-system interactions in policymaking. For instance, interviews with involved actors would be a way to reveal the underlying tensions and conflicts present in multi-system interactions.

Another significant pattern in the mapping is that actor couplings show the largest number of interlinkages between systems. As illustrated in Table 2, in a municipality such as Gothenburg, several actors play key roles across multiple systems. This pattern of actor couplings represents a potential strength allowing for broader multi-system interactions. Indeed, the studied actor couplings in the Gothenburg municipality are a starting point where additional couplings (technology, institutional) can be initiated and where synergies can be highlighted and exploited. As highlighted above, this emphasizes the critical need to map key actor couplings and identify missing actors and resolve the gaps by involving key actors. In our case, important actors from the food system, such as food producers and retailers, were missing, e.g., in dialogue groups. This stands in stark contrast to the energy and transport systems where private sector actors are highly involved and exert significant influence. This lack of representation of the food system could explain the limited number of technological, institutional, and functional couplings highlighted between the systems across the studied documents. Once identified, the lack of representation (and the uncovered potential of interactions with the food system) may rather simply be handled by involving relevant actors. Theoretically, while previous studies highlighted the importance of different types of couplings and positioned structural couplings as prerequisites for functional ones (Andersen & Geels, 2023; Konrad et al., 2008), our analysis suggests that actor couplings can serve as a foundation for building other types of structural couplings.

Apart from having more limited interactions with the other systems, the food system exhibits minimal structural similarity to the energy and transport systems, especially from the vantage point of a municipal actor within an urban context. While municipalities often exert significant control over the energy and transport sectors, the food system is markedly different. It is characterized by a decentralized, heterogeneous, and intricate mix of subsystems, lacking the centralized oversight typically seen in energy and transport systems. This decentralization results in a more complex and less uniform structure, posing unique challenges for urban governance and integration into broader socio-technical transitions. Such complexity may explain why food in our study was predominantly considered by the municipality from the perspective of disposal and the focus on earlier stages of the supply chain (i.e., food production) was entirely absent.

Finally, it is interesting to notice that in contrast with the energy and transport systems, where increased or stronger interactions with other systems are typically encouraged, the food system in our study showed signs of aiming to reduce its interactions with the transport system. For example, the pilot indoor growing project by virtue of being situated in the urban context, inherently reduces the need for extensive transportation, thereby lessening its interaction with the transport system.

From a policy perspective, this raises the question of how to organize multi-system interactions, when these interactions aim at being reduced. In such situations, e.g., in cases where dependencies with negative consequences on the environment, it may be necessary for a neutral, long-term thinking actor with no (or little) commercial interest to act as an orchestrator of multi-system interactions. Gothenburg municipality, as a public actor with societal and long-term interests (rather than commercial interest), and as the owner of several municipal companies within the energy, food, and transport systems, distinguishes itself as the primary governing actor of urban multi-system interactions and may therefore be suitable for playing such an orchestrating role. More concretely, this means that representatives of the municipality may lead dialogues and collaborations in projects where one of the aims is to lower the level of interactions between systems.

From a theoretical perspective, this finding adds nuance to prior research highlighting that multi-system interactions can have adverse effects, such as asymmetries or sub-optimal solutions (Andersen et al., 2023). In particular, our results suggest that multi-system interactions should not be a goal in and of themselves; in some cases, reducing or limiting interactions may prove more conducive to supporting sustainability transitions.

Conclusion and Suggestions for Future Research

In this chapter, we went beyond the typical focus on dual interactions, i.e., mapping and explaining interconnections between two systems, which have until now mainly been the focus on previous empirical studies of multi-system interactions, and instead considered mutual interconnections across three systems, i.e., the food, energy, and transport systems. Specifically, we mapped the inter-system interactions between key actors, infrastructures/technologies, and institutions across the food, transport, and energy systems in Gothenburg municipality, through the analysis of municipal documents, including policy recommendations, guidelines, action plans, and strategies.

Mapping inter-system linkages revealed planned, emerging and established technology couplings, implicit and explicit institutional couplings, and multiple key actor couplings across the energy, food, and transport systems. Notably, while the municipality of Gothenburg explicitly recognizes the interdependence of transition processes and systems, consistent with urban transition studies (Grin et al., 2017; Hodson et al., 2024), the prevailing focus in the documents is on dual interactions between the energy and the transport systems, rather than broader multi-system interactions. This highlights the challenges of effectively integrating and prioritizing multi-system linkages and underscores the difficulties of operationalizing visions for multi-system transitions, even in urban environments, which are often seen as natural sites for such interactions (cf. Frantzeskaki & Rok, 2018).

The mapping performed in this study proved to be a useful tool for identifying strengths and weaknesses of existing structures put in place to foster multi-system interactions. Among the strengths, structural actor couplings showed the largest number of interlinkages across systems. From a policy perspective, this provides a potential way forward to drive multi-system transitions; when key multi-system actors are identified, additional interactions, synergies, and roadmaps can be developed. Actor couplings therefore represent interesting avenues for future research aimed at accelerating multi-system transitions. For instance, it would be interesting to consider the key multi-system actors from an intermediation perspective, considering their potential roles as system entanglers (Löhr & Chlebna, 2023).

At the same time, existing structures, exemplified by municipal plans, projects, and dialogue arenas, showed a notable weakness in terms of enabling sufficient and balanced (i.e., multi rather than dual) interactions across all three studied systems. In particular, the food system was underrepresented and, when present, considered from a limited perspective of the disposal stage. This could at least partially be explained by particularities of the food system, representing a decentralized, heterogeneous, and intricate mix of subsystems, lacking the centralized oversight typically seen in, e.g., energy and transport systems.

This study predominantly focused on the analysis of the policy documents, leading to some limitations. First, the emphasis was placed on structural preconditions rather than the processual dynamics of multi-system interactions. Second, the mapping reflected the perspective of municipal departments that were in charge of writing the policy documents. To address these gaps, we encourage further in-depth studies involving a wider range of organizations' sources of data. Such studies could better capture processual dynamics, including tensions and conflicts, and provide deeper insights into the roles of various actors in urban multi-system transitions.

References

Andersen, A. D., & Geels, F. W. (2023). Multi-system dynamics and the speed of net-zero transitions: Identifying causal processes related to technologies, actors, and institutions. *Energy Research & Social Science, 102*, 103178. https://doi.org/10.1016/j.erss.2023.103178

Andersen, A. D., Geels, F. W., Steen, M., & Bugge, M. M. (2023). Building multi-system nexuses in low-carbon transitions: Conflicts and asymmetric adjustments in Norwegian ferry electrification. *Proceedings of the National Academy of Sciences of the United States of America, 120*(47), e2207746120. https://doi.org/10.1073/pnas.2207746120

Breitschopf, B., Grimm, A., Billerbeck, A., Wydra, S., & Köhler, J. (2023). Towards understanding interactions between socio-technical systems in

sustainability transitions. *Energy Research & Social Science, 106*, 103323. https://doi.org/10.1016/j.erss.2023.103323
Broto, V. C. (2017). Urban governance and the politics of climate change. *World Development, 93*, 1–15.
ER. (2017). *Strategisk plan för omställning av transportsektorn till fossilfrihet (Strategic plan for fossil-free transtion of the transport sector).*
Ferloni, A. (2022). Transitions as a coevolutionary process: The urban emergence of electric vehicle inventions. *Environmental Innovation and Societal Transitions, 44*, 205–225. https://doi.org/10.1016/j.eist.2022.08.003
Frantzeskaki, N., Broto, V. C., Coenen, L., & Loorbach, D. (2017). *Urban sustainability transitions* (Vol. 5). Routledge.
Frantzeskaki, N., & Rok, A. (2018). Co-producing urban sustainability transitions knowledge with community, policy and science. *Environmental Innovation and Societal Transitions, 29*, 47–51. https://doi.org/10.1016/j.eist.2018.08.001
Fudge, S., Peters, M., & Woodman, B. (2016). Local authorities as niche actors: The case of energy governance in the UK. *Environmental Innovation and Societal Transitions, 18*, 1–17. https://doi.org/10.1016/j.eist.2015.06.004
Geels, F. W. (2007). Analysing the breakthrough of rock 'n' roll (1930–1970) multi-regime interaction and reconfiguration in the multi-level perspective. *Technological Forecasting and Social Change, 74*(8), 1411–1431. https://doi.org/10.1016/j.techfore.2006.07.008
Grin, J., Frantzeskaki, N., Broto, V. C., & Coenen, L. (2017). Sustainability transitions and the city: Linking to transition studies and looking forward. In *Urban sustainability transitions* (pp. 359–367). Routledge.
Gustafsson, S., & Mignon, I. (2020). Municipalities as intermediaries for the design and local implementation of climate visions. *European Planning Studies, 28*(6), 1161–1182. https://doi.org/10.1080/09654313.2019.1612327
Haley, B. (2015). Low-carbon innovation from a hydroelectric base: The case of electric vehicles in Quebec. *Environmental Innovation and Societal Transitions, 14*, 5–25. https://doi.org/10.1016/j.eist.2014.05.003
Hebinck, A., Klerkx, L., Elzen, B., Kok, K. P. W., König, B., Schiller, K., Tschersich, J., van Mierlo, B., & von Wirth, T. (2021). Beyond food for thought-directing sustainability transitions research to address fundamental change in Agri-food systems. *Environmental Innovation and Societal Transitions, 41*, 81–85. https://doi.org/10.1016/j.eist.2021.10.003

Hodson, M., Geels, F. W., & McMeekin, A. (2017). Reconfiguring urban sustainability transitions. *Analysing Multiplicity. Sustainability, 9*(2), 299. https://doi.org/10.3390/su9020299

Hodson, M., McMeekin, A., & Lockhart, A. (2024). Urban infrastructure reconfiguration and digital platforms: Who is in control? *Environmental Innovation and Societal Transitions, 50*, 100816. https://doi.org/10.1016/j.eist.2024.100816

Holscher, K., Frantzeskaki, N., McPhearson, T., & Loorbach, D. (2019). Tales of transforming cities: Transformative climate governance capacities in new York City, U.S. and Rotterdam. *Netherlands. J Environ Manage, 231*, 843–857. https://doi.org/10.1016/j.jenvman.2018.10.043

Huang, P., & Broto, V. C. (2018). Interdependence between urban processes and energy transitions: The dimensions of urban energy transitions (DUET) framework. *Environmental Innovation and Societal Transitions, 28*, 35–45. https://doi.org/10.1016/j.eist.2018.03.004

Huttunen, S., Kivimaa, P., & Virkamäki, V. (2014). The need for policy coherence to trigger a transition to biogas production. *Environmental Innovation and Societal Transitions, 12*, 14–30. https://doi.org/10.1016/j.eist.2014.04.002

Kanger, L., Schot, J., Sovacool, B. K., van der Vleuten, E., Ghosh, B., Keller, M., Kivimaa, P., Pahker, A.-K., & Steinmueller, W. E. (2021). Research frontiers for multi-system dynamics and deep transitions. *Environmental Innovation and Societal Transitions, 41*, 52–56. https://doi.org/10.1016/j.eist.2021.10.025

Konrad, K., Truffer, B., & Voss, J. P. (2008). Multi-regime dynamics in the analysis of sectoral transformation potentials: Evidence from German utility sectors. *Journal of Cleaner Production, 16*(11), 1190–1202. https://doi.org/10.1016/j.jclepro.2007.08.014

Löhr, M., & Chlebna, C. (2023). Multi-system interactions in hydrogen-based sector coupling projects: System entanglers as key actors. *Energy Research & Social Science, 105*, 103282. https://doi.org/10.1016/j.erss.2023.103282

Markard, J., Geels, F. W., & Raven, R. (2020). Challenges in the acceleration of sustainability transitions. *Environmental Research Letters, 15*(8), 081001. https://doi.org/10.1088/1748-9326/ab9468

McMeekin, A., Geels, F. W., & Hodson, M. (2019). Mapping the winds of whole system reconfiguration: Analysing low-carbon transformations across production, distribution and consumption in the UK electricity system (1990–2016). *Research Policy, 48*(5), 1216–1231. https://doi.org/10.1016/j.respol.2018.12.007

Meynard, J. M., Jeuffroy, M. H., Le Bail, M., Lefèvre, A., Magrini, M. B., & Michon, C. (2017). Designing coupled innovations for the sustainability transition of agrifood systems. *Agricultural Systems, 157*, 330–339. https://doi.org/10.1016/j.agsy.2016.08.002

Mignon, I., & Bergek, A. (2016). System- and actor-level challenges for the diffusion of renewable electricity technologies: An international comparison. *Journal of Cleaner Production, 128*, 105–115. https://doi.org/10.1016/j.jclepro.2015.09.048

Mignon, I., Lindahl, J., & Melander, L. (2023). *The impact of value logics on business model design—The case of solar parks in Sweden 2023 EURAM conference, June 2023*. Dublin.

Nykamp, H., Andersen, A. D., & Geels, F. W. (2023). Low-carbon electrification as a multi-system transition: A socio-technical analysis of Norwegian maritime transport, construction, and chemical sectors. *Environmental Research Letters, 18*(9), 094059. https://doi.org/10.1088/1748-9326/acf67a

Ohlendorf, N., Löhr, M., & Markard, J. (2023). Actors in multi-sector transitions - discourse analysis on hydrogen in Germany. *Environmental Innovation and Societal Transitions, 47*, 100692. https://doi.org/10.1016/j.eist.2023.100692

Raven, R. (2007). Co-evolution of waste and electricity regimes: Multi-regime dynamics in The Netherlands (1969–2003). *Energy Policy, 35*(4), 2197–2208. https://doi.org/10.1016/j.enpol.2006.07.005

Raven, R. P., & Verbong, G. P. (2009). Boundary crossing innovations: Case studies from the energy domain. *Technology in Society, 31*(1), 85–93. https://doi.org/10.1016/j.techsoc.2008.10.006

Rohracher, H., & Späth, P. (2017). Cities as arenas of low-carbon transitions: Friction zones in the negotiation of low-carbon futures. In *Urban sustainability transitions* (pp. 287–299). Routledge.

Rosenbloom, D. (2019). A clash of socio-technical systems: Exploring actor interactions around electrification and electricity trade in unfolding low-carbon pathways for Ontario. *Energy Research & Social Science, 49*, 219–232. https://doi.org/10.1016/j.erss.2018.10.015

Rosenbloom, D. (2020). Engaging with multi-system interactions in sustainability transitions: A comment on the transitions research agenda. *Environmental Innovation and Societal Transitions, 34*, 336–340. https://doi.org/10.1016/j.eist.2019.10.003

Sharp, D., Raven, R., & Farrelly, M. (2024). Pluralising place frames in urban transition management: Net-zero transitions at precinct scale. *Environmental*

Innovation and Societal Transitions, 50, 100803. https://doi.org/10.1016/j.eist.2023.100803

Sutherland, L.-A., Peter, S., & Zagata, L. (2015). Conceptualising multi-regime interactions: The role of the agriculture sector in renewable energy transitions. *Research Policy, 44*(8), 1543–1554. https://doi.org/10.1016/j.respol.2015.05.013

Thomson, L. (2022). Leveraging the value from digitalization: A business model exploration of new technology-based firms in vertical farming. *Journal of Manufacturing Technology Management, 33*(9), 88–107. https://doi.org/10.1108/Jmtm-10-2021-0422

Werner, V., & Onufrey, K. (2022). If electric trucks are the solution, what are the problems? A study of agenda-setting in demonstration projects. *Energy Research & Social Science, 91*, 102722. https://doi.org/10.1016/j.erss.2022.102722

Werner, V., Onufrey, K., & Magnusson, T. (2021). From protection to selective exposure: Commercial demonstrations as steppingstones for upscaled technology diffusion. *International Journal of Automotive Technology and Management, 21*(3), 250–272. https://doi.org/10.1504/IJATM.2021.116604