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Building Resilience for Electrified Public Bus Transport: A Conceptual Framework for Mapping Disruptions

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Executive Summary

This paper presents a framework for conceptualizing resilience in the context of electrifying public bus transport systems in Sweden, developed by incorporating stakeholder insights. The framework was operationalized by identifying 43 potential disruptions to bus services in their transition to large-scale electrification, categorizing them by thematic origin and type of challenge, and mapping them along a generalized bus service value chain, which constitutes our conceptual framework unit of analysis. Disruptions were identified through a review of academic and grey literature, as well as Swedish news. Mapping the identified and categorized disruptions in the framework, allowed formations of visual clusters that can inform recommendations to strengthen resilience in electrified bus services. We found coordination between PTAs, PTOs, and energy actors to be key, requiring planning, monitoring, and technological advancements. This approach for framing and operationalizing resilience provides insights for researchers and decision-makers, helping formulate targeted strategies to enhance system resilience.

Keywords: Electric Vehicles; Heavy Duty electric Vehicles & Buses; Trends & Forecasting of e-mobility; Supply and value chain; Sustainable Energy

1 Introduction

The transport sector must undergo major operational, infrastructural, and technological changes to assist climate change mitigation. Shifting to public transport (PT) reduces greenhouse gas emissions as it is more energy efficient than passenger cars [1,2]. When electrified with low-carbon electricity, PT systems hold an even greater potential to accelerate transport sector decarbonization [2].

In Europe, the PT sector is challenged by a slow recovery after the Covid-19 pandemic. In a comprehensive survey on personal mobility choices in Europe, around 46% of respondents answered that they had reduced their PT usage in 2021 compared to pre-pandemic levels [3]. Similarly, in Swedish public bus transport (PBT), our case study country in this paper, the Covid-19 pandemic also led to reduced travel demand and, in turn, decreased ticket revenues and a widened gap between costs and revenues [4]. Recent reports from Swedish trade organizations show that these funding gap challenges linger and that pressures on the sector are compounded by current and projected bus driver shortages [5] along with a recent trend of declining customer satisfaction levels [6]. New technologies, such as battery electric vehicles (BEVs), may affect public bus fleet compositions and introduce cost pressures, while also adding strain on the sector through new infrastructure dependencies for charging [7]. These pressures could exacerbate vulnerabilities of PT and negatively influence the sector's resilience, something which would in turn affect equitable access to transport, particularly for low-income groups navigating the low-carbon transition [8]. Despite all these, existing literature has paid limited attention to strengthening PT resilience amidst electrification.

Prior studies devoted to battery electric bus (BEB) resiliency have provided insights on strategies for robustness against specific types of disruptions, such as charging station failures or natural disasters [9,10], but often fall short in capturing a more comprehensive and systemic understanding of PBT resiliency. While a few studies attempt to classify a broader range of PBT-related disruptions [11,12], they rarely centre the implications of new technologies resulting from electrification. In parallel, the sustainable transitions literature identifies a wide range of challenges related to the adoption and scaling of BEBs, typically framed as technological, economic or institutional barriers [7,13]. However, this body of work tends to place emphasis on obstacles to BEB market expansion and their implications for overall service provision, often omitting questions of resilience within the already electrified share of the bus fleet.

Our paper focuses on this gap and we aim to develop a framework that incorporates stakeholder insights on how to define resilience for Swedish PBT when it is electrified and to develop a better understanding for how to map disruptions stemming from electrification in order to recommend measures for strengthening PT resilience in light of electrification. We thus aim to answer the following research questions: *(i) How can resilience be conceptualized in the context of the transition to electrified public bus transport? (ii) How can we map disruptions related to electrified bus systems and services in order to help operationalize resilience-enhancing strategies?*

We focus on the Swedish context, specifically the current status of its PBT system in its transition toward large-scale electrification, defined here as the point at which the share of the BEB fleet is so substantial that it could no longer be realistically replaced solely by existing replacement traffic options in the event of a major disruption, thereby requiring additional resilience-enhancing measures. Research and policy development are essential to ensure the scalability and resilience of electrified PBT systems in both urban and regional contexts. This research, focusing on Sweden as a frontrunner in bus electrification, aims to provide insights for building PBT resilience in other countries advancing bus electrification.

2 Background

2.1 Resilience in the transport sector

The concept of resilience is elusive and the way it is defined influences its assessment and the decision making around it [14,15]. A common approach to resilience is distinguishing it into three broad concepts: engineering resilience, ecological resilience and socio-ecological resilience [16,17]. Engineering resilience is premised on equilibrium thinking, focusing on the resistance to disturbance and speed of returning to equilibrium after a disturbance [18], whereas ecological resilience acknowledges that the system can shift to new stable states when pushed far away from the equilibrium [19]. Socio-ecological resilience considers both social and ecological systems and assumes that these are interlinked through adaptive cycles of growth and embed multiple equilibria and that disturbances are regenerative and necessary for building system robustness [20,21].

Engineering resilience is more common for assessing transport systems [20]. For example, in the context of transport systems, [22, p. 3] posits the definition *"Resilience is the ability of a transport system to prepare for and to withstand, absorb and adapt to shocks, and to recover from the consequences in a timely and efficient manner."*, reflecting the elements of engineering resilience. Following this construal, transport systems are considered to be in a default steady-state characterized by predictability and stability [17,20]. Disruptions are thus regarded as negative events disturbing the steady-state and threatening system functioning [17,20].

2.2 Case study: Sweden's transition to low-carbon public bus transport

Sweden's PT operates within a decentralized governance framework. The responsibility for planning, procuring and financing lies primarily with regional Public Transport Authorities (PTAs) in line with EU Regulation (EC) 1370/2007, and supplemented with Swedish law through the Public Transport Act (Lag 2010:1065 om kollektivtrafik) from 2012 [23]. The PTAs coordinate PT services within their respective regions but typically outsource operations to private service providers through public procurement and a process of competitive tendering. There are some exceptions, however, in two out of 21 regions, municipal companies are responsible for all services [24]. The Swedish government, however, remains important for providing strategic direction and co-financing mechanisms [24].

Swedish PT is leading the transport sector's sustainability transition, accounting only for 1.5% of national transport greenhouse gas emissions [25]. Over 95% of Sweden's procured bus traffic already runs on renewable fuels, mainly biodiesel and biogas, and its PBT fleets are now shifting towards electrification, driven by expected climate and economy benefits [26]. This shift also frees up biofuels for sectors where electrification is less feasible, such aviation, benefiting the transport sector as a whole.

By 2024, 1,453 BEBs were operating in Sweden, corresponding to about 10% of the total bus fleet of 14,176 buses. As shown in Figure 1, the region of Västra Götaland had most BEBs in 2024 (584), corresponding to 16.7% of its bus fleet, followed by Skåne (277 BEBs, 22.6%), while Stockholm, the most populous region, had 162 BEBs (6.1% of its fleet). Several regions, including Gotland, Kronoberg, Jönköping, Örebro, and Blekinge had no BEBs, but operate some hybrids buses. The electrification of buses has accelerated since 2020; seven regions had surpassed a 10% BEB share, compared to just one region prior to that. Given Swedish PBT's strong reliance on procurement, close PTA-operator collaboration, and its rapid pace of electrification, it provides an important case for studying resilience.

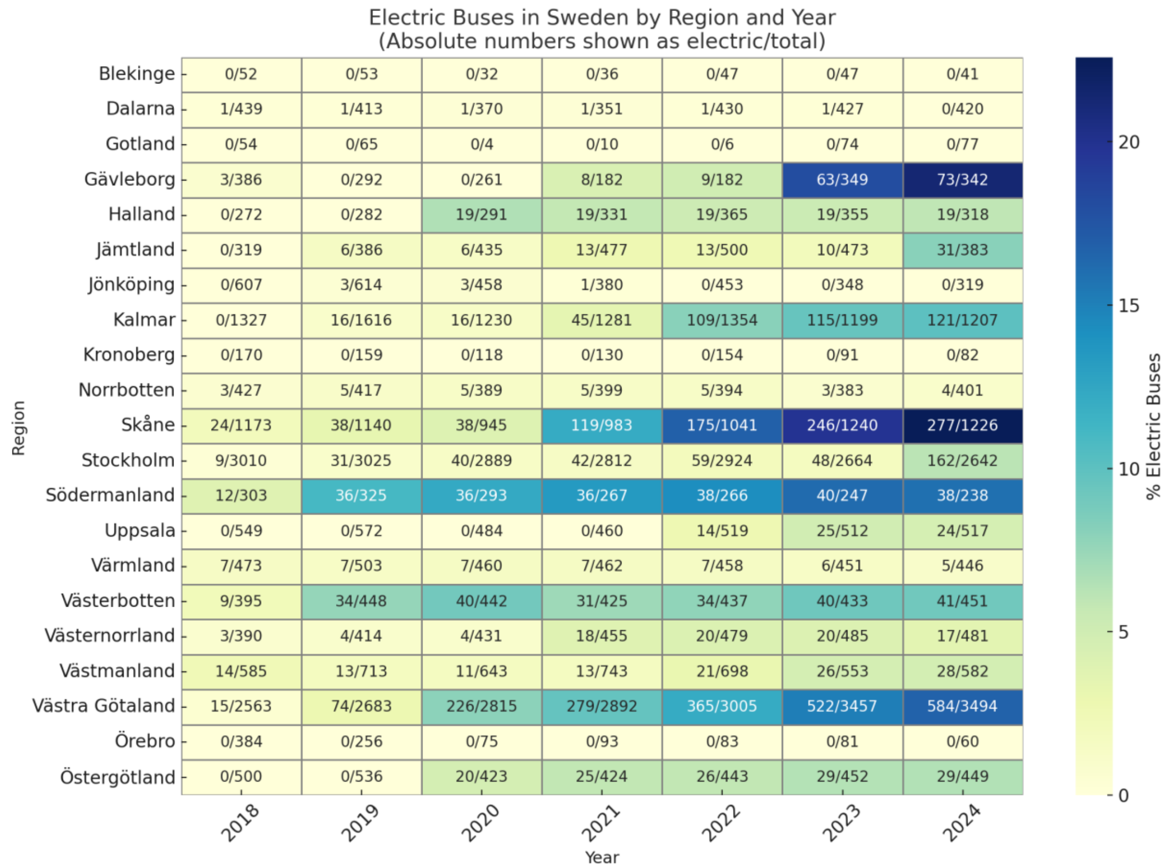

Figure 1: Share and number of BEBs in Sweden by region and year (2018–2024). The heatmap shows the percentage of BEBs in each region, with absolute numbers annotated as electric/total, adapted from [27].

3 Methods

A first step in developing strategies for improved resilience of PBT in light of electrification was to define what resilience means in the context of our work, and then to document and classify disruptions resulting from this PBT transition. To do so, we developed a conceptual framework (CF) for mapping disruptions by addressing the following questions posed by [14,21]: resilience “of what” (system boundaries and features), “for what purpose” (purpose of the system) and “to what” (characteristics of disruptions).

Recognizing the plurality of resilience interpretations, we involved stakeholders relevant to PBT in setting the research priority to ground our conceptual framework in their understandings of resilience. First, stakeholders were engaged in a two-hour long workshop in September 2024 to discuss resilience and disruptions in the context of PT. Workshop participants consisted of four PTA representatives, one representative from the Swedish Defence Research Agency (FOI), and one representative from an expert and network organization for a fossil-free transport sector and sustainable regional development. To complement the workshop insights, we also conducted a total of six semi-structured interviews, between September 2024 and March 2025, with representatives of public transport operators (PTOs) (3), of a PTA (1) and of trade organisations for PTOs (1) and PTAs (1). Each interview lasted between 30-60 minutes and all but two were conducted by at least two of the authors. A set of open-ended guiding questions were designed to understand the interviewees’ i) priorities when it comes to the resilience of PBT electrification, ii) their approach to assessing related disruptions, and iii) how electrification influences their need for stakeholder dialogue on resilience. Detailed notes were taken during both semi-structured interviews and the workshop. These were analysed using the guiding questions for framing resilience presented above and thus used to develop a stakeholder-informed CF.

The final step in the data collection aimed at gathering a comprehensive set of disruptions linked to the electrification of PBT in Sweden. Here, we undertook a literature search to locate a broad range of potential disruptions, encompassing both scientific and grey literature, including earlier inventories of specific disruptions identified in analysis of electric buses in Stockholm. In addition, we also searched for news through Google Search using search Swedish words such as: “problem” (problem/problems), “inställda” (cancelled), “åtgärdas” (being fixed), “kaos” (chaos) in combination with the word “elbuss” (electric bus). For each identified disruption, we also took into consideration the reason behind and consequences of them, together with any links to a specific charging technology.

4 Conceptual framework development: Defining resilience through stakeholder insights

4.1 Resilience of what: system boundaries and features

Within the context of PBT electrification and resilience, the stakeholders highlighted the need for setting system boundaries and clarifying roles and responsibilities, particularly distinguishing between providing a service and contributing to broader societal resilience. PT fills an important societal function, contributing to Swedish national climate targets [28] and transport policy goals pertaining to basic access to transport, and to considerations of public health [29]. As the PBT system electrifies, it becomes more integrated with the energy system. This reshapes PBTs societal role and altering its risk landscape, both in everyday life and in times of crisis. The stakeholders noted that this system integration increases vulnerability by heightening dependence on electricity and its infrastructure, exposing PT systems to broader energy security risks [30]. However, the integration could also support energy system redundancy, e.g. through BEBs serving critical loads via bi-directional charging, potentially enhancing collective resilience across both systems [31].

Transitioning to BEBs could also be considered a disruption to existing PBT service operations, as BEB fleets imply flexibility limitations and challenges to traditional scheduling and operational practices [32]. Interviewees noted that these flexibility limitations, along with long recovery times, set higher demands on monitoring and planning, such as using digital tools to track battery status, temperature, range and charging speed. This digitalization brings new cybersecurity and information and communication technology risks which can escalate into broader societal vulnerabilities. While electrification is not the primary cause, its interplay with digitalization creates risk dynamics not seen in traditional diesel-based systems.

Moreover, we found that the transition to BEBs is also reshaping PBT service value chains. Stakeholders pointed to increased risks linked to globalized vehicle supply chains, especially in a more geopolitically unstable world. They raised concerns about supply chain risks in the transition, as the production of BEBs are currently concentrated to a few East Asian suppliers, and as PTAs' attention to socially sustainable sourcing is increasing [33].

We defined the system boundaries of our CF to capture these potential changes in PBT's societal role and changes to value chains with electrification. Our CF focuses on the provision of PBT services in context of electrification, leaving broader societal impacts and cross-sectoral resilience contributions outside of the scope. Inspired by approaches found in agricultural systems research [34,35], we adopted the PBT service value chain as our unit of analysis. The CF was built around a generalized value chain for PBT, adapted from [36] and refined with stakeholder insights. It consists of the following seven value chain activities: "System design and planning", "Transport service procurement", "Energy supply and infrastructure", "BEV production, supply and maintenance", "Routing and scheduling", "Transport operations", and "Societal effects". Value chains offer a structured way to map disruptions and identify resilience-enhancing strategies [35].

4.2 Resilience for what purpose: purpose of the system

As outlined in section 4.1, our CF focuses on the provision of PBT services that may be disrupted by both the transition to electrified transport itself, and by the new vulnerabilities that electrification introduces. Thus, we adopted an engineering resilience approach, viewing the level of service that PBT provides as a steady state of system functioning. At the same time, the stakeholders reminded us that PBT is a provider of an essential societal service that must maintain a baseline level of service even during crises. Stakeholders questioned whether an electrified system, relying on new types of critical infrastructures, could uphold this obligation under severe conditions. At a deeper level, this challenge was linked to the lack of a definition of a minimum service that is expected from PBT in times of crisis, which in turn affects resource allocation priorities. It is possible that the acceleration of systemic changes due to electrification has surfaced such operational challenges for PBT actors, and again, while electrification is not the main culprit behind the issue (in this case its rather a lack of harmonized definitions of service levels in crisis) it exacerbates the need to find solutions that work more robustly and systematically compared to previous ad-hoc solutions. Considering this, we defined the system's steady state as the level of PBT services currently provided under normal conditions.

4.3 Resilience to what: characteristics of disruptions

To characterize disruptions to be mapped, we considered organizational, relational, regulatory, technical, operational and financial challenges, spanning from everyday disturbances to more severe or antagonistic threats that may hinder the provision of PBT services in the Swedish context. We distinguished between shocks and stressors as they require different organizational responses: shocks disrupt services suddenly, highlighting the need for redundance and contingency planning, while stressors build gradually and as the BEB fleet expands, challenging system capacity and calling for adaptive strategies. Thereby, each disruption was assigned a context of disruption type. While electrification itself could be viewed as a disruption, as discussed in section 4.1, our focus was not on disruptions associated with initial BEB adoption. Nor did we attempt to map disruptions in a system that has reached its BEB targets, as such analysis would be highly speculative. Instead, we examined disruptions that may emerge during the transitional phase, as the share of BEBs in the bus fleets scale up towards large-scale electrification.

4.4 Operationalizing the framework: Disruption mapping for resilience strategies

Operationalizing our CF involved mapping a detailed set of disruptions, categorized by theme and disruption type, along the PBT value chain. We initially identified 104 BEB-related disruptions, primarily through a stakeholder-informed disruption inventory for electric buses in Stockholm, compiled by the Region Stockholm PTA [37], supplemented by 12 news events and one academic article [32]. This list was refined into 43 disruptions by excluding those outside of our CF system boundaries and by consolidating those similar in cause and consequence. The final set of disruptions were organized into five thematic categories: "Coordination and dependency", which concern failure in actor coordination, such as negotiation and agreement, as well as challenges reliance on supply chains or third parties; "Regulatory constraints", which pertains to regulations and standards; "Technological shift", which encompasses both hardware and software breakdowns, as well as the abilities of systems, "Operational transformation", which addresses the new work practices and service performance that the new technologies entail; and "Financial viability", costs. Our CF, including the categorized and mapped disruptions is presented in Figure 2. A list of the comprehensive set of disruptions, including short descriptions of each, is detailed in Appendix A. The disruption mapping helped us identify recurring patterns across the PBT system under electrification, offering insights into where vulnerabilities arise and how resilience-enhancing strategies can be operationalized.

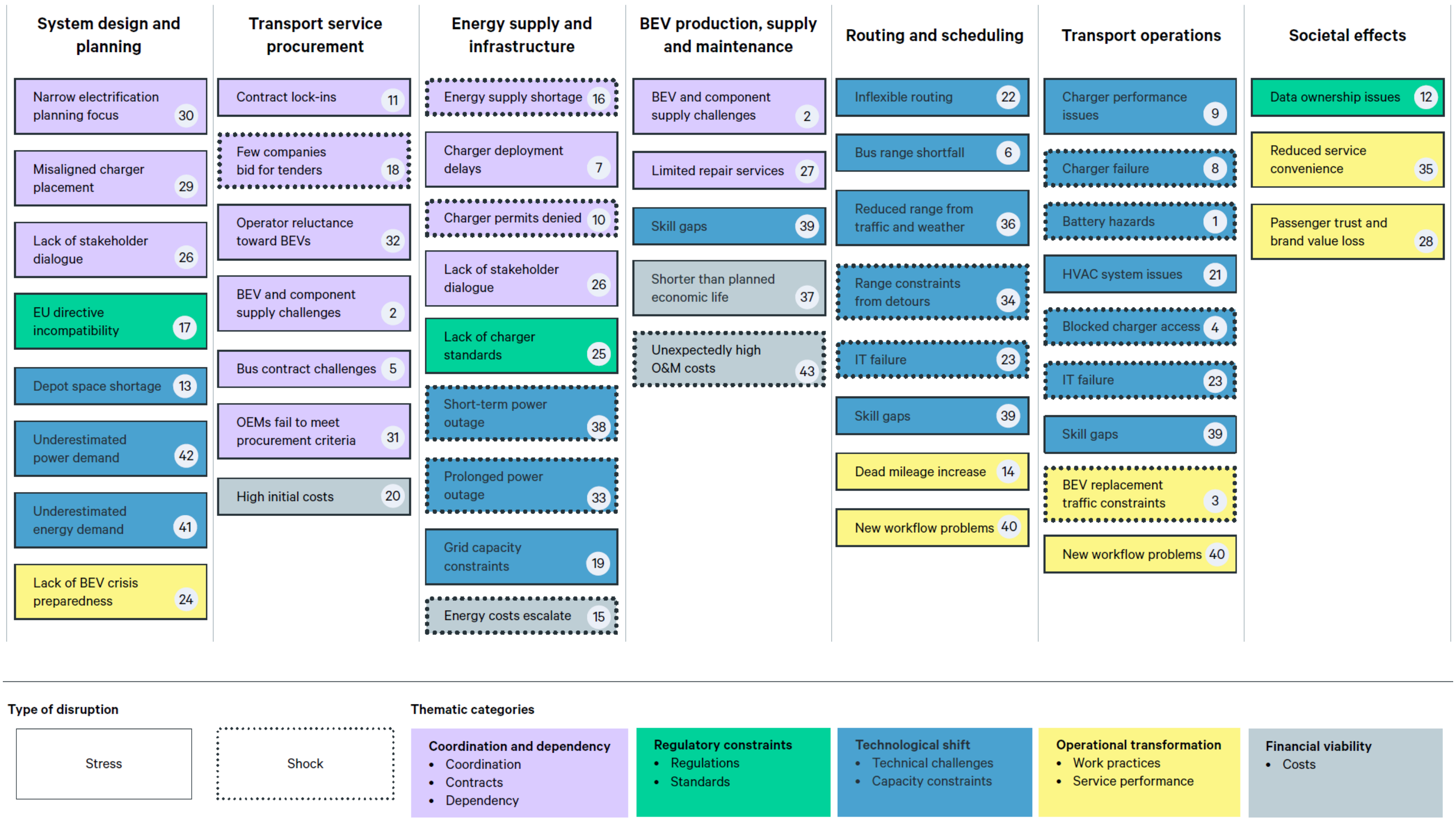

Figure 2: Conceptual framework for the resilience of public bus electrification. The framework has been operationalized by mapping identified and categorized disruptions. Each disruption is assigned a unique ID number and further described in Appendix A.

Stress-type disruptions are primarily concentrated in "System design and planning", "Routing and scheduling" and "Transport service procurement". These disruptions are mostly associated with limited foresight into how electrified PBT systems might develop, and with inaccurate estimations of what is required of technology and infrastructure, as well as with lengthy coordination between stakeholders and with formation of new supply chains. In contrary, shock-type disruptions are more common under "Energy supply and infrastructure" and "Transport operations". These are often tied to the function of technological systems and the charging of BEBs, as well as broader challenges at the integration of the energy and transport sector.

Several disruptions are institutional in nature, falling under the categories of "Coordination and dependency" and "Regulatory constraints". Most belong to the former category and are concentrated in the three leftmost value chain activities, especially in "Transport service procurement". This suggests that many potential vulnerabilities arise from structural dependencies, such as limited supplier diversity, rigid contracts, and low repair capacity, all of which reduce PBT system adaptability and indicate a need to revise frameworks for managing supplier and contractual constraints. Regulatory misalignments, such as conflicts with EU directives, missing standards for charging infrastructure, and unclear data regulations can further contribute to delays, higher costs, and institutional uncertainties.

Most functional-oriented disruptions categorized as "Technological shift" and "Operational transformation" are concentrated under “Transport operations” and “Routing and scheduling”. This aligns with where electrification most directly impacts day-to-day functions. In the former thematic category, our identified disruptions reveal limitations in planning models’ ability to account for the operational constraints BEBs. Disruptions under “Transport operations” further expose integration issues between vehicles, charging systems and digital platforms. Additionally, disruptions belonging to “Operational transformation” spans into “Societal effects” as challenges stemming from unfamiliar work practices and service performance issues linked to electrification can affect passengers and diminish the appeal of PBT services.

Lastly, clusters of financial disruptions are less discernible but relevant in planning and infrastructure contexts. The thematic clustering suggests that while some disruption types are system-wide, others concentrate in specific governance areas. This highlights the crucial role of PTAs, PTOs and energy actors, particularly their coordination and collaboration, in strengthening PBT system resilience when it electrifies. Addressing these vulnerabilities also requires robust planning models to balance operational performance with system constraints of BEB fleets, continuous system monitoring along with advancements in battery and charging technologies. Moreover, the most frequent intersections between mapped disruption thematic categories and value chain location are: “Technological shift” in “Transport operations” (7 disruptions), “Coordination and dependency” in “Transport service procurement” (6), and “Technological shift” in “Routing and scheduling” (6). These intersections suggest specific areas where governance and planning practices could be adjusted to support more robust and adaptive electrified PBT systems.

While we identified and mapped a broad range of disruptions to PBT electrification, our CF inevitably misses certain aspects. Most of the captured disruptions are mundane events rather than deliberate attacks. Some disruptions, such as energy supply shortage, could arise from both intentional and natural causes, as the disruption does not specify origin. Additionally, most identified disruptions were drawn from a 2018 disruption inventory based on stakeholder input. Since bus electrification took off after 2020 for most regions, except for the largest ones, this inventory reflects a degree of speculation, and some risks may have since been mitigated by technological advances or experience from expanded deployment. Strategies for building more resilience should also consider prioritization, for example through risk assessments that consider probabilities, vulnerabilities and consequences, or other methods to determine resilience measures to prioritize, based on factors such as PBT system size or the stage of electrification.

5 Conclusions and policy implications

This paper has conceptualized resilience in the context of PBT electrification by developing a dedicated CF and operationalized it to provide insights into strategies for strengthening system resilience. The CF is built around a generalized public bus transport value chain with the purpose of providing today’s level of services and is intended to be used to map disruptions that may emerge as the PBT system transitions into large-scale electrification. The paper has further applied a structured mapping of 43 disruptions linked to the electrification of PBT Disruptions were categorized by thematic origin, for example technical, regulatory, financial, coordination-related; by value chain activity, spanning planning, and procurement to operations and societal effects; and by disruption type, distinguishing between acute shocks and longer-term stressors. The results illustrate how disruptions arise not only from the introduction of new technologies but from their interaction with existing institutional frameworks, infrastructure capacities, and organizational processes.

Several patterns can be identified. Many stress-type disruptions emerge in the upstream planning, procurement and infrastructure development processes, including underestimated energy and power demand, depot space constraints, and misalignment of charger locations. These reflect a limited integration between energy and transport planning and a lack of anticipatory capacity in system design processes. Disruptions further downstream, linked to operational processes, tend to be more sudden, involving charger failures, IT breakdowns, or heating and ventilation problems.

A range of institutional, organizational and societal factors also contribute to system vulnerability. Disruptions such as contract lock-ins, limited competitive tendering and unmet procurement criteria point to a need for revising procurement practices to better accommodate new technologies and supply chain conditions. Internal organizational capacity is also a critical factor, with challenges including workforce skill gaps, limited BEV crisis preparedness and replacement capacity, and the need for workflow adjustments. While fewer in number, disruptions tied to broader societal concerns, such as user trust and data governance, may carry significant long-term implications for the legitimacy and public acceptance of electrified PBT.

With many disruptions originating upstream in the value chain, procurement plays a central role in building more resilient PBT systems. Procurement practices, however, are complex and slow to adapt to new demands introduced by electric buses. Resilience has also not been systematically integrated in procurement, despite the significant impact of disruptions on both costs and public perception of PBT.

Our mapping highlights the need for more integrated and strategic governance to enhance the resilience of electrified PBT systems. Strengthening coordination between PT and energy system actors is essential, particularly to support joint scenario development and energy-informed planning. Procurement frameworks should support more flexibility and responsiveness, incorporating adaptive contracts to accommodate technological shifts and evolving supply chains. Operational resilience could be strengthened through institutional capacity building, such as the development of robust planning models, real-time system monitoring and adaptive response strategies. While some disruptions can be addressed at the local or operator level, others, such as standardization and supply chain vulnerabilities, necessitate coordinated action at regional and EU levels.

The framework also lays the groundwork for future development. It could be extended to include temporal phases; indicators for frequency, severity and criticality; and clearer mapping of interdependencies between disruptions. These additions would enhance its use in scenario planning and stress-testing of electrified PBT systems. In this context, disruptions are not anomalies but reflections of system interactions during transition. Making them visible enables more informed and robust planning, which remains a key component of PTA planning through risk assessments.

Finally, the framework could usefully be applied to other settings, with varying degrees of electrification and differing institutional, spatial, and demographic characteristics. Analysing several contexts would enable comparative analysis would help further identify strategies for enhancing the resilience of electric PBT systems and supporting long-term system performance.

Acknowledgments

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Appendix A.

A list of the mapped disruptions is shown in Table A.1, including a short description of each disruption. Each ID corresponds to the mapping in Figure 2. References marked with "*" indicates that the disruption was mentioned in the stakeholder workshop or interviews.

Table A.1: Descriptions of all mapped disruptions to electrified public bus transport.

ID	Mapped disruption	Description	Reference
1	Battery hazards	Fires or explosions involving batteries	[37,38]
2	BEV and component supply challenges	Inabilities to deliver due to rapid market growth	[37,39]
3	BEV replacement traffic constraints	Charging time delays response to unplanned service needs	[37]
4	Blocked charger access	Access limited by queues and obstructing vehicles	[37]
5	Bus contract challenges	Lengthy procurement processes and insufficient lead-times	[37]
6	Bus range shortfall	Battery capacity shortcomings and/or under dimensioned charging infrastructure	[37]
7	Charger deployment delays	Prolonged construction times and stakeholder disagreements on land-use	[37]

8	Charger failure	Hardware and software issues	[37,40,41]
9	Charger performance issues	Insufficient charging at low temperatures	[37,42]
10	Charger permits denied	Stakeholder disagreements	[37]
11	Contract lock-ins	Inflexibility from too high or detailed requirements	[32,37]
12	Data ownership issues	Connected vehicles sending data to the manufacturer	[43]
13	Depot space shortage	BEB services require more buses	[37]
14	Dead mileage increase	Depots not optimally placed	[37]
15	Energy costs escalate	Electricity rates skyrocket	[37]
16	Energy supply shortage	Local shortage during peak demand hours, national shortage	[37]*
17	EU directive incompatibility	New directives with different requirements	[37]
18	Few companies bid for tenders	Lack of role clarity in operations and ownership, high risks for operators	[32,37]
19	Grid capacity constraints	Grid capacity not dimensioned for future developments	[37,44]
20	High initial costs	Transition requires new technologies, supplier take high costs initially	[32,37]
21	HVAC system issues	Auxiliary heaters give up when it's too cold	[37,45]
22	Inflexible routing	Batteries make buses too heavy to use certain streets	[37,46]
23	IT failure	BEB operation is highly dependent on IT systems	*
24	Lack of BEV crisis preparedness	Range limitations and unclear collaborations forms	[37]
25	Lack of charger standards	Various suppliers but no standards for charging infrastructure	[32,37]
26	Lack of stakeholder dialogue	Lack of a common goal and knowledge of consequences	[32,37]
27	Limited repair services	Workshops do not offer BEB repair, vehicles left stranded	[37]
28	Passenger trust and brand value loss	Delays and cancelled BEB departures inconvenience customers	[47]
29	Misaligned charger placement	Flexible contracts allow bus network redesign	[37]
30	Narrow electrification planning focus	Lack of a holistic view of regional travel needs	[37]
31	OEMs fail to meet procurement criteria	Few manufacturers that meet all sustainability criteria	[48]
32	Operator reluctance towards BEVs	Few suppliers, high costs as technology is new	[32,37]
33	Prolonged power outage	Long power failure downtime (>24h)	[37]
34	Range constraints from detours	Road work etc. may require changes in routes and range	[37]
35	Reduced service convenience	Shorter range, increased bus transfers for passengers	[37,46]
36	Reduced range from traffic and weather	Traffic delays cannibalize on charging times, batteries deplete at low temperatures	[37,49]
37	Short than planned economic life	Rapid developments make technologies outdated quickly	[32,37]
38	Short-term power outage	Power outage (>1h) from external causes like storms or sabotage	[37]
39	Skill gaps	New technology requires different skills	[32,37]
40	New workflow problems	Lack of routines and unaccustomed to new practices	[37]
41	Underestimated energy demand	Higher energy demand than planned for	[37]
42	Underestimated power demand	Higher power demand than planned for	[37]
43	Unexpectedly high O&M costs	Including costs for charger operations, battery replacements, damage repair, charger relocation	[32,37]

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