future transportation

Article

A Political Economy and Multi-Stakeholder Perspective of Net-Zero Emission Urban Bus Transportation in the United Kingdom

Iraklis Argyriou

Wright Technology and Research Centre, School of Mechanical and Aerospace Engineering, Queen's University Belfast, 50 Malone Rd, Belfast BT9 5BS, UK; i.argyriou@qub.ac.uk

Abstract: The transition to net-zero emission urban bus (ZEB) systems is receiving increased attention in research and policymaking. Most studies in this area focus on techno-economic aspects and the views of a narrow group of stakeholders. This offers limited insight into the range of barriers that constrain transitions in real-world contexts. This article offers a political-economic and multi-stakeholder perspective on the technical and non-technical barriers to ZEB transitions within the UK context. It develops a theory-guided empirical case study, informed by stakeholder theory perspectives and semi-structured interviews with stakeholders in the local bus transportation system. It finds that a transition to net zero will require addressing technical, policy, market, and cooperative barriers across sectors and policy levels. On the one hand, this relates to high costs and performance uncertainties over ZEB technology and infrastructure. On the other hand, it concerns unsustainable bus networks from passenger patronage and coordination perspectives, stakeholder cooperative gaps, and high car use and dependency in urban areas. Policy portfolios and stakeholder collaborations, beyond a 'net-zero' and sectoral focus, could tackle barriers to system-level change. Further application of the theoretical framework can contribute to a broader body of knowledge about transition barriers operating in different political and economic contexts.

Keywords: net-zero emission transitions; local bus transportation; political economy; barriers; UK

check for updates

Citation: Argyriou, I. A Political Economy and Multi-Stakeholder Perspective of Net-Zero Emission Urban Bus Transportation in the United Kingdom. *Future Transp.* **2023**, *3*, 429–456. https://doi.org/10.3390/futuretransp3020026

Received: 11 December 2022
Revised: 27 February 2023
Accepted: 3 March 2023
Published: 4 April 2023

1. Introduction

ZEB systems have a key role in supporting critical socio-economic activities while contributing to addressing the climate impacts of fossil-dependent societies. They offer inclusive and affordable services that are accessible and reduce congestion, road accidents, greenhouse gas (GHG) emissions, pollutant emissions (NO_x and $PM_{2.5}/PM_{10}$), and noise [1]. They can also leverage local economic recovery and growth by connecting businesses, people, and communities to economic and social opportunities [2]. In the UK, a ZEB vehicle is defined as one that has no combustion engine on board, has no tailpipe air pollutant emissions, and saves at least 30% in GHG emissions compared to a Euro VI diesel engine of equivalent passenger capacity [3]. A single 18 m city bus consumes about 40,000 L of diesel per year. The electrification of its operation will result in reductions of over 100 tons of CO_2 equivalent. Large-scale deployment of ZEBs can also drive GHG reductions in the power sector by stimulating long-term planning and investments in grid decarbonization [4].

In this context, the transition to ZEB systems has received increased attention from policymakers and other stakeholders throughout the world [5]. At the level of the European Union, ZEB deployment is supported through revised environmental directives and initiatives such as the European Green Deal and the Sustainable and Smart Mobility Strategy. Various countries and cities internationally (UK, Norway, Sweden, Australia, China) have also adopted ZEB R&D, policy, and investment programs [1,6–9].

There is thus a growing interest in developing effective policy and technology roadmaps to support the fundamental change, or transition, of the bus transportation sector to reach net-zero emissions by mid-century [10,11]. Such roadmaps need to address the complex character of urban bus systems, which are comprised of co-evolving social and technical elements, including technologies, policies, infrastructures, markets, institutions, and behaviors [12,13]. Urban bus systems are therefore difficult, but not impossible, to transition. However, for such a system-level change to occur, there is a need to address both the technical and non-technical barriers that constrain the transition.

In addition, transport transitions are first and foremost place-based phenomena. This means that ZEB systems are embedded within particular, often highly localized political, institutional, regulatory, physical, and economic contexts [14,15]. As a result, ZEB priorities, barriers, and capacities vary according to context [16,17]. From a political-economic (and therefore systems) perspective, this context-specificity relates to the location and distribution of institutional authority, resourcing, and power between central and local levels of government. It also relates to the character and objectives of state approaches to economic policy and market regulation [15,18,19]. The systematic analysis of barriers within domestic (central and local) political-economic contexts can generate a greater understanding of the factors that actually constrain transitions in the real world. Such insight, in turn, can constructively inform policy and stakeholder responses that aim to address ZEB transition barriers and problem areas with a view to affecting system-level change.

Yet, perhaps paradoxically, there is sparse empirical research on the diverse barriers that can and do constrain ZEB transitions. Most studies to date have examined technical and economic barriers related to the performance and market uptake of ZEB vehicles and infrastructure. Such barriers include high initial investment costs and disparities in the Total Cost of Ownership (TCO) (measuring direct and indirect costs) between ZEB and diesel buses. Seasonal variations in the battery performance of battery electric vehicles (BEVs) due to changing weather conditions and a lack of infrastructure have been reported. In addition, the need for additional buses to maintain the same service level (in order to account for BEV charging downtimes) further underpins the capital financial outlays for bus operators. In addition, BEV range limitations pose operational and financial barriers to operators, although recently this has become less of a problem due to battery improvements [4,7,9,20,21]. The wider range of ZEB barriers, however, including policy, political, and cooperative ones, remains underexplored.

Previous studies of ZEB barriers have also paid less attention to the political, institutional, and market contexts within which they operate as well as to the perceptions of diverse ZEB stakeholders beyond policy and industry. For example, Xylia and Silveira [9] explored the barriers and drivers in relation to renewable energy fuels for urban bus transportation in Sweden. Their analysis, based on interviews with bus operators and public bodies, suggested three types of barriers: costs, the deployment of infrastructure (from an economic perspective), and uncertain policy conditions. Ou et al. [21] found that integrated policies are required to promote various electric bus technologies as a future public transportation option in China. Their study focused on vehicle emissions and the need for improved vehicle fuel efficiency. However, the role of stakeholders in promoting alternative fuels was not addressed. In a similar vein, Song et al. [20] addressed the strategic role of stakeholders in the development of public electric buses in China. Their study applied modeling (game theory) analysis from a largely technocratic perspective (all participants make decisions on the basis of clear costs and gains). Less attention was placed on institutional and political aspects or the views of stakeholders beyond government and industry. Guno et al. [4] in their analysis of sustainable public transport transitions in the Philippines identified technological and economic factors as the main barriers to the adoption of electric public transport. Political and legal barriers were briefly highlighted, but there was no detailed discussion of their transition implications or how barriers are shaped by domestic political and institutional arrangements.

Another study examined the dynamics of transport transitions in Great Britain through the multilevel perspective analytical heuristic [14]. Employing a whole-system reconfiguration perspective, the author examined the various landscape pressures, regime relations, and sustainability innovations that shape transition challenges and possibilities for different transport modes, including buses. This analysis extended out to 2016; however, significant ZEB agendas and policies have been adopted in the UK since then. In addition, although it addressed the role of stakeholders and institutions in transition, it paid less attention to the factors that constrain transitions.

Gaps from a political-economic and multi-stakeholder viewpoint are also identified in future-oriented analysis of urban mobility systems that delineate historical transition reviews or future pathways presuming long (usually multiple decades) timeframes. This body of work nevertheless overlooks the institutional, policy, and market contextual aspects of transitions as they unfold in real time in the real world [22]. Other forward-looking studies of transport transitions (e.g., scenario analysis and other back casting studies) have discussed the role of technology and capital finance in achieving desired sustainable transport futures. However, consistently non-technical, expert-based political and societal factors were rarely examined in these studies, leaving gaps between scenario-based research and actual policy implementation unanswered [9,23]. Finally, some more recent studies have examined transition barriers to net-zero carbon cities [24], but without a particular focus on urban bus systems.

Considering the above-identified research gaps, this article examines, from a multi-stakeholder perspective, the technical and non-technical—policy/political, market, and cooperative—barriers to ZEB transitions within a particular political-economic context, the UK. It develops a qualitative case study, informed by stakeholder interviews, to answer two questions:

- What barriers constrain the transition to ZEB systems in the UK?
- How do the UK's institutional, policy, and market contexts shape these barriers?

As of March 2021, there were 37,800 buses in Great Britain (England, Scotland, and Wales) and 1163 buses in Northern Ireland on the road, offering local bus services (In the UK, Public Service Vehicle (PSV) licensing authorities use specific terms to define local bus services. As a rule, operations will use PSVs to carry passengers who pay separate fares for particular routes or short distances. The overall route distance can be any length as long as passengers can get off within fifteen miles of boarding [25].) for a wide range of social groups and individuals [26,27]. The article's focus is on these local services, which account for the bulk of local bus transportation in UK cities and their wider territory (e.g., metropolitan areas and large urban conurbations). The case study is timely because of the ambitious ZEB plans and activities that are currently being worked out in different UK cities [1,28–30]. However, there is limited understanding of the barriers that may constrain the realization of these plans. For example, Innovate UK, non-departmental public body, published its UK Transport Vision 2050: Investing in the Future of Mobility in August 2021 [10]. This document aims to address the challenges, opportunities, and changes that the UK transport sector will likely confront over the next 30 years (including ZEB transportation) by 'bringing together UK government and industry around a single common vision for the expected future of UK transport' [10] (p. 4). The vision implies a range of fundamental changes, not solely of a technological nature but also in transport demand patterns, governmental regulations and policies, business models, user choices, behavioral changes, etc. Transitional visions can be helpful to visualize opportunities and set off change. However, the actual workings of transition processes can reveal barriers to the implementation of change [9].

This article contributes to a greater understanding of the nature of the technical and non-technical barriers that constrain the actual transition to ZEB systems. Furthermore, it examines how transition barriers are shaped by domestic, political, institutional, and market contexts [9,23,31]. From a research perspective, it develops a theory-informed empirical analysis of ZEB barriers. This is accomplished by combining stakeholder theory and environmental governance perspectives to empirically elicit stakeholder perceptions of transition barriers within domestic political economies. The application of the framework to the UK context contributes to developing a broader body of empirical contextual knowledge of transition barriers for an emerging field of inquiry—ZEB transitions. The article also develops research implications for the future study of ZEB transitions.

In addition, the analysis resonates with the work of ZEB practitioners. By offering contextual insight into transition barriers and their implications for system-level change, it can inform a well-rounded diagnosis of ZEB problem areas in the UK and comparable transition contexts. This is a core task that needs to be undertaken before defining comprehensive transition responses [32]. The findings suggest that policy and corporate transition strategies need to address a multitude of barriers beyond a 'net-zero' and bus sectoral focus if they wish to be effective and inclusive. As such, a portfolio-based approach and broader stakeholder collaborations can constitute effective means for addressing barriers across sectors and policy levels. In this regard, the article identifies two wider issues that ZEB practitioners need to explicitly address: unsustainable bus networks from a passenger patronage, financial, and coordination perspective; and patterns of high car use and car dependency in urban areas.

The article proceeds as follows: Section 2 presents the study's theoretical framework, which draws on stakeholder theory and cooperative environmental governance perspectives. Section 3 describes the research design process and its main steps for the case study analysis of ZEB barriers in the UK context. Section 4 describes the institutional, policy, and market context for ZEB transportation in the UK. This is followed by Section 5, which draws on the views of high-level UK stakeholders to outline an ideal ZEB system in the UK in 2050 and discuss the barriers—technical, market, policy/political, and collaborative—for realizing the transition to the ideal system. Section 6 discusses the broader research and policy implications of the UK transition barriers analysis. Section 7 offers the article's conclusions, limitations, and future research implications for the study of ZEB transitions.

2. Theoretical Background

In sustainability transitions, due to the complexity of decisions and the multiplicity of actors involved or affected, different stakeholders are not always in agreement with the transition paths that should be enacted. As such, the degree of influence of each one can be decisive for defining future directions. Stakeholder theory can fruitfully capture the crucial role of actor dynamics in transitions. Initially developed from a business perspective, stakeholder theory has been applied to examine environmental sustainability and transition studies [33,34]. It forms a large body of knowledge that focuses on considering the interests of various stakeholders. The theory has a core focus on the objectives that a stakeholder (defined as an individual or an organization) seeks to achieve through the management of its external (stakeholder) relations [33].

The theory suggests that for any business to be successful, it needs to create value for its various external stakeholders, be they the government, customers, suppliers, employees, the community, investors, banks, etc. In this regard, all stakeholders together are responsible for the realization of outcomes that none of them can create alone (ibid.). A core task of corporate managers, then, is to create value for their organization's stakeholders. This is carried out by aligning the interests of different stakeholders in pursuit of creating mutual interests among these stakeholders instead of primarily weighting conflicting interests [34]. All people or groups with legitimate interests that participate in an organization thus do so to obtain benefits, and no set of interests has precedence over another [33].

A stakeholder theory perspective can resonate well with cooperative environmental governance perspectives that emphasize transition analysis from various vantage points and qualities. Mainstream transition studies tend to adopt an expert, top-down, and technocratic perspective. In doing so, they overlook the crucial role of multiple actors and the different insights and ideas they can bring to identifying transition pathways [33,35]. What is more, there is a difficulty in categorizing actors that are outside the industry or government sphere, as well as a difficulty in distinguishing between individual and organizational levels in transition roles and agencies [36]. Cooperative environmental governance, instead, emphasizes management regimes as forms of 'social regulation in which groups originating in different spheres of social life and reflecting distinct perspectives and interests participate in debate and negotiation to achieve a common understanding of a scientific problem and then implement a collective plan for its resolution' [37] (p. 22).

Stakeholder theory and cooperative environmental governance perspectives align with the multi-stakeholder and cross-sectoral character of ZEB transitions. First, transportation is largely a 'derived demand'. It is generated by decisions made in other sectors/contexts, beyond the policy levers of mobility planning, largely economic and employment-related, for example, but also including leisure time decisions and activities. In other words, transportation is mostly of instrumental value and, not in itself something valued and desired by people. In order to reduce urban transport emissions, therefore, cross-sectoral coordination is required to take into account the mobility consequences of non-transport decisions made in different public and private sectors and settings [17]. One such key sector is energy. As Seto et al. [38] (p. 385) argue, 'getting to net-zero involves large-scale systemic changes across all provisioning systems that are founded on a net-zero electricity grid that is enabled by increasingly low-cost renewable electricity'. From a life-cycle perspective, if not fully decarbonized, the production of electricity and hydrogen for bus transportation will jeopardize net-zero emissions targets [11].

ZEB transitions can thus catalyze the decarbonization of the power sector and the wider surface transportation system [11,39]. Public transit fleets account for a relatively small fraction of the total vehicle and energy requirements for fueling. However, they can serve as an important lever for governments to increase public acceptance of new, net-zero technologies. They can also support the maturation of vehicle supply chains, promote the deployment of large-scale refueling infrastructures, and experiment with novel policy approaches. For instance, the predictable and long-term energy demand from ZEB fleets can facilitate long-term planning for grid restructuring and decarbonization. It can also mobilize capital for energy and transport infrastructure more generally [39].

Second, in multi-scalar and contested environmental fields characterized by uncertainty, such as transport transitions, cooperative governance approaches point towards bridging the views of the multiple stakeholders affected and intervening in transition processes [40]. The perceptions of multiple stakeholders operating within and across spatial levels become important in the development of a shared understanding of transition barriers [12]. Future-oriented analysis that incorporates the views of multiple stakeholders can help promote more detailed and coherent pathways of change [41]. At the same time, transport transitions are an uneven phenomenon, both institutionally and geographically. Therefore, their contextual analysis can generate insight into how specific political and institutional conditions influence ZEB barriers and their systemic workings [17]. Figure 1 offers a graphical representation of the theoretical framework for informing ZEB barrier analysis with a view to identifying problem areas for system-level change.

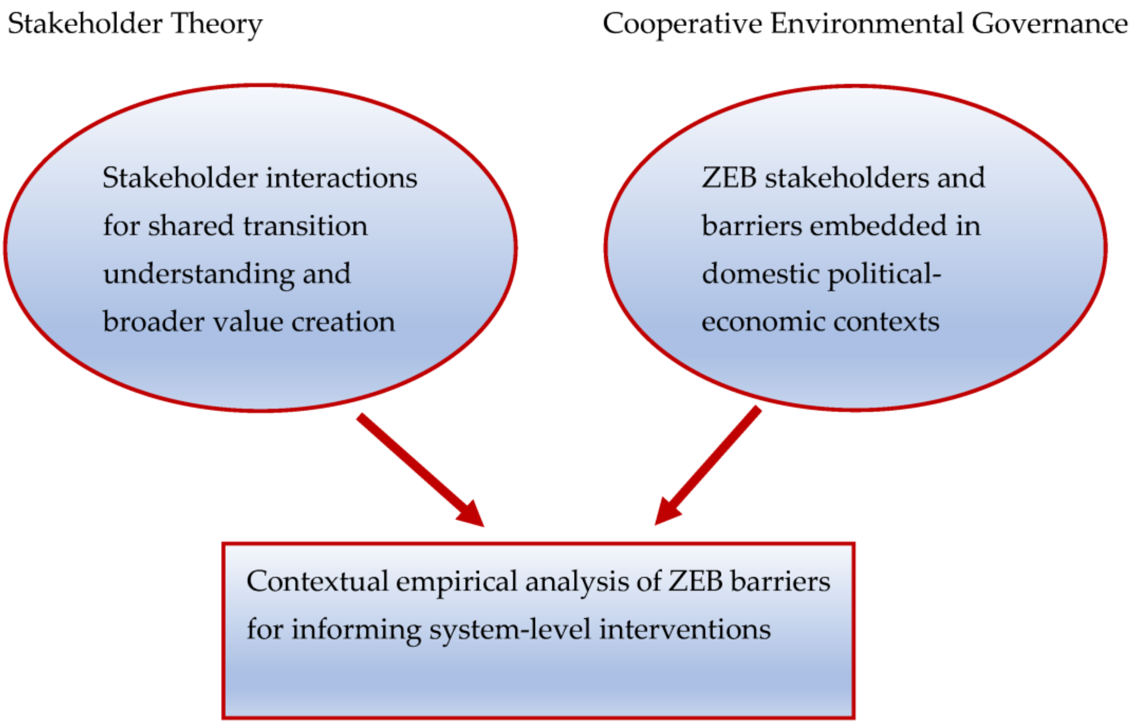

Figure 1. Theoretical framework for ZEB transition barrier analysis.

3. Materials and Methods

The article develops a theory-informed exploratory case study of ZEB barriers in the UK context. Figure 2 presents the case study research design process. This is followed by a description of its key steps and techniques (summarized in Appendix A).

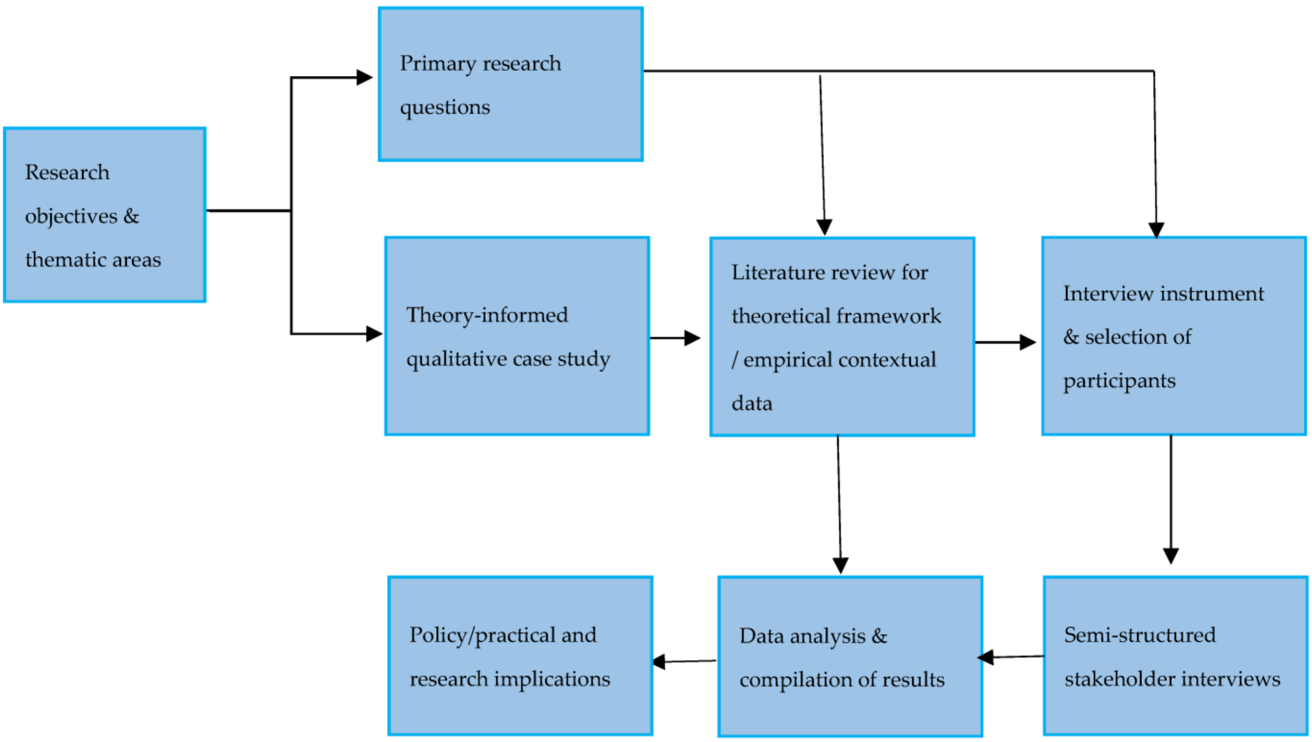

Figure 2. Overview of the research design process.

3.1. Research Thematic Areas and Questions

The identification of the research thematic areas and questions was guided by the study's research aim to develop empirical insight into ZEB barriers from a multi-stakeholder and explicitly political-economic perspective. This pointed to two thematic areas based on which primary research questions were formulated. The first was the wider range of technical and non-technical barriers to ZEB transitions. The second was the multilevel domestic political-economic contexts within which ZEB stakeholders and barriers are embedded and operate. Accordingly, two primary research questions were developed concerning the variety of transition barriers and how they are shaped by domestic institutional, policy, and market contexts.

3.2. Methodological Approach

Robson [42] suggests that complex social phenomena can be comprehensively examined through qualitative case study analysis that is based on in-depth information from a small number of individuals. To address its research questions, the article developed an exploratory empirical case study of transitional barriers. The case study was informed by stakeholder theory and cooperative environmental governance perspectives that stress the multi-stakeholder and political-economic character of ZEB transitions. In the study of complex social phenomena (such as transport transitions), semi-structured interviews enable key themes to be explored without restricting respondents to subject matter solely defined by researchers [19]. Transition researchers have sought to clarify stakeholder levels of analysis by distinguishing between the level of individual actors (e.g., entrepreneurs, consumers, policymakers) and the level of organizational actors such as organizations, social entities, groups, or networks [36]. Given the case study's focus on transition barriers and stakeholders from a system perspective, we adopted the organizational level as the unit of stakeholder analysis. Semi-structured interviews were conducted with UK ZEB stakeholders from the policy realm, market, industry, and civil society. Interview participants were invited to describe an ideal ZEB system in 2050 and discuss the types of barriers that should be tackled to realize their conceived ideal system. Rather than pre-categorizing transition barriers according to prior research (for example, Sippel and Till [43] offer a typology of climate change barriers at the local level), we took an open perspective in the discussions by prompting participants to consider the wider range of ZEB barriers, operating within and across different policy/spatial levels (e.g., national, regional, and local). This led to addressing both technical (e.g., techno-economic performance and uncertainties over net-zero technology and infrastructure) and non-technical barriers (e.g., policy priorities, regulatory approaches, collaborative relations, etc.). ZEB barriers were examined within the specificities of the UK political-economic context, which is characterized by a strong, if not dominating, political center but also by ongoing processes of institutional restructuring and decentralization [13,14,44,45]. This approach provided both a broader analytical context for ZEB transitions and enabled the elicitation of detailed insight into transition barriers as experienced by key stakeholders. The methodological approach thus involved a single case study that placed the primary unit of analysis at the urban level (the transition of the local bus system) and incorporated four embedded sub-units of analysis, namely the different types of barriers: techno-economic, market, policy/political, and cooperative [46].

3.3. Literature Review

Secondary data were drawn from two literature strands to inform the study's thematic areas, questions, theoretical framework, and empirical context. The first included academic studies and gray literature (policy reports, statistical fact sheets) from the UK and international experience on urban bus transportation/public transportation and the barriers and drivers of net-zero bus transitions. The second strand involved a broader academic and policy review of the technical and institutional aspects surrounding a low carbon/net-zero transition of cities, urban bus transportation, and the power sector (in the context of transport transitions). Taken together, the secondary material offered baseline information on the current institutional and market arrangements for UK urban bus systems, as well as their net-zero stage of development. It also offered a broader analytical scope by incorporating wider aspects of ZEB transitions. For instance, this included the linkages between public transportation transitions and sustainable energy transitions at both an upstream and downstream level. It further related to the embeddedness of cities and their bus systems in institutional and regulatory arrangements that operate within and across spatial levels.

3.4. Interview Instrument and Selection of Participants

Draft interview questions were developed under two general themes, in alignment with this study's research aim and questions. The first involved the current state of the UK bus system, an overview of the challenges it faces, and the sustainable bus agenda of the respective (interviewee) stakeholder. The second addressed the ideal net-zero bus system in the UK in 2050 and the barriers, drivers, and collaborations likely to influence a real-world transition to the ideal system. The interview instrument was refined through consultation with experts from the W-TECH Centre and the Centre for Sustainability, Equality, and Climate Action at Queen's University Belfast.

The interviews sought to elicit transition barriers from a variety of stakeholder vantage points. A heterogeneous group of stakeholders from the policy, market, industry, and third sector with known involvement in ZEB agendas in the UK was approached. They included representatives from local and regional government bodies, local and regional transport authorities, and public bus operators. It further involved private bus operators, bus manufacturers, and private companies (green energy suppliers, land use planning/energy consultants). Non-governmental campaign and lobby organizations on sustainable transport as well as intermediaries (e.g., policy/industry networks and professional associations) were also approached. To maximize insight into policymaking and project aspects, individuals with multiple years of direct activity in urban bus planning and delivery were approached [35]. Participants thus had experience in one or more sectors, including bus transportation, land use planning, and energy, in the context of sustainable and net-zero bus development. Most of them held a senior position at the director or executive level (Appendix B offers background information on participants and their organizations). Twenty-six interviews were conducted online between May 2021 and June 2022, lasting from 45 to 60 min. A snowball method of recruitment was applied, where each interviewee was invited to make referrals to their own ZEB stakeholders. Interview participants represent geographically diverse cities and regions in England and the UK's devolved administrations of Scotland, Northern Ireland, and Wales. While this is not to claim that interviews captured the full range of stakeholders, they embody the sectoral and geographical depth and breadth necessary to reflect substantive aspects of UK-wide transition discourses and agendas. Whereas further stakeholder engagement would be helpful to gain the views of important groups such as marginalized communities or national state agencies, the employed data are envisaged to reflect key ZEB transition trends and barriers in the UK context.

3.5. Data Analysis and Compilation of Results

Data analysis was based on the following approach [47], which was applied in local sustainability analysis [48]. First, the case study's primary and sub-units of analysis were established, namely the urban bus system and the four types of transitional barriers. The primary unit of analysis involved the current urban bus system and its ideal ZEB version in 2050. The sub-units of analysis involved the 'technical', 'market', 'policy', and 'cooperative' barriers that constrain the transition to the ideal system. For the primary unit, secondary data were used to map the baseline policy, operational, and (un)sustainability characteristics of the current UK urban bus system (Section 4). In addition, interview transcriptions were cross-referenced to derive the main similarities and differences across participant views on the ideal system (Section 5.1).

Likewise, content analysis of the interview transcriptions was undertaken to identify similarities and differences across participants on the barriers and controversies surrounding a transition to the ideal system. Transcriptions were reviewed intensively to identify broader text passages as well as individual points closely related to the sub-units of the analysis (the four types of barriers). To take account of the open character of semi-structured interviews, an exact and repeated reading of each transcription was performed. This prevented hastily classifying text passages to a specific type of barrier and avoided overlooking data that initially did not seem to relate to transitional barriers. Thus, attention was given not only to the questions that directly related to 'barriers', but also to whether aspects introduced in response to each question or taken up later on in the interview were associated with transitional barriers. To assist with this task, keywords that connote a 'barrier' meaning, such as 'challenges', 'constraints', 'difficulties', 'hindrances', 'limitations', 'tensions', and 'controversies', were given attention in the reading of the entire text passages.

Accordingly, interview transcriptions were individually reviewed in succession, and content was categorized under the subunits of analysis in order to systematically locate data for later use. These data were then compiled (Section 5) by following a similar process of cross-referencing participant views in order to identify the fuller range of key discrete barriers by type (e.g., technical, policy, etc.). For example, if many participants talked about the importance of high TCOs in constraining the ZEB financial ability of operators, then that was identified as a key financial barrier. To give a sense of the level of stakeholders addressing the same barrier, we used terms such as "all', 'nearly all', 'most', 'few', and one participant(s)" when reporting results. In the case that a quite small number of participants, e.g., one or two, offered a certain barrier viewpoint, the reporting of that was judged on the basis of its relevance to a system-level transition constraint. The content analysis of the primary data generated insight into the technical and non-technical transition barriers operating within the UK political-economic context. This in turn informed the development of policy/practical and research implications for ZEB transitions (Sections 6 and 7).

4. Case Study Background Context: The UK Urban Bus System

Bus use in the UK has been in long-term decline, and bus travel has become relatively expensive, with fares rising faster than the retail price index [14]. The combined effect of this steady decline and the impact of COVID-19 in Great Britain led to a 68% reduction in local passenger numbers in the financial year ending in March 2021 when compared with the same period ending in March 2020 and a decline of 86% from 1960. Bus mileage was less severely impacted (e.g., decreased by 21% in England outside London and by 2% in London), largely due to the COVID-19 support grants to operators introduced to keep services running [26]. Nevertheless, buses remain important for many people in the UK, accounting (pre-pandemic) for over 60% of all public transport trips, over-represented by the poorest in society [14].

The UK bus industry was deregulated in 1986, except in London, where Transport for London (TfL) oversees a franchised network, and in Northern Ireland, where the state-owned operator, Translink, operates most services. The industry was then privatized with the aims of stimulating competition, improving services, reducing fares, and increasing bus use (yet in Great Britain, around a dozen operators remain under local government ownership but perform as arms-length businesses without direct political control or the ability to receive general subsidies [49]). Privatization initially resulted in a range of small companies, but subsequent takeovers created an oligopoly dominated by five bus groups (FirstGroup, Go-Ahead, Stagecoach, Arriva, and National Express), which account for around 80% of the (UK-wide) market share. The bus markets are locally organized, with companies competing in deregulated networks (commercially registered services) or for specified routes (routes in franchised networks as in London or unprofitable 'socially necessary' non-commercially registered routes in both franchised and deregulated networks that are subsidized by the state). The bus industry is heavily subsidized, with 40–47% of its revenue coming from state subsidies. Bus use is most prevalent among lower-income families and among young and elderly people. Local bus use is primarily for shopping, education, leisure activities, and commuting, with most trips covering one to five miles [14].

The UK political model of devolution encourages transport policy variation across England and the devolved administrations of Scotland, Northern Ireland, and Wales. This is largely because of the separation of powers between the UK Parliament and the devolved assemblies. Devolved administrations are also free to allocate central government block grants between different policy areas [45]. Central government transport responsibilities are generally of a regulatory nature (e.g., taxation and economic regulation), whereas devolved responsibilities relate to road infrastructure, bus policy, and concessionary fares. Local governments set out local transport strategies and manage local budgets for school transport, travel concessions, and socially necessary bus services. Within deregulated networks, local authorities and operators tend to collaborate through partnership agreements. This takes various forms depending on the scope of these agreements and the level of control that local transport authorities have over key aspects of the network: Voluntary Quality Partnerships, Statutory Quality Partnerships, Advanced (statutory) Quality Partnerships (AQPs), or Enhanced Partnerships (EPs). In EPs, which are placed between AQPs and franchising, local authorities have certain powers over service frequency, bus improvement objectives, and vehicle emissions regulation [49].

Transport is the largest carbon-emitting sector of the UK economy. In 2019, domestic transport emissions accounted for 122 MtCO2e, or 27% of total greenhouse gas (GHG) emissions [50]. In the early to mid-2000s, UK policymakers saw urban bus networks as instruments for addressing local air pollution, GHG, and traffic congestion. Relevant activities over the next 10–15 years are driven by policy-industry networks comprised of the central government, devolved and local authorities (mainly in large conurbations), industry-oriented intermediaries such as Zemo Partnership, bus operators, and three domestic ZEB manufacturing firms—Wrightbus, Switch Mobility Ltd., and Alexander Dennis Limited. These initial efforts focused on clean-tech innovation through RD&D and supportive measures (grants and low-emission zones in cities and town centers) [51].

More recently, ZEB activities have intensified and been linked to ambitious policy and corporate decarbonization goals, post-COVID green recovery governmental plans (including the 'Leveling Up' agenda), and national growth rationales through industrial leadership within a post-Brexit globalized economy context. Various policy and funding programs and mechanisms, enacted at the central, devolved, and city/regional levels, aim to promote ZEBs as well as the wider viability and expansion of local bus networks (see Appendix C). Many of these policies also exemplify, at least on a rhetorical level, the need to reduce car use by promoting a modal shift to public transport and active travel [27–30,52–54].

Despite this facilitative policy context, there are several transition barriers, and the current penetration of ZEB fleets is marginal. For example, there are around 39,000 buses serving the whole UK, and the DfT reported in its annual statistics that ZEB penetration in Great Britain was at a mere 2% (wholly electric buses) as of March 2021. Some regional variation can be noted, most notably regarding TfL's network, where electric buses were at 5% [55]. No hydrogen buses were reported in the DfT 2021 statistics. However, since summer 2021, hydrogen buses have been on the road (c. 80), in pilot schemes or on book orders, for various UK areas, including Aberdeen (Scotland), London, Birmingham, the West Midlands, Cardigan (Wales), and Belfast (Northern Ireland). Section 5 outlines key features of an ideal ZEB system in 2050 before examining the multitude of barriers that need to be addressed to make progress on the transition.

5. Results

5.1. The Ideal ZEB System in 2050

Participants' responses to the ideal bus system revolved around two core dimensions. The first related to technical aspects of ZEB vehicles and fueling. The second concerned wider socio-economic aspects of sustainable future bus systems that serve societal needs at large while contributing to the achievement of net-zero carbon targets. The deployment of net-zero emission fleets was highlighted as an obvious point of reference for any future ZEB system. Beyond that, some participants placed the ideal system in the context of an energy transition from fossil fuels to renewable energy at the national level and a corresponding spatial organization of ZEB infrastructure (e.g., the location of electrified bus depots) at the local level. Nearly all participants took up a 'technology agnostic' perspective, one open to both electric and hydrogen systems, largely related to place-based urban physical characteristics and sustainable energy capabilities (e.g., along bus route/range issues or green fuel supply chains). In this context, a few participants identified local green electricity and hydrogen generation systems, as well as micro-grids, as key ZEB technological configurations. Besides technical aspects, some participants highlighted that sustainable bus networks that serve the needs of cities and their people are integral components of any ideal ZEB system:

> 'The net-zero electric buses are very visible but what we've got to focus on is that it's more than that. We got to make sure that they're sustainable. We got to get people on board the bus, they got to move quickly through traffic, they've got to go to where you want to go. This itself requires showcasing bus systems are safe and socio-environmentally important'.

The ideal bus system is then fast and efficient, enjoys free flow conditions, and uses just enough buses to enable the cost-effective operation of services that serve the mobility needs of the entire population for diverse trip purposes. ZEBs have road space priority and have become a permanent feature of the urban fabric where people use them first. The ideal system also provides people with the ability to live a full life without having to own a car. In short, ZEBs feed into a broader sustainable transport system at the urban to regional level by interacting with and complementing transport services provided to passengers and by serving a fundamental modal shift away from car transportation.

5.2. Techno-Economic Barriers

A core barrier for bus operators is the higher ZEB TCO (the sum of the purchase price of an asset plus operating costs for its lifetime) compared to diesel fleets. The TCO differences are driven by the high capital costs of electric and hydrogen vehicles that can reach 500–700,000 euros, or two to three times the cost of diesel buses of equivalent passenger capacity. Additionally, ZEB infrastructure can be costly. For instance, Translink puts this figure at around one-fifth of the upfront cost for a fleet of 100 ZEBs (80 electric/20 hydrogen) that are currently deployed by the operator. Hydrogen production is also particularly complex and costly, while the lack of local production capacity may be of particular concern to operators.

> 'We need to look at hydrogen because of the issue of mileages and ranges and so on, but the way it can be delivered is where the challenge lies. Is it green, grey or blue hydrogen, where is it sourced from, how reliable is the supply? Can we actually do something to generate it ourselves than relying on bringing supplies in?'

For electric buses, the current battery range of around 140 miles is a 'big challenge'. (Progress in battery performance and local network characteristics may ease 'range anxiety' risks. For example, trials for a 150-mile range are being conducted in the London area, while TfL suggests that over 85% of its current bus operations can be fulfilled under present battery performance). This is because range restrictions can have a major impact on operational costs by rendering vehicle and driver schedules less flexible, requiring more vehicles and drivers to operate the network for the same spatial coverage and service frequency. Operators also tend to pay commercial rates for electric charging because this is treated as a power supply that goes into a bus depot. The electrification of depots may also require major network upgrades. This raises issues around who should pay for the upgrades and whether there is rationale for the socialization of such costs, for instance by spreading them to a wider set of groups that will benefit from the intervention or to the state.

Yet, current rules of the Office of Gas and Electricity Markets (Ofgem), the energy regulator for Great Britain, do not allow for such a cost-benefit approach. If operators request a certain amount of power from the network, they need to pay to make sure the network can cope with that load (part of the central government grants address the deployment of infrastructure into depots and (to a lesser extent) the need for extra cabling). For instance, if a depot is at the end of a line, then all that cable must be upgraded or a new substation must be installed. However, in other cases, the upgrade may involve a massive substation rather than just some cabling. In fact, many depots would still need a substation because they are large, but there are smaller operators too that may have fleets of a dozen buses; these may require just a couple of chargers.

In the end, an operator may have 100 buses in one depot, and it costs them around 70,000 euros just to pay for someone to dig up the hole and put a cable in. Or it can cost 7 million euros for the same number of buses, just in a different location because a new substation is required. These cost ranges can be due to historical reasons (e.g., because of past decisions on grid expansion to support certain local businesses or housing development) and independent of bus operators, who may happen to locate their depot close to the bus network but away from grid capacity.

Operators may also find it difficult to bring electricity to the depot incrementally. For example, if they only need 5% of their fleet to be electric, the question is whether they deploy the equivalent 5% of electric charging points or whether they go for laying out charging in the whole depot before they actually need full bus electrification capacity at that scale. There are also many unknowns about ZEB vehicle costs, with the often-held view by stakeholders that 'we don't know how much it will cost' indicating vehicles will likely turn out quite expensive. Further concerns relate to uncertainties over the lifetime of ZEB vehicles. In the UK, bus vehicles are normally depreciated over a fifteen-year period, which is what a frontline operator will count as an end-of-life vehicle. Typically, vehicles will then be passed on to smaller operators. With net-zero, an operator could end up in a position where it is unknown whether these new vehicles will last for fifteen years. It is expected that they will do so, but UK bus operators faced breakdown and maintenance problems with hybrid diesel-electric buses that first entered the market in 2018. Due to a shorter-than-expected lifetime, they had to write them off sooner, which means no residual value and the inability to pass them on to smaller operators.

> 'We start to see green finance coming, but at present there is a big question around residual values, you know electric buses today how much will they be worth in seven years or ten years? What do we then do with the second-hand batteries, do we sell them on? Do they have value? No one really knows yet, so there aren't people jumping ahead'.

Furthermore, there are concerns over maintenance costs, again linked to the recent experience with the hybrid buses that were considerably heavier and technically more complicated to maintain than diesel buses. This increases their maintenance costs significantly. There are expectations nonetheless that ZEBs are going to be less complex and heavy than hybrids. These are unknowns, however, especially for hydrogen buses, as electric buses have been in real-life operation longer and more relevant information has been gathered. Lastly, increasing diesel and electricity prices driven by the recent geopolitics in the Ukrainian region have created new dynamics. Recently, one operator in Scotland converted to fifty-five electric buses, only to find out that electricity prices have tripled, making it cheaper to run the buses on diesel-generated electricity than buying from the national grid. Whereas some operators have experience in hedging diesel prices, similar negotiating experience for electricity and hydrogen is absent, and this generates uncertainty over their price volatility.

5.3. Market Barriers

The COVID-19 pandemic generated massive implications for local bus networks and markets in the UK. Besides the erosion of revenue streams for bus operators, it has made it difficult to foresee future demand, including when or whether bus use will return to pre-pandemic levels (at present, recovery is estimated at 70–80%). As such, the pandemic poses a systemic risk to operators over profit levels and their financial ability to invest in the bus system. Eroded revenue streams in turn challenge the financial ability of operators to deliver net-zero, but also their broader ability to still exist in the market.

Operators in the UK bus market also tend to accrue low profit margins. As a result, they cannot absorb the high upfront costs of ZEB vehicles, at least not soon or without being compelled and/or financially supported to do so. Therefore, there is a level of profitability before an operator can invest in ZEBs, and the figure generally held in the UK is at or above 10%. However, even most of the five big operators that dominate the market have a profit margin somewhere from 5 to 10%. The reality to date is that no ZEB service has been deployed in the UK without public funding support. The availability of public funding over the longer term, however, could have repercussions on the transition approach or pace of operators. This is because even if TCO models show that ZEBs can be more affordable than diesels over a fifteen-year timeframe, if operators expect governmental funds to be available, they may decide to postpone transition activities in light of ‘free’ future funding.

Regarding green market financing, there are currently some opportunities for bus operators. Nevertheless, there are complications linked to a company’s borrowing status. For example, most of the big-five private operators are ‘triple-B’ or ‘triple-B minus’ rated. This means that they are just investment grade and hence at tier-1 interest rates. If these operators start to take on debt for net-zero investments, this may increase their balance sheet liability, which can then lead them to a lower rating and investment grade. Balancing debt ratios with operational needs is thus a major concern for all operators. Furthermore, smaller operators, which are found throughout bus networks in the UK, tend to lack the financial and technical capacity for procuring, managing, or maintaining ZEB fuels, fleets, and infrastructure. Furthermore, some operators express fears of being ‘early adopter’ of new technologies that are not well established in the market or technologically mature. This concern is partly driven by the variety of low-carbon/zero-emission bus propulsion systems and fuels that are currently available in the UK market.

The deregulated bus markets outside London and Northern Ireland are typically ‘captured’ by commercial bus operators with no real incentive to compete and resistance to having their powers eroded. They would rather retain the status quo, which gives them the commercial freedom to make their own decisions and the potential for higher levels of financial reward. Indeed, historically and to date, operators in the UK have consistently opposed greater control and coordination of the network by the public sector. For example, this may relate to fundamental regulatory changes that could threaten the commercial interests of operators. A recent example is the bus franchise proposal that was put forward by the Greater Manchester regional government in 2020 and which was opposed by big operators in the area. Yet, bus operators are expected to be pragmatic and work with local transport authorities on whichever model of regulation is/will be in place, partly because they will have an opportunity to be commercially successful. In addition, publicly funded infrastructure within deregulated bus markets can generate ownership and management complexities:

> ‘Let’s say public funding goes to private operators to invest in electric buses and electrify their depot in X City. What happens is if that operator goes bankrupt, and the investment sits with this private company that you have no control over? That kind of relationship with operators, and how they can almost do what they want with these assets, can be tricky’.

Lastly, limitations in the upstream segment of domestic supply chains constrain manufacturing capacities for fast enough ZEB production. Further capacity issues relate to the availability of skilled workers for hydrogen vehicles. Such shortages can add uncertainty for operators, who will want to know that any technical breakdowns will be fixed promptly and without adverse effects on daily operational schedules.

5.4. Policy/Political Barriers

Central government funding for ZEBs is fragmented, competitive, short-term, resource intensive, and time-consuming (six months to a year for the bid process). It is also conditioned by certain rules (e.g., the exclusion of school or socially necessary routes):

> 'Poorly, central government likes to say this is the funding and then ask local government to bid. Whereas local government would prefer more continuity and understanding of what the funding stream will be for everybody. Local and regional government would also like more control over how this funding is spent'.

As such, ZEB funding arrangements, though helpful for bringing down TCOs, constrain local authorities and operators in planning strategically for the transition, while many authorities lack in-house capacity to bid. For example, in March 2022, over 230 million euros from the second round of the Zero Emission Buses Regional Area (ZEBRA) scheme (which aims to support 943 ZEBs in England) were allocated to twelve local transport authorities. However, six expressions of interest that proceeded to the business case submission stage were dropped. Wider barriers to local government finances, due to austerity policies introduced in response to the 2007-08 economic crisis, further constrain the ability of local authorities to develop and administer ZEB (and wider sustainable transport) plans.

Policy rhetoric and conflicting priorities around bus decarbonization and the continuation of unsustainable car travel patterns pose further barriers. As one participant argued, the UK government has 'one foot on two different icebergs at the moment': the £27 billion road building program agreed in the 2021 Spending Review will just increase car use, drive up emissions, and divert resources away from sustainable modes such as the bus or rail. In addition, the UK Transport Decarbonization Plan (TDP) and the Bus Back Better strategy (the first national bus strategy for England outside London), both introduced in 2021, have an aspirational rather than an actionable orientation. This includes broader issues such as the current price disparity between car and bus transportation. TDP also seems to rely on technology somehow riding to the rescue in the future. It is also full of contradictory statements about roads and the need to cap traffic without providing a clear pathway and implementation strategy for achieving its decarbonization targets. In this context, a few participants linked transition barriers to the political approach of the current UK Conservative government, which:

> 'supports private enterprise over efficiency, over the needs of local communities, and over the planetary longevity, as well as it is reluctant to fund the huge expansion of public transport that is required to address the climate crisis'.

In a similar vein, one participant suggested that the neoliberal character of UK government policies and decision-making cultures privileges certain actors over others. This is evident, for instance, in the greater access to ZEB government grants by the big five private bus operators. Smaller operators that generally run the dirtier bus vehicles have much lower expertise and capacity to access these funds.

Besides ZEB aspects per se, nearly all participants referred to incumbent patterns of high car use as a major barrier to a viable transition. As a result, the largest controversy over ZEB development will likely revolve around plans that aim to give priority of urban space use to buses at the expense of car-based transportation (internal combustion engines and electric vehicles alike). The restriction of car use and dependency in urban areas then becomes a core element of any viable ZEB transition. TDP and Bus Back Better identify the need to reduce car use; however, no major central government policy plans have been formulated in this direction. As one participant suggested, 'to date, UK central government has not tried to push people limit car use, what is going to be the hardest behavior change in transport use over the next 20 to 30 years'.

The car-centric policy approach of the UK government can be observed in the frozen level of fuel duties over the past twelve consecutive years. High-level governmental personnel perceive car use reduction proposals as politically unpopular. Thus, although TDP acknowledges the need to switch from cars to buses and active travel, UK transport ministers state publicly that people can carry on with their existing travel behaviors as long as there is a switch to electric cars. In fact, a national road use pricing scheme has been debated by policymakers as a way of tackling UK-wide transport emissions, congestion, and prospective losses in public revenues in light of the large penetration of EV cars (which will not bear fuel duties). However, no concrete outcomes have emerged so far:

> 'For the central government to then say this (national charging scheme) is not a good idea while they know it's the answer means it's the politics of you know trying to score an easy goal between one party and another party. It happens nationally and it happens locally'.

Pro-car political rationales play out at the local level too. City governments are increasingly aware, in particular at the officer level, that car reduction plans need to be developed and implemented. Unfortunately, such plans do not fit well with the often-populist agendas of local politicians, so signing them off is not easy. Car transportation is also regularized/normalized through narrow-scope governmental techniques that overlook wider system-level implications of transport interventions. For example, appraisal frameworks such as the Department for Transport's (DfT) Transport Appraisal Guidance Toolkit (applicable in England) prioritize car transportation by favoring business cases that overemphasize small journey time savings for a very large number of people that will save a 'few seconds here and there'. Instead, wider health, social, and environmental benefits are ignored and sidelined in the evaluation process. Yet congested, car-packed roads can have major implications for the bus transition. This is because even if the funding and expertise for ZEBs exist, but these vehicles are stuck in congestion, their financial and service attractiveness will be adversely impacted. Recently, UK devolved administrations have begun to introduce changes in their transport appraisal frameworks, albeit at a slow pace.

5.5. Cooperative Barriers

Cooperation gaps constrain prospects for wider ZEB adoption. Such gaps can be traced to the rigid stance that is adopted by some key stakeholders—within the central government, local governments, and bus operators—according to which each group positions itself as the main actors who can and should deliver the transition. Top-down divisions in political and policy responsibilities drive further tensions. While the central government clearly must determine national (net-zero) transport policy, local and regional governments have concerns that the government adopts a 'one size fits all' policy perspective without fully considering local contexts. In addition, although the role of partnerships between central government, local government, and operators is deemed critical, quite often such stakeholder blocks do not work well in reality as effective partnerships.

At the same time, bus operators argue that they should just be allowed to 'get on and run buses', and they critique the central and local governments for bringing too much regulation into the market. Operators also claim that they offer bus routes where people want to travel. Local governments, however, have policy reasons for putting routes where very few people want to travel in order to support public amenities such as education, sport, leisure, and healthcare. Tensions thus emerge around whether bus services should be provided where people want to travel or where a policy need may exist. As such, if the ZEB transition will rely heavily on public finance, this could generate conflicts because the desires of the government for a bus network could be very different from those of a private operator that will be mainly concerned with profitability.

Further cooperative gaps exist between transportation and electricity stakeholders, as well as relevant policy frameworks, that remain siloed. Specifically, none of the Distribution

Network Operators (DNOs), the (bus) Original Equipment Manufacturers, Ofgem, or electricity suppliers believe that it is their primary task to address the transition. Yet, a whole ecosystem approach is necessary to effect fundamental change in incumbent bus systems. In addition, many traditional electricity supply companies do not recognize the need for change. One of the biggest barriers may therefore turn out to be the role of such wealthy and powerful companies as they try to protect their status quo. A big gap will then persist until large power companies (such as Électricité de France) do not perceive the low-carbon electricity transition as a threat to their interests and they realize micro-grid markets that could be beneficial for ZEB operations. In addition, historically, DNOs were set up as government-funded, regulated monopolies that mainly dealt with housing developers or energy industry actors. Nevertheless, ZEB transitions create the need for new relationships and partnerships. Stakeholders from both the transport and energy sectors need to learn more about how each other works and how they could further cooperate. This is made all the more difficult due to the deregulated, disparate character of the existing energy and transportation systems, each having multiple competitive, i.e., private, for-profit actors. This makes coordination difficult, time-consuming, and costly.

Moreover, DNOs are not necessarily acting proactively for the transition. For example, they would only respond to requests from operators about depot electrification rather than suggesting options to circumvent relevant barriers. Yet, depot charging strategies can have serious financial implications. For instance, if an operator asks about the upgrade costs, DNOs may respond that it will cost 6 million euros at the point where the depot is located. However, DNOs will not necessarily inform operators that it may cost 60,000 euros if operators move their depot to another location. The setup of DNOs is therefore not conducive to making the transition as efficient and cheap as possible. The UK government is taking steps to address these issues, but such changes require time. Table 1 summarizes the technical and non-technical barriers and their implications for ZEB transitions in the UK context:

Table 1. ZEB barriers and implications in the UK context.

Barriers	**Impact for ZEB Transition**
Techno-economic	
High TCOs	Unjustifiable investments unless public funding support makes TCOs comparable to diesel ones.
Uncertainties over ZEB technology (vehicles/batteries/maintenance)	Fear of 'early adoption' of immature technology. Potential lock-in to unsustainable ZEB fleets; adverse impacts on wider ZEB market potential (e.g., secondary markets).
High cost/uncertainties over hydrogen fuel production and supply	Unviable business case unless hydrogen projects feed into wider value streams.
Depot electrification	Upgrade costs can be considerably high depending on depot location.
Market	
Unsustainable passenger patronage	Uncertainties over future bus demand threaten ZEB business viability and constrain long-term planning.
Low/moderate profit margins	ZEB capital constraints even for big operators.
Complications over green financing	ZEB borrowing may adversely affect investment grading.
Corporate capacity gaps	Smaller operators lack ZEB financial/technical abilities.
Fragmented/deregulated bus networks	Inertia by private bus operators to alter existing corporate goals and practices.

Table 1. *Cont.*

Barriers	Impact for ZEB Transition
Policy/Political	
Ad-hoc/competitive public funding	ZEB public funds unavailable across bulk of operators and urban areas.
Inadequate policymaking	Lack of real action plans increase implementation gaps. Policy approach tends to favor powerful/skillful local authorities and operators.
Political unwillingness to restrict car use	Obdurate high car use and dependency constrains modal shift to public transportation and ZEB financial viability (e.g., through congested roads).
Narrow transport appraisal methods	Car transportation and small journey time-savings favored over public transportation and wider socio-economic benefits.
Cooperative	
Central-local government gaps	'One-size fits' policy approach by central government does not fully appreciate place-based character of ZEB transitions.
Transport-energy gaps	Weak collaboration between key stakeholders (including at transport-energy nexus) constrains wider transition agency coordination.
Conflicting stakeholder objectives	Divergent objectives between public and profit oriented stakeholders can create tensions around ZEB network planning, especially if public funds are provided.

6. Discussion: Barrier Diagnosis for a Systematic Transition Approach

Many of the technical barriers around the performance and uptake of ZEB technology and infrastructure, summarized in Table 1, were found to be in agreement with previous studies. This involved high TCOs [4], the availability of BEV charging infrastructure [4,7], the mobilization of capital investment for delivering infrastructure [39], as well as range concerns [4,7,9]. Some differentiation, however, can be observed that reflects the place-based character of ZEB systems (spatial/weather conditions, domestic industrial supply chains, variable levels of market maturation, etc.). Regarding net zero fuel choices, our findings suggest that, despite concerns over costs and performance, hydrogen has a role to play in ZEB systems in 2050, in particular for longer distances. This diverges from scenario analysis for a net zero energy system in India in 2050, which suggests that BEVs should be the primary propulsion system, followed by carbon neutral Bio-CNG fleets that address 'range anxiety' concerns for longer distance routes [16]. Moreover, unlike the UK case, barriers to BEV uptake in Norway involved 'installing streetside fast charging infrastructure within dense urban areas, supplying energy for heating and cooling the buses, and potentially dealing with cold winter conditions' [7]. In addition, the authors suggest that financial disparities between ZEB-diesel TCOs are a key issue for local authorities due to the public tender model that is applied for allocating bus service routes. In the UK, high ZEB TCOs were reported to be a key barrier for bus operators operating within deregulated bus markets.

In addition, the unavailability of charging facilities (procured from overseas) and planning complexities (geographical characteristics of a region, types of charging stations, pricing modalities, etc.) were reported for the Philippines [4]. In the UK, the availability of charging infrastructure was not identified as a barrier per se. Instead, the potentially high costs of depot upgrades, which are largely borne by bus operators, and the lack of pro-activeness by regulated energy stakeholders such as DNOs were highlighted. Thus, to maximize value for practitioners and industry stakeholders, transition analysis needs to address in detail the localized spatial and institutional contexts within which techno-economic barriers operate. However, care must be taken when assessing the transfer of relevant lessons between urban areas domestically or across countries.

A major divergence with previous studies is found in the relative importance attributed to technical versus policy/political barriers. Guno et al. [4] found that technological and economic factors were the main barriers to public transport electrification. Song et al. [20] suggested that the development of the electric vehicle industry for public transportation networks in China is closely related to the availability of public subsidies from the central and local governments. This is because electric bus manufacturers, bus companies, and providers of charging infrastructure will be motivated to invest and consume more when more subsidies are on offer. While public subsidies have been central, our analysis suggests that various policy and political factors influence the ZEB market and infrastructural development in the UK. Finance gaps are more complex and cannot be adequately addressed alone by governmental match funding that reduces initial investment costs. Frozen fuel duties that reduce the relative cost attractiveness of bus use, the competitive nature of ad-hoc ZEB grants, and organizational capacity gaps (for local authorities and operators alike) pose further barriers to ZEB business cases.

At the same time, two broader policy/political barriers were identified. The first was an unsustainable bus system in terms of declining passenger patronage (and, as such, operational revenues) and network coordination. The second was persistent high car use that erodes ZEB's financial viability but also provides wider ZEB-driven benefits to the local transport system as a whole. Put simply, the full conversion of bus fleets to net-zero will not necessarily signify a viable transition unless broader changes, i.e., a fundamental re-allocation of road space and a modal shift away from private transportation, are realized. The viability of ZEB transitions therefore becomes dependent upon state efforts to explicitly steer car-based local transport systems towards expanding public (bus) transportation. In the UK context, such efforts were found to be conditioned by broader factors such as national transport and energy policymaking, localized cultures of car transportation, and transport devolution political and policy agendas. It is at the intersection of multilevel institutional processes of transport and energy planning and the material configuration of car-oriented urban areas that systemic ZEB barriers consolidate.

ZEB barriers thus operate through a complex web of inherited and interwoven structures that cut across broader (than bus sectoral) transportation, incumbent energy systems, pre-existing urban built environments, and long-standing transportation habits [56]. On the one hand, this relates to the nature of national political systems and their respective central-local institutional transition dynamics [15]. On the other hand, it concerns the large and small (seemingly mundane) decisions through which urban infrastructures and the built environment are created, maintained, and reconfigured or not. A deeper view into transition barriers therefore requires attention to the ways in which decisions shaping the urban built environment and end-user mobility practices intermingle with institutional processes in particular governance systems (e.g., hierarchical; polycentric) [44].

As a result, policy and corporate responses need to simultaneously create and integrate transport, land-use, and energy strategies (including appropriate levels of state funding) that are conducive to realizing the ZEB transition. Vertical governmental coordination and horizontal stakeholder collaborations that cut across transport, urban planning, and energy then become central [9]. This finding diverges from previous studies that identified interactions between transport market stakeholders and the government (induced by available state subsidies) as the main cooperative platform for ZEB industry and market development [20]. It also departs from studies [7] that emphasized the central role of a single policy level—the municipal—by stressing the importance of both the political center (central government/devolved administrations) and of central-local institutional configurations.

Furthermore, comprehensive transition responses need to address interdependencies and feedbacks across barriers. For instance, a few participants highlighted the role of 'vicious cycles' for ZEB prospects. Specifically, they noted that declining bus use, which is driven by fragmented, deregulated markets and poor government policies, leads to increases in the cost of bus services. These costs result in poorer services. Consequently, many people do not travel by bus and instead use cars on ever more congested roads, further reducing the attractiveness of buses to end users. To maintain agreed-upon service levels, bus companies need to operate extra buses on their routes. This pushes up fares, which further continues the spiral of declining bus users, poorer services, etc. For fleet-wide ZEB conversions, such feedback loops are exaggerated due to the extra upfront capital costs and technical needs (e.g., extra BEVs to accommodate range and charging issues).

In addition, there is a need to scale up disparate projects and initiatives in portfolios aiming to effect system-level change. From a policy perspective, this requires moving from a 'government-by-project' approach to a 'systematic program of government' [14]. Integrated policy mixes consisting of public transportation subsidies, emission reductions from the supply side of electricity and hydrogen, and internal combustion engine bans will be crucial to promote technology development, fuel switching, and behavior change [11]. Yet, the UK case suggests that urban planning frameworks and material arrangements in support of ZEB transportation should be necessary ingredients in policy mixes. Transport elasticity analysis that quantifies the sign (positive/negative) and degree of influence of different factors on ZEB bus patronage could constructively inform such integrated policy mixes. This is because evaluation of the determinants of bus demand and its future levels in light of a net-zero pathway, can point to transition gaps/implications in relation to the characteristics of the urban built environment form/layout, infrastructural capacities, the financial viability of ZEB projects, and transport economic and pricing structures [57,58]. In this context, ZEB elasticity analysis can be directly relevant to two major barriers identified in the empirical analysis, namely declining bus use and high car use and dependency in UK cities. Contextual and mode-specific analysis [57] of ZEB transport elasticities could involve examining the effect of a single variable, such as the urban or regional gross domestic product, that embodies partial economic and territorial variables [58]. Alternatively, a more integrated view could extend focus to a set of variables drawing from socio-demographics, economics (e.g., fare/fuel prices), spatial factors (e.g., bus service quantity/population density), and temporalities (e.g., diurnal/seasonal) [57].

A portfolio approach can also be beneficial in overcoming conflicts and competition among measures aiming to address different barriers [24]. Besides having policy portfolios in place, we agree with Smeds and Jones [17] (p. 34), who argue for the need to 'ask what the deadline is for enabling actions to overcome barriers in order to facilitate actual policy implementation'. Thus, the assessment of barriers by transition phases that reflect a more or less advanced ZEB state (e.g., technology performance and market maturity, institutional readiness, stakeholder attitudes, etc.) [59] can fruitfully inform transition roadmaps.

Lastly, given the uneven ZEB capacities and stages of development institutionally and geographically, there is a rationale for the distribution of resources and cross-learning across urban areas and stakeholder groups. Trusted agencies such as the UK Energy Saving Trust (EST) could play a leading role by tapping into their long experience and stakeholder engagement in local sustainability issues. Membership organizations such as the Zemo Partnership and the Urban Transport Group could also use their visibility and extended networks to lobby for greater ZEB resources and coordinate mentoring programs. The latter can be an effective way to assist and motivate less advanced local authorities to identify transition barriers and start devising plans to address them [9,60].

Such policy and corporate responses bear the potential to impact ZEB stakeholders in various ways. First, they can foster conducive conditions for accelerating ZEB industry and market development by creating and aligning stakeholder objectives, resources, and action plans across sectors and policy levels. Second, they can set the scene for wider collaborations on the basis of broader stakeholder value streams and comparative skills. Third, they may promote wider organizational capacities through ZEB resource development and (re)distribution as well as knowledge sharing.

Besides practical implications, a number of theoretical insights can be noted. The study departs from analytical approaches to 'systemic transformation' that are centered on policy nurturing of technical innovation systems to accelerate technological regime shifts [61]. It suggests that critical policy-engaged analysis has a key role to play in uncovering the wider range of technical and especially non-technical barriers that ZEB plans need to address in domestic political economies. In addition, its theoretical framework stresses the importance of soliciting and learning from multiple stakeholder perspectives in developing a shared understanding of transition barriers and problem areas.

The study also points to the need for developing a finer-grained conceptual view of the transition role of the state, local and national, and how the state can or should identify barriers to system change, and design appropriate policies to overcome them. For example, in the UK state, ZEB resources are typically accessed by large local authorities and bus operators. Smaller authorities and operators tend to lag behind because of inadequate expertise and financial capabilities. State policies and regulations, thus, as means of steering transitions, are not neutral but inscribe and privilege particular social interests. In addition, certain UK policies (fuel taxation, massive road building programs) increase the relative cost of ZEB transportation and perpetuate car travel as the dominant transportation mode for society and the economy. These policies are driven by powerful agencies such as the UK Treasury and its institutional stakeholders (e.g., the National Highways and National Infrastructure Commission) [62]. Addressing who and how the state constrains the ZEB transition is key to assessing the prospects of interventions that can hasten the transition. Analysis of the 'whereabouts' of ZEB barriers thus needs to examine the role of multiple and dispersed sites of state powers and functions within particular contexts [18].

Finally, Delmar [63] suggests that 'generalizability' in qualitative research builds on recognizability or communalities, similarities and differences in situations. A 'situation' is determined by attributes such as time, space, relations, power, and context. The UK case revealed the importance of examining such attributes from a political-economic perspective in order to develop contextual knowledge of the types of barriers and their impacts on ZEB transitions. The analysis therefore becomes relevant to other areas to the extent that aspects around 'time' (e.g., phases of transition), 'context' (e.g., political, institutional, market, etc.), and 'power' (e.g., sites/functions of state transition power) depict commonalities. Table 2 below summarizes the policy/practical, and research implications of the UK case study.

Table 2. Transition policy/research implications of ZEB barriers analysis in the UK context.

Barrier	Policy/Practical Implications	Research Implications
Multitude of barriers operating within and across sectors and policy levels.	Integrated plans at the intersection of ZEB transportation, energy, and urban planning.	Critical policy-engaged analysis can uncover the wider range of ZEB barriers, and their workings, in domestic political economies.
High TCOs, and uncertainties over ZEB technical performance and market residual values increase investment risks for bus operators.	Portfolio approach to address barriers, and their interdependencies, across sectors and levels.	Stakeholder and environmental governance perspectives can inform rich empirical analysis of ZEB barriers from political-economic and multi-stakeholder viewpoint.

Table 2. *Cont.*

Barrier	Policy/Practical Implications	Research Implications
Mismatch between scale of problem (UK-wide tackling of ZEB barriers) and policy resources/action plans at both central and local levels.	States play a key role in shaping both transition barriers and opportunities to tackle barriers.	Need for broader conceptualizations of state role in transitions. Multiple sites of state power, beyond a net-zero and bus sectoral focus.
Political reservations to support car use and dependency reduction in urban areas.	Need for vertical (central-local government) institutional coordination and horizontal (at the urban level) stakeholder collaboration.	Application of the theoretical framework in comparable political-economic contexts can contribute to a broader body of ZEB empirical contextual knowledge.
Cooperative gaps between policy levels (central-local) and key stakeholder groups (e.g., transport-energy).	Transition resources, capacities, and knowledge transfer to address barriers across majority of urban areas and stakeholders.	Generalizability of empirical lessons requires evaluation of situational attributes such as context, power, and time.

7. Conclusions

The transition to ZEB systems requires addressing various barriers across technology, policy, institutions, and markets through the engagement of multiple stakeholders. Previous studies have examined the technical barriers that constrain ZEB transitions. However, the role of non-technical barriers and how barriers (technical and non-technical) are shaped by domestic political and economic contexts remain largely underexplored. Lack of attention to the variety of barriers operating within political economies masks understanding of the factors that actually constrain transitions in the real world. Consequently, gaps are created between transition plans/roadmaps and the realities of system-level change on the ground. This article aimed to address such gaps in transition analysis by examining ZEB barriers from a political-economic and multi-stakeholder perspective. In doing so, it developed a theory-informed qualitative case study of the technical and non-technical barriers that constrain ZEB transitions within the UK political-economic context. The study's theoretical framework drew on stakeholder theory and cooperative environmental governance perspectives to account for the multi-stakeholder and contextual character of transitions. The UK barriers analysis was informed by semi-structured interviews with ZEB stakeholders from the policy, market, industry, and third sector.

In accordance with previous studies, the analysis found that techno-economic barriers around technology and infrastructural costs, performance, and residual values constrain the wider ZEB market and industry development. However, it also revealed the importance of policy/political, market, and cooperative barriers for system-level change. Such barriers include policy and funding gaps at both the central and local levels. They also relate to fragmented, deregulated bus networks that depict inertia toward change and lack wider transition resources and agency. Political unwillingness to restrict car-based transportation poses further barriers by limiting prospects of a modal shift to public transportation and by eroding the financial viability of ZEB fleets on congested roads. Vertical and horizontal cooperative gaps involving the central government, the local government, bus industry stakeholders, and energy stakeholders (e.g., DNOs, utilities) were also identified. In this context, ZEB barriers were found to consolidate at the intersection of multilevel institutional processes of transport and energy planning and the material configuration of car-oriented urban built environments. Any UK-wide viable ZEB transition, therefore, requires more than the full conversion to ZEB vehicles and infrastructure. It is predicated upon tackling barriers beyond a net-zero and bus sectoral focus, concerning the restriction of car use and dependency in urban areas, the expansion of bus passenger patronage, and the deployment of decarbonized electricity grids and hydrogen supply chains [4,39]. Our analysis thus aligns with that of Singh and Chudasama [12], who suggest that resorting alone to technical measures of decarbonization is both necessary and insufficient to accomplish a system-level transition. In short, state governance (e.g., policies, regulations, and guidance) will be central in any transition, and a sole, or major, focus on market-based transitions is risky and sub-optimal from a functional, systems perspective.

At the same time, the multitude of barriers operating across sectors and levels suggest that no single organization or sector can alone effect system-level change, nor indeed that the state by itself can achieve this. Thus, the corporate agendas of a wide range of stakeholders need to be supportive to effect policy and industry change [12]. In this regard, stakeholder collaborations could serve as platforms for developing a shared understanding of transition problem areas and for co-creating solutions. Reflective deliberative processes offer the opportunity to link the actions of diverse stakeholders operating at different levels and be flexible enough to deal with uncertain futures and changing transition demands. To be truly effective, they would need to engage stakeholders from the wider spectrum of society, recognize the legitimacy of their interests, and enable their meaningful intervention in the process [37]. In addition, they should entail a commitment to participants in terms of sharing information and implementation of the proposed actions [41].

To the best of our knowledge, the UK case is one of the first empirical studies offering a deeper view into technical and non-technical ZEB barriers from a political-economic perspective. However, future studies could advance understanding by addressing further analytical aspects. Scholars have reported the importance of engaging with a wide range of stakeholders from the state, industry, community, and third sectors when examining transitions [14,36,64]. Thus, barriers analysis could elicit the views of further stakeholders, such as national and regional governmental agencies, politicians, community groups, and bus end-users. It would also be valuable to document lessons from less successful local authorities and bus operators regarding the barriers that they encountered and why any responses that they undertook did not sufficiently address them.

Moreover, empirical analysis of barriers interdependencies could offer a deeper view into the mechanisms through which inertia to change is consolidated. This will require new analytical approaches that address the different types of lock-in mechanisms and their implications for the path dependencies of incumbent bus systems [65]. In addition, ZEB transitions require long-term planning, but it is equally necessary to ensure that concrete progress is made as soon as possible [17]. Transitions are complex phenomena characterized by qualitatively different states in terms of the performance and uptake of technologies, the maturity of institutions and markets, and stakeholder attitudes [59]. Therefore, barrier analysis could incorporate a temporal dimension in order to become more relevant to different contexts and stakeholders and to better inform short- and medium-term action plans. Examining barriers in relation to different transition phases (e.g., pre-development; take-off; acceleration; stabilization) [66] could be a starting point for gaining a more granular view of how barriers and their implications differentiate over the course of ZEB trajectories.

Finally, as shown, tackling transition barriers will require the mobilization of resources and agency across state and non-state stakeholders. ZEB-oriented corporate organizational frameworks are therefore central to the transition. Previous studies have identified such core organizational dimensions, including financial issues, staffing, organizational cultures, communications, credibility, influence, etc. [67]. Insights from organizational and corporate governance studies could thus inform the elaboration of analytical frameworks that evaluate stakeholder capacities and relations in transition processes.

Funding: This research was funded by the Engineering and Physical Sciences Research Council in the context of the 'Prosperity Partnership: Roadmaps to Zero Net Emissions in Urban Public Transport' project, grant number EP/S036695/1.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of Queen's University Belfast (HAPP 2021-33, 19/05/2021).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data sharing is not applicable to this article due to confidentiality reasons.

Acknowledgments: The author wishes to thank all interview participants who provided case study input as well as John Barry, Teresa McGrath, and Luke Blades who provided comments on the whole article draft.

Conflicts of Interest: The author declares no conflict of interest. The funders had no role in the design of the study, in the collection, analysis, or interpretation of data in the writing of the manuscript,' or in the decision to publish the results.

Appendix A

Table A1. Summary of research design process steps and techniques.

Research objectives and thematic areas	• Explore ZEB transitions from a multi-stakeholder and political-economic perspective. • Place-based analysis of technical and non-technical ZEB barriers in the UK context.
Research questions	Two primary questions: • What barriers constrain the transition to net-zero emission urban bus systems? • How do the UK's institutional, policy, and market contexts shape these barriers?
Methodological approach	• A theory-informed qualitative case study of ZEB transition barriers operating within the UK political-economic context. Empirical analysis draws from semi-structured interviews with UK stakeholders in the local bus transportation system.
Literature review	• Peer-reviewed publications, policy/technical reports, and corporate agendas to develop the study's theoretical framework and elicit background data for the existing UK urban bus system and its ZEB transition.
Interview instrument and selection of participants	• Draft questionnaire for semi-structured interviews was validated with researchers at Queen's University Belfast. • Questionnaire focused on technical and non-technical barriers and how they operate within the specificities of the UK's institutional, policy, and market contexts. • Diversification of participants by sector (policy, market, industry, third sector) and geographical representation (England and the devolved administrations of Northern Ireland, Scotland, and Wales). The snowball method of sampling.

Table A1. *Cont.*

Data analysis and compilation of results	• Background context for the UK case, based on secondary data. Content analysis, based on repeated readings of interview transcriptions, was conducted to identify similarities and differences across participant views on key characteristics of the ideal ZEB system in 2050 and the types of transition barriers that needed to be overcome to realize the ideal system. Attention placed to whether issues related to barriers emerged in relation to the full set of interview questions by searching transcriptions for keywords bearing a 'barrier meaning' (constraints, challenges, hindrances, limitations, etc.). Data on the ideal system and transition barriers were marked and located for later use. Transition barriers were categorized and reported according to four types—the sub-units of the empirical analysis: techno-economic, market, policy/political, and cooperative. • Development of broader policy and research implications for ZEB transition analysis based on the study's theoretical approach and empirical findings of the UK case.

Appendix B

Table A2. Interviewed Stakeholders.

Type of Organization	Name of Organization	Participant Sector/Role	Gender/ Nationality
Municipal and regional bodies	Nottingham City Council Liverpool City Region Combined Authority Oxford City Council	Principal Public Transport Officer Assistant Director for Bus Development Principal Green Transport Planner	M/UK M/UK M/UK
Local transport authorities	Transport for London Transport for the West Midlands Transport for the West Midlands Transport Scotland	Head of Bus Business Development Director of Integrated Transport Services Bus Development Manager Head of Bus Greening	M/UK M/UK MUK M/UK
Bus operators	Translink (Northern Ireland) Go-Ahead Group FirstGroup (Wales) Lothian Buses (Scotland)	Director of Service Operations Director of Bus Performance Business Developer Executive Business Development Manager	M/UK M/UK F/UK M/UK
Bus manufacturers	Switch Mobility Ltd.	Commercial Director	M/UK
Civil sector organizations	Transport Action Network Campaign for better transport Better Buses for Greater Manchester	Director of Sustainable Transport Adviser to the Director Campaigns and Events Coordinator	M/UK M/UK F/UK
Intermediaries	Urban Transport Group Royal Town Planning Institute Royal Town Planning Institute Zemo Partnership	Policy and Research Advisor on Urban Transport Chief Executive in Planning and Transport Infrastructure Specialist Program Manager and Leader of Bus Working Group	F/UK F/UK M/UK M/UK

Table A2. *Cont.*

Type of Organization	Name of Organization	Participant Sector/Role	Gender/ Nationality
	UK Local Government Association Confederation of Passenger Transport UK	Senior Adviser on Transport and Local Growth Policy Manager on Transport and Environment	M/UK F/UK
ZEB market developers and consultants (private entities)	Element Energy (consultancy firm) B9 Energy Ltd. (green energy company) AECOM (Infrastructure firm) Zenobe (Electric Transport-as-a-Service solutions) Consultant	Director (Low Carbon Transport Technologies) Managing Director Associate Director for Transport Planning Director of Business Development Independent transport consultant	F/France M/UK M/UK M/UK M/UK

Appendix C

Table A3. Policy provisions, plans, and mechanisms for ZEB (and wider bus) development in the UK.

Policy/Legislation by Central/ Devolved Government	Funding and Incentives by Region
UK Central Government	England
Climate Change Act 2008. Amended in 2019 to at least a (net-zero) 100% reduction in UK-wide GHG emissions by 2050. UK Bus Service Act 2017 (applicable to English areas; franchise powers to local authorities). Road to Zero Strategy (2019). Bus Back Better: National Bus Strategy for England (2021). Ten-point Plan for a Green Industrial Revolution (2020). Pledge for deployment of 4000 ZEBs by December 2024 (end of current UK Government term). TDP (y. 2021) (bus provisions applicable to England). Consultation initiated in March 2021 on the end of diesel and petrol bus vehicle sales at latest by 2032.	ZEBRA scheme 310 million euros in capital grant funding to local authorities outside London. Phase II awarded in March 2022. COVID-19 Bus Service Support Grant. Extended to March 2023. Bus Service Improvement Grants (linked to EPs or franchising). Bus Service Operators Grant (BSOG). Discretionary grant to operators at 40 Euro cents/liter for diesel buses, and 25 Euro cents/Km for zero emission buses at the tailpipe. Greater London franchise and Greater Manchester commercial services no longer supported.
Scottish Parliament	Scotland
Clean air/low/zero emission zones (all devolved regions, in joint planning with local authorities). Scotland Climate Change Plan 2018–2032: Economy-wide net-zero emissions by 2045; goal for a 20% reduction in car kilometers by 2030. For the transport sector, a reduction in GHG emissions of 41% is expected by 2032. Scotland Transport Act 2019 (franchise power to local authorities).	Network Support Grant (from 1 April 2022 replaced BSOG and COVID-19 support grant). ScotZEB: Zero Emission Bus Challenge Fund. Phase II expected to launch in 2023/24. ZEB Market Transition Scheme. Funded by the national transport agency Transport Scotland. Total of 600,000 euros targets SME bus and coach operators; community, home-to-school, and transport-to-healthcare bus operators. Currently no operational incentives for zero emission buses under the Network Support Grant.
Northern Ireland Assembly	Northern Ireland
Northern Ireland (NI) Climate Change Act 2022 (net-zero GHG emissions by 2050). NI Department for Infrastructure (DfI) to set out GHG reduction sectoral plans for different areas of the economy.	Capital grant funding is provided on an ad-hoc basis to Translink by DfI. Currently no direct operational grants for zero emission buses.

Table A3. *Cont.*

Policy/Legislation by Central/ Devolved Government	Funding and Incentives by Region
Welsh Parliament	Wales
The Wales Transport Strategy 2022. Goal for zero tailpipe bus emissions by 2040. Bus White Paper 2022 proposes bus franchising. Welsh Government has committed to introduce legislation to achieve (economy-wide) net-zero GHG emissions by 2050	Capital grant funding on an ad-hoc basis to local authorities. COVID-19 support grants extended to March 2023. Currently no direct operational incentives for zero emission buses.
Sub-national authorities	Sub-national areas
Local and regional bus strategies. Road re-allocation measures (bus priority lanes, congestion charging (London), workplace parking levy).	In London's franchised network, TfL retains fare revenues. Higher ZEB price contracts to operators for a guaranteed period.

References

1. DfT. *Bus Back Better. National Bus Strategy for England*; DfT: London, UK, 2021.
2. Degen, A. Building back European public transport after COVID-19. In *Urban Mobility after COVID-19. Long-Term Strategies for the Sustainable Mobility Transition in European Cities*, 1st ed.; Abdullah, H., Robles, E.S., Eds.; CIBOD: Barcelona, Spain, 2021; pp. 57–61.
3. Zemo Partenrship. Defining a Zero Emission Bus. 2021. Available online: https://www.zemo.org.uk/work-with-us/buses-coaches/projects/defining-a-zero-emission-bus.htm (accessed on 8 February 2023).
4. Guno, C.S.; Collera, A.A.; Agaton, C.B. Barriers and drivers of transition to sustainable public transport in the Philippines. *World Electr. Veh. J.* **2021**, *12*, 46. [CrossRef]
5. World Economic Forum. How to Accelerate the Net-Zero Transition in Transport. 2022. Available online: https://www.weforum.org/agenda/2022/01/how-to-accelerate-the-net-zero-transition-in-transport (accessed on 22 March 2022).
6. Fuel Cell Electric Buses. Clean Buses in Europe Conference. 2022. Available online: https://www.fuelcellbuses.eu/public-transport-hydrogen/clean-buses-europe-conference (accessed on 13 April 2022).
7. Thorne, R.J.; Hovi, I.B.; Figenbaum, E.; Pinchasik, D.R.; Amundsen, A.E.; Hagman, R. Facilitating adoption of electric buses through policy: Learnings from a trial in Norway. *Energy Policy* **2021**, *155*, 112310. [CrossRef]
8. T&E. Electric Buses Arrive on Time. Marketplace, Economic, Technology, Environmental and Policy Perspectives for Fully Electric Buses in the EU. 2018. Available online: https://www.transportenvironment.org/wp-content/uploads/2021/07/Electric-buses-arrive-on-time-1.pdf (accessed on 7 April 2022).
9. Xylia, M.; Silveira, S. On the road to fossil-free public transport: The case of Swedish bus fleets. *Energy Policy* **2017**, *100*, 397–412. [CrossRef]
10. Innovate UK. Transport Vision 2050: Investing in the Future of Mobility. 2021. Available online: https://www.ukri.org/wp-content/uploads/2022/01/IUK-110122-UK-Transport-Vision-2050.pdf (accessed on 19 June 2022).
11. Bu, C.; Cui, X.; Li, R.; Li, J.; Zhang, Y.; Wang, C.; Cai, W. Achieving net-zero emissions in China's passenger transport sector through regionally tailored mitigation strategies. *Appl. Energy* **2021**, *284*, 116265. [CrossRef]
12. Singh, P.K.; Chudasama, H. Conceptualizing and achieving industrial system transition for a dematerialized and dicarbonized world. *Glob. Environ. Chang.* **2021**, *70*, 102349. [CrossRef]
13. Geels, F.W. A socio-technical analysis of low-carbon transitions: Introducing the multi-level perspective into transport studies. *J. Transp. Geogr.* **2012**, *24*, 471–482. [CrossRef]
14. Geels, F.W. Low-carbon transition via system reconfiguration? A socio-technical whole system analysis of passenger mobility in Great Britain (1990–2016). *Energy Res. Soc. Sci.* **2018**, *46*, 86–102. [CrossRef]
15. Ehnert, F.; Kern, F.; Borgström, S.; Gorissen, L.; Maschmeyer, S.; Egermann, M. Urban sustainability transitions in a context of multi-level governance: A comparison of four European States. *Environ. Innov. Soc. Transit.* **2018**, *26*, 101–116. [CrossRef]
16. Vats, G.; Mathur, R. A net-zero emissions energy system in India by 2050: An exploration. *J. Clean. Prod.* **2022**, *352*, 131417. [CrossRef]
17. Smeds, E.; Jones, P. Developing transition pathways for mobility in European cities–challenges and new approaches. In *Urban Mobility after COVID-19. Long-Term Strategies for the Sustainable Mobility Transition in European Cities*, 1st ed.; Abdullah, H., Robles, E.S., Eds.; CIBOD: Barcelona, Spain, 2021; pp. 31–36.
18. Johnstone, P.; Newell, P. Sustainability transitions and the state. *Environ. Innov. Soc. Transit.* **2018**, *27*, 72–82. [CrossRef]
19. Marsden, G.R.; May, A.D. Do institutional arrangements make a difference to transport policy and implementation? *Lessons for Britain. Environ. Plan C Gov. Policy* **2006**, *24*, 771–789. [CrossRef]
20. Song, Z.; Liu, L.; Gao, H.; Li, S. The underlying reasons behind the development of public electric buses in China: The Beijing case. *Sustainability* **2020**, *12*, 688. [CrossRef]

21. Ou, X.; Zhang, X.; Chang, S. Alternative fuel buses currently in use in China: Life-cycle fossil energy use, GHG emissions and policy recommendations. *Energy Policy* **2010**, *38*, 406–418. [CrossRef]
22. Moradi, A.; Vagnoni, E. A multi-level perspective analysis of urban mobility system dynamics: What are the future transition-pathways? *Technol. Forecast. Soc. Chang.* **2018**, *126*, 231–243. [CrossRef]
23. Olsson, L.; Hjalmarsson, L.; Wikström, M.; Larsson, M. Bridging the implementation gap: Combining backcasting and policy analysis to study renewable energy in urban road transport. *Transp. Policy* **2015**, *37*, 72–82. [CrossRef]
24. Liakou, L.; Flanagan, B.; Altman, N.; Rendle, N.; Kiernicka-Allavena, J.; Wildman, A.; Heyder, M.; Gresset, S.; Diaz, A.; Castañeda, M.; et al. *Net-Zero Cities. Report on City Needs, Drivers and Barriers towards Climate Neutrality*; Eurocities: Brussels, Belgium, 2022.
25. The UK Rules. Operating Registered Local Bus Services. 2021. Available online: https://www.theukrules.co.uk/rules/driving/businesses/running-a-local-bus-service.html (accessed on 12 July 2022).
26. DfT. *National Statistics. Transport Statistics. Great Britain: 2021*; DfT: London, UK, 2021.
27. DfI. The Northern Ireland Transport Statistics 2020–2021 Statistical Report Has Been Published Today. 2021. Available online: https://www.infrastructure-ni.gov.uk/news/northern-ireland-transport-statistics-2020-2021-statistical-report-has-been-published-today (accessed on 12 October 2022).
28. UK Parliament Environmental Audit Committee. Growing back Better: Putting Nature and Net-Zero at the Heart of the Economic Recovery. 2021. Available online: https://publications.parliament.uk/pa/cm5801/cmselect/cmenvaud/347/34702.htm (accessed on 18 October 2022).
29. HM Treasury. *Spending Review 2020*; HM Treasury: London, UK, 2020.
30. HM Government. New Target Will Require the UK to Bring All Greenhouse Gas Emissions to Net-Zero by 2050. 2019. Available online: https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law (accessed on 16 March 2021).
31. Peck, J. Neoliberalizing states: Thin policies/hard outcomes. *Prog. Hum. Geogr.* **2001**, *25*, 445–455. [CrossRef]
32. Wieczorek, A.J.; Hekkert, M.P. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. *Sci. Public Policy* **2012**, *39*, 74–87. [CrossRef]
33. Nora, G.A.M.; Alberton, A.; Ayala, D.H.F. Stakeholder theory and actor-network theory: The stakeholder engagement in energy transitions. *Bus Strategy Environ.* **2023**, *32*, 673–685. [CrossRef]
34. Hörisch, J.; Schaltegger, S.; Freeman, R.E. Integrating stakeholder theory and sustainability accounting: A conceptual synthesis. *J. Clean. Prod.* **2020**, *275*, 124097. [CrossRef]
35. Westman, K.L.; Castán Broto, V. Techno-economic rationalities as a political practice in urban environmental politics in China. *Environ. Plan C Politics Space* **2019**, *37*, 277–297. [CrossRef]
36. Avelino, F.; Wittmayer, J.M. Shifting power relations in sustainability transitions: A multi-actor perspective. *J. Environ. Policy Plan* **2016**, *18*, 628–649. [CrossRef]
37. Castán Broto, V.; Macucule, D.A.; Boyd, E.; Ensor, J.; Allen, C. Building collaborative partnerships for climate change action in Maputo, Mozambique. *Environ. Plan A* **2015**, *47*, 571–587. [CrossRef]
38. Seto, K.C.; Churkina, G.; Hsu, A.; Keller, M.; Newman, P.W.; Qin, B.; Ramaswami, A. From low-to net-zero carbon cities: The next global agenda. *Annu. Rev. Environ. Resour.* **2021**, *46*, 377–415. [CrossRef]
39. Ku, A.Y.; de Souza, A.; McRobie, J.; Li, J.X.; Levin, J. Zero-emission public transit could be a catalyst for decarbonization of the transportation and power sectors. *Clean Energy* **2021**, *5*, 492–504. [CrossRef]
40. Castán Broto, V.; Boyd, E.; Ensor, J.; Seventine, C.; Macucule, D.A.; Allen, C. *Participation and Planning for Climate Change: Lessons from an Experimental Project in Maputo, Mozambique*; Climate and Development Knowledge Network (CDKN): Cape Town, South Africa, 2015.
41. Mullally, G.; Revez, A.; Harris, C.; Dunphy, N.; Rogan, F.; Byrne, E.; McGookin, C.Ó.; Gallachóir, B.; Bolger, P.; O'Dwyer, B.; et al. *A Roadmap for Local Deliberative Engagements on Transitions to Net Zero Carbon and Climate Resilience*; Environmental Protection Agency: Dublin, UK, 2022.
42. Robson, C. *Real World Research: A Resource for Social Scientists and Practitioner-Researchers*, 2nd ed.; Blackwell Publishers: Oxford, UK, 2002.
43. Sippel, M.; Till, J. What about Local Climate Governance? A Review of Promise and Problems. Munich Personal RePEc Archive. 2009. Available online: http://mpra.ub.uni-muenchen.de/20987 (accessed on 8 September 2022).
44. Haarstad, H. Where are urban energy transitions governed? Conceptualizing the complex governance arrangements for low-carbon mobility in Europe. *Cities* **2016**, *54*, 4–10. [CrossRef]
45. Shaw, J.; MacKinnon, D.; Docherty, I. Divergence or convergence? Devolution and transport policy in the United Kingdom. *Environ. Plan C Gov. Policy* **2009**, *27*, 546–567. [CrossRef]
46. Yin, R.K. *Case Study Research: Design and Methods*, 5th ed.; Sage Publications Inc.: Los Angeles, CA, USA, 2014.
47. Schmidt, C. The analysis of semi-structured interviews. In *A Companion to Qualitative Research*, 1st ed.; Flick, U., von Kardorff, E., Steinke, I., Eds.; Sage: London, UK, 2004; pp. 253–258.
48. Argyriou, I. Urban energy transitions in ordinary cities: Philadelphia's place-based policy innovations for socio-technical energy change in the commercial sector. *Urban Res. Pract.* **2020**, *13*, 243–275. [CrossRef]
49. White, P. Prospects in Britain in the light of the Bus Services Act 2017. *Res. Transp. Econ.* **2018**, *69*, 337–343. [CrossRef]

50. DfT. *Transport and Environment Statistics 2021 Annual Report*; DfT: London, UK, 2021.
51. LowCVP. *Emission Bus Guide*; Low Carbon Vehicle Partnership: London, UK, 2016.
52. Zemo Partnership. Government Commits £200 m to Roll-Out of up to 1000 more Electric & Hydrogen Buses. 2022. Available online: https://www.zemo.org.uk/news-events/news,government-commits-200m-to-rollout-of-up-to-1000-more-electric-hydrogen-bus_4362.htm (accessed on 13 July 2022).
53. Zemo Partnership. Bus & Coaches: Grant Funding & Incentives. 2022. Available online: https://www.zemo.org.uk/work-with-us/buses-coaches/low-emission-buses/grant-funding-incentives-.htm (accessed on 19 October 2022).
54. Haigh, C. *Pathways to Net-Zero. Report on a Roundtable Discussion Series*; Greener Transport Solutions: London, UK, 2022.
55. DfT. *Percentage of Buses used as Public Service Vehicles by Emissions Standards and Fuel Type by Metropolitan Area Status and Country: Great Britain*; DfT: London, UK, 2021.
56. Mackinnon, D.; Shaw, J.; Docherty, I. Devolution as process: Institutional structures, state personnel and transport policy in the United Kingdom. *Space Policy* **2010**, *14*, 271–287. [CrossRef]
57. Shantz, A.; Casello, J.; Woudsma, C.; Guerra, E. Understanding factors associated with commuter rail ridership: A demand elasticity study of the GO transit rail network. *Transp. Res. Rec.* **2022**, *2676*, 131–143. [CrossRef]
58. Libardo, A.; Nocera, S. Transportation elasticity for the analysis of Italian transportation demand on a regional scale. *Traffic Eng. Control* **2008**, *49*, 187–192.
59. Castán Broto, V.; Mah, D.; Zhang, F.; Huang, P.; Lo, K.; Westman, L. Spatiotemporal perspectives on urban energy transitions: A comparative study of three cities in China. *Urban Transform.* **2020**, *2*, 11. [CrossRef]
60. Argyriou, I.; Fleming, P.W.; Wright, A. Local climate policy: Lessons from a case study of transfer of expertise between UK local authorities. *Sustain. Cities Soc.* **2012**, *5*, 87–95. [CrossRef]
61. Li, L. The governance of low-carbon transitions in a Multilevel perspective framework: How does the concept of 'system transformation' work? *Energy Res. J.* **2020**, *11*, 45–53. [CrossRef]
62. Craig, M.P.A. 'Treasury control' and the British environmental state: The political economy of green development strategy in UK central Government. *New Political Econ.* **2020**, *25*, 30–45. [CrossRef]
63. Delmar, C. "Generalizability" as recognition: Reflections on a foundational problem in qualitative research. *Qual. Studies* **2010**, *1*, 115–128. [CrossRef]
64. Frantzeskaki, N.; Dumitru, A.; Anguelovski, I.; Avelino, F.; Bach, M.; Best, B.; Binder, C.; Barnes, J.; Carrus, G.; Egermann, M. Elucidating the changing roles of civil society in urban sustainability transitions. *Curr. Opin. Environ. Sustain.* **2016**, *22*, 41–50. [CrossRef]
65. Klitkou, A.; Bolwig, S.; Hansenc, T.; Wessbergd, N. The role of lock-in mechanisms in transition processes: The case of energy for road transport. *Environ. Innov. Soc. Transit.* **2015**, *16*, 22–37. [CrossRef]
66. Barry, J.; Hume, T.; Ellis, G.; Curry, R. *Working Paper 1: Society-Wide Transitions*; Queen's University Belfast: Belfast, UK, 2016.
67. Hodson, M.; Marvin, S. Can cities shape socio-technical transitions and how would we know if they were? In *Cities and Low Carbon Transitions*, 1st ed.; Bulkeley, H., Castán Broto, V., Hodson, M., Eds.; Routledge: Oxford, UK, 2011; pp. 54–70.