Societal Embedding of Innovation: Current Transitions in Electric Vehicle Roadside Charging Infrastructure (EVRCI) Provision

Barry D Wilson
Adjunct Associate Professor, University of Hong Kong, barry@initiatives.com.hk

Abstract

This paper considers the current situation of Electric Vehicle Roadside Charging Infrastructure roll-out, utilising qualitative data obtained from a small research study identifying perceptions of impacts and concerns arising across global scenarios from roadside infrastructure. It places them within the context of the Theory of Transitions, utilising recent developments in socio-technical theory as the basis for examination. In particular it focuses on the potential for social and environmental impacts from technology innovation by gaining a better understanding of the full extent of stakeholders involved and processes at play beyond those of mere demand and supply; considering wider, macro level contributory factors that are necessary for successful innovation diffusion of new technology.


ALFEN
POWER TO ADAPT
Please hold card
over reader below
Left Socket
ID - 01
Charge Point ID
Right Socket
ID - 02


SureCharge
Chargepoint ID


ABB
SHARGE
alt


ALFEN

Introduction

Globally there is an urgency to transition to electric vehicles (EV's) to reduce carbon emissions in meeting climate goals. Provision of adequate charging infrastructure is a key component in that transition yet the business case for providing publicly available EV charging continues to face challenges due to low utilisation rates, consumers' low willingness to pay for charging, and high upfront and operating costs of infrastructure, in particular, DC fast charging infrastructure (US. NRDC, 2020). As such governmental policies worldwide have looked to assist the transition through implementation of various 'technology-forcing' regulations to assist in societal transformation. The use of providing "stick and carrot" type incentives in promoting innovation, where it would otherwise be difficult to change, have been regularly adopted since the 1960's, particularly as a means to address societal and environmental issues (Geels et al., 2021). Examples include the Clean Air Act -1970 that advanced the introduction of automotive emissions control (Gerard & Lave, 2007), and the Motor Vehicle Safety Act (NTMVSA) – 1966, resulting in airbags being installed into vehicles in the US (Geels & Penna, 2015). Scholars have documented these contested struggles, seemingly binary on the surface - between policy promoters on the one hand and a reluctant market demand on the other, as being much more complex and being affected by multiple factors that influence the successful diffusion of innovation.

Global approaches in transitioning to an EV society under technology-forcing incentives, similarly, appear to be following this above noted binary approach, being evaluated predominantly on demand and supply considerations in addressing the type and suitability of locations for electric vehicle roadside charging infrastructure (EVRCI). In many cases a lack of clarity exists in how policy is formulated, moreover there is no given reference to the needs and interests of third-party public space stakeholders. With extremely little empirical data in this emergent sector there exists significant risk potential for both inappropriate and inefficient development in the EV public charging environment.

The paper leans primarily on positioning research data within the Societal Embedding Framework (SEF) (Kanger et al., 2019), being a framework commonly used in the electricity and mobility environments (Geels, 2012).

Background

Research Context

Research on EVRCI roll out has focused considering optimised locations for infrastructure based on either consumer demand or capacity in supply. Within Hong Kong, study has been predominantly on the later, analysing energy management and software techniques related to electric grid capacity (Hu et al., 2018; Song et al., 2017). However Sylvia He at the Chinese University Hong Kong has researched urban context as a determinant for deployment of infrastructure networks, with the availability and access of charging points affecting the perception of convenience towards EV take up and integration of accessibility-based policies, which compares attitudes and context in Canada and Denmark with those in Beijing and Hong Kong (S. He et al., 2022; S. Y. He et al., 2022; He et al., 2016; Renaud-Blondeau et al., 2022). Literature revue regarding the availability of charging across a number of countries found studies analysing the framework conditions for the medium- to long-term demand for charging infrastructure are rare and that the question of how much public charging infrastructure is needed cannot be answered equally for all countries (Funke et al., 2019).

Most studies have focused on the demand and supply gap in spatial and numerical terms, where poor public access to sufficient charging infrastructure has largely restricted electric vehicle (EV) market penetration. The US has adopted a laissez-faire, private sector approach, whereas the UK prioritises the public sector (Chen et al., 2020). Analysis provided by mobility consultants Lystra in 2018, commissioned by the Committee on Climate Change, aimed to identify optimal EV public charging infrastructure growth for Great Britain up to 2030. Adopting various models and scenarios, it explored factors including increased battery range, trip pattern, different charger type availability, charging speeds and time, as well as behavioural, 'range anxiety' considerations (Systra, 2018). The findings formed the basis for a 2020 Briefing Paper to the House of Commons (Hurst, 2020), whilst Hardinghaus, Löcher and Anderson used recent data from Berlin, focused on charging demand from individual users, infrastructure efficiency, and carsharing operators and their business models, in providing several policy recommendations for charging infrastructure build-out and operation (Hardinghaus et al., 2020).

Recent research has started to look at the specific issue of charging for those drivers who do not have access to private, off-street, residential charging options. The Transport Studies Unit at the University of Oxford addressed the issue of charging preferences for such car owners in the UK, with considerations such as charging costs and frequency, space availability and duration, walking distance and experience, as well as security measures affect preferences, as do existing perceptions and sociodemographic background (Budnitz et al., 2022). The UK Department of Transport undertook deliberative and quantitative research in this area, identifying that just under a quarter (24%) of households in England cannot take advantage of home charging and would require access to on-street parking in order to transition to EV ownership. The research was conducted to understand whether increased provision of specific charging options would encourage future uptake of EVs amongst this audience and in doing so was able to inform government policy. (UK. Government, 2022c).

Development and Practice

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) research benefits optimisation and risk reduction strategies to better understand and quantify future EV charging impacts using OpenDSS – a grid-modelling software for traditional and advanced distribution technologies, resources, assets, and controls (NREL, 2025). The simulations pinpoint

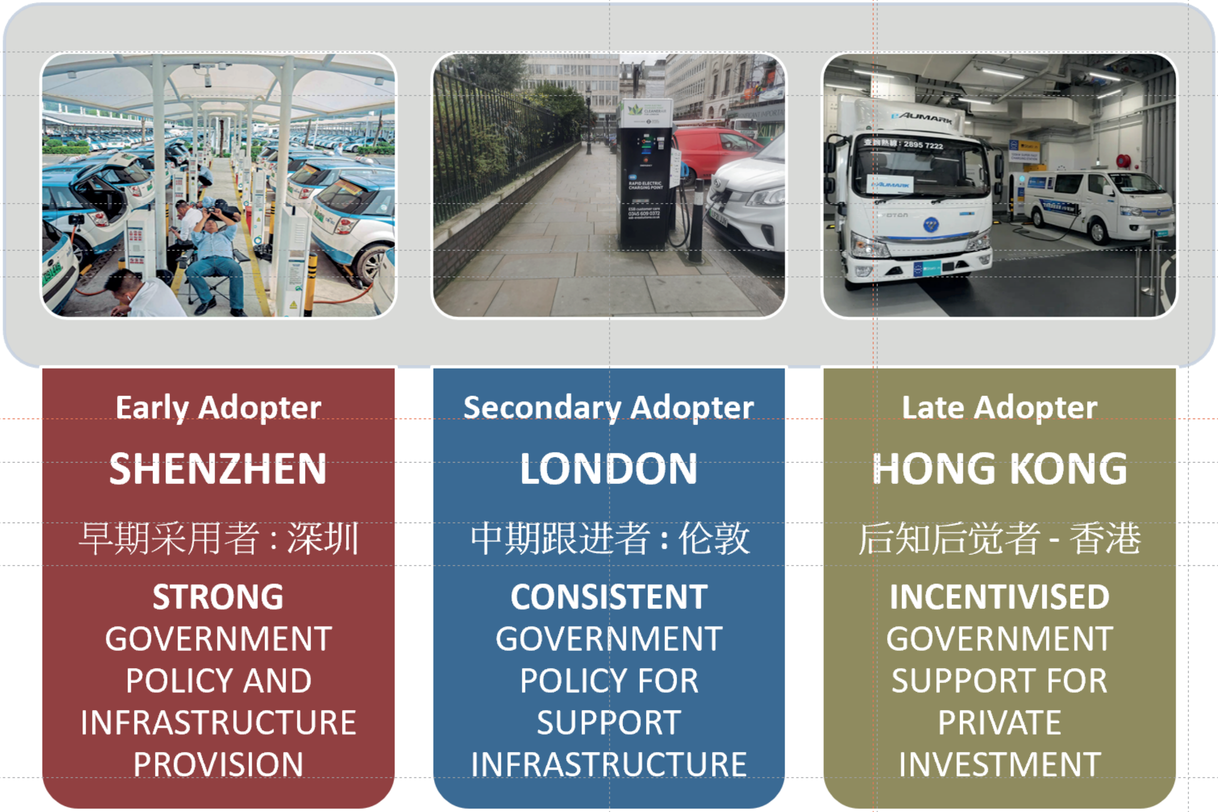

Figure 1. A Comparison of EVRCI Roll Out Adoption in Three Cities

required grid improvements to effectively serve distributed load increases. Findings are targeted at the needs of EV drivers and optimisation of electricity demand.

Meanwhile, between 2014 and 2020, the City of Berkeley, California, offered an innovative Residential Curbside Electric Vehicle Charging Pilot, the first of its type in the US, to allow residents who lack off-street parking a means of charging their EVs at home (City of Berkeley, 2017). Subsequently in 2020, Berkeley City Council adopted Berkeley's first Electric Mobility Roadmap (City of Berkeley, 2020). A case study of indirect infrastructure costs for Plug-In Electric Vehicle (PEV) integration along with ways to mitigate and manage the hidden costs transferred to customers for the Sacramento Municipal Utility District (SMUD) was evaluated as early as 2014 (Berkheimer et al., 2014). The California Public Utilities Commission develops policies to support the deployment of zero-emission vehicles

(ZEV) to achieve California's renewable energy, air quality, and climate change goals, working with utilities to provide rebates, rates, charging infrastructure, and vehicle-grid integration technologies to ZEV drivers (US. California PUC).

In early guidance, Hall and Lutsey published several UK White Papers relating to the global assessment of charging infrastructure deployment practices, challenges, and emerging best practices through The International Council on Clean Transportation (ICCT). These focused on the major EV markets and early adopters with a particular focus on quantifying the EV charging infrastructure gap the US and UK markets (Hall & Lutsey, 2017). More recently Calvillo and Turner provided insight on the wider energy system impacts of the expected EV roll-out in the UK, in terms of fuel changes, energy costs, CO2 emission reduction and network investments; and how different EV charging strategies increase or mitigate the impacts of the expected large-scale penetration of EVs (Calvillo & Turner, 2020).

In April 2022 the Office for Zero Emission Vehicles (OZEV) provided guidelines to local authorities on how to take advantage of the newly developed "On-Street Residential Chargepoint Scheme (ORCS)" (UK. Government, 2022b) and the £10 million "Local EV Infrastructure (LEVI) fund pilot (UK. Government, 2022a). Both schemes provide access to grant funding that can be used to part-fund the procurement and installation of on-street EV charging infrastructure for residential needs, in line with the minimum technical specifications thereby ensuring that on-street parking is not a barrier to realising the benefits of owning an EV.

However global charging infrastructure development has certainly been led by China to this point, where EV charging has been a matter of national policy since 2014. Over the past decade, China rapidly has grown its public fast-charging network through intensive government support strategies, realising significant economies-of-scale to dramatically lower the cost of purchasing and installing public fast-charging stations whilst keeping fast-charging prices relatively affordable. Whereas the UK and Hong Kong have primarily used direct purchase grants and tax breaks for consumers, Shenzhen has further focused intensely on electrifying public transport fleets (Fig. 2). Development of China's electric vehicle charging infrastructure is reported annually by the National Energy Administration utilising data from the Electric Vehicle Charging Infrastructure Promotion Alliance (CN. CIPA, 2020). Its deployment programme up to 2020 was addressed thoroughly by Ji and Huang with regards to policies, methodologies, and challenges (Ji & Huang, 2018). The nation's EV charging deployment is defined by a massive existing network that continues to grow rapidly and a new, ambitious three-year government plan for further expansion. By late 2025, the country was already the undisputed global leader in EV charging infrastructure with 4.625 million public charging facilities, an increase of 36.0% over the previous year (Liu, 2025). Government support remains strong and almost every second charging point in China is now DC (46%) (Zheng, 2025).

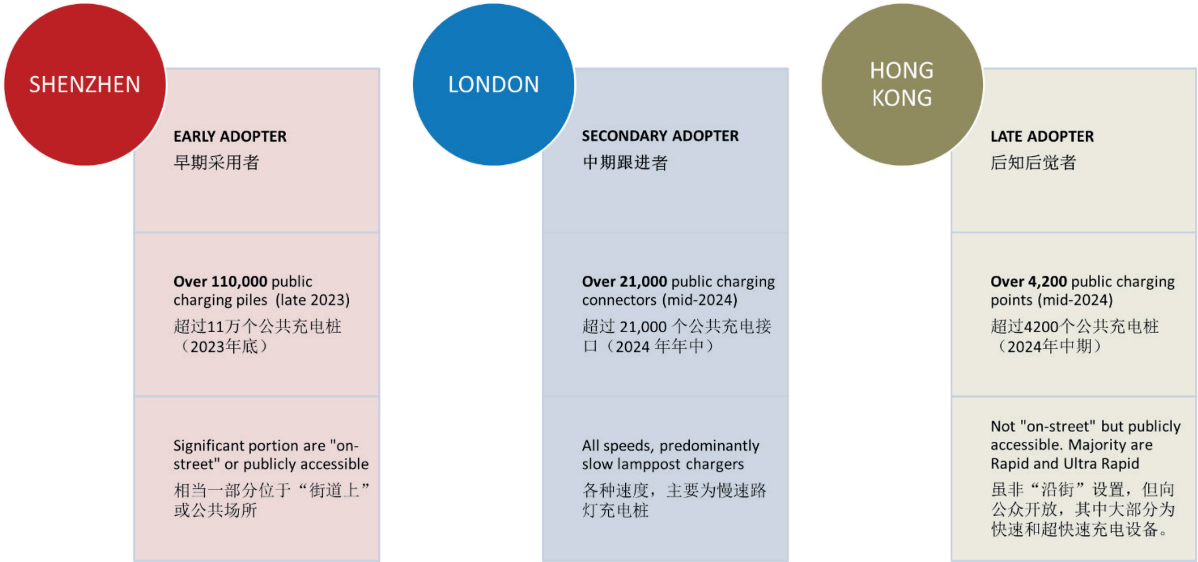

Figure 2. Extent and types of plug-in charging infrastructure in Shenzhen, London and Hong Kong

As was initially suggested, it can be seen that research and policy have been predominantly approached from the duel standpoints of both user demand and availability to access or from the limitations on electric supply and quality of provision. Little or no evidence supports research or consideration being given to implications on the public realm, including stakeholders who do not own a vehicle or do not need to directly utilise public charging facilities, or the wider public who may be affected adversely by such investment, installation, and impacts, many of which have yet to be identified or considered. Furthermore, extensive, public space facilities may need to be provided in support of public transport, e-bikes and micromobility vehicles, and private commercial fleets, all of which require alternative charging infrastructure to that of cars and light vehicles.

Theoretical Background

With all innovating technologies and the associated market disruption, it quite follows that there is scarce little research already published about that sector at the time of emergence. In the case of EV technology, as we have seen, this holds true (Kanger et al., 2019; Köhler et al., 2019), whereby little has been published before 2018. What does exist is an extensive range of work in the study of socio-technical (ST) systems and how they transform. Technologies can be said to operate through user contexts, which are shared within an operational environment, both physical and regulatory. In these environments user demand and technical supply form an interrelated ST-system. Transitions of an existing system through a newly emerging technology can witness system innovations, which manifest can witness system innovations, which manifest themselves through four different forms of innovation typology according to Abernathy and Clark – 'architectural', 'niche', 'incremental', and 'revolutionary' (Abernathy & Clark, 1985). This has formed the starting point for ongoing and divergent study by researchers since, and consistent among them is that innovations are a multi-actor process with a range of stakeholders (Elzen et al., 2004). Morton, Anable and Brand initially looked at policy making in relation to EV demand through a framework of uncertainty (Morton et al., 2014), identifying six parameters including 'consumers', 'policy', 'infrastructure', 'technical', 'economic', and 'social uncertainties'. This was based on Meijer's work on developing a framework for ST-transformations (Meijer et al., 2006). ST-transition theories remain at the heart of multiple studies by Arie Rip (Deuten et al., 1997) , Rene Kemp (Kemp et al., 2001), Johan Schot, (Geels & Schot, 2007), Frank Geels (Elzen et al., 2004) and their colleagues researching in the Netherlands in the last two decades, looking at transitions and pathways in systems innovation.

Whilst ST-systems do not generally appear to consider the public at large as being a key stakeholder in the user-demand, supplier-technology paradigm, it can be found that 'transition frameworks' do tend to describe the multiple actors involved in the societal embedding of new technology. This goes beyond the demand and supply side participants and involves changes in the structure of a society, which addresses a wider audience dependent upon the context and across varying timeframes.

Societal Embedding Framework (SEF)

Work in sustainability transitions has increased rapidly over the last decade, with sub-themes being explored and bridges emerging across differing socio, political, economic and technical disciplines which are able to build on and continue to validate the core concepts and frameworks (Köhler et al., 2019). One particular aspect has been the concept of technological diffusion within the wider environment and the process of a societal embedding framework (SEF), which explores previously underdeveloped areas of study. Kanger highlights deficiencies in the favoured Multi Level Perspective (MLP) framework in terms of lack of exploration of the entirety of the ST-system in which technologies function, being particularly limited to the 'micro' and 'meso' environments since technology adoption tends to focus on the main actors. He attempts to look into wider 'macro' domains through a Societal Embedding Perspective (Kanger et al., 2019).

Introduced by Deuten in 1997, SEF initially introduced three environments: - 'business'; 'policy'; and 'culture' (Deuten et al., 1997) but has been refined by others with the addition of a 'user' environment (Mylan et al., 2019) and 'transnational' environment (Kanger et al., 2019) to consider technological diffusion in five embedding environments (Fig. 3). Kanger also proposes that transitions occur in a series of three phases – 'emergence', 'acceleration' and 'stabilisation' (Kanger et al., 2019), whist others have added 'decline' (Schot, 1992), 'stagnation' (Sovacool et al., 2018) and 'destabilisation'

(Turnheim & Geels, 2012) as possible phases during embedding.

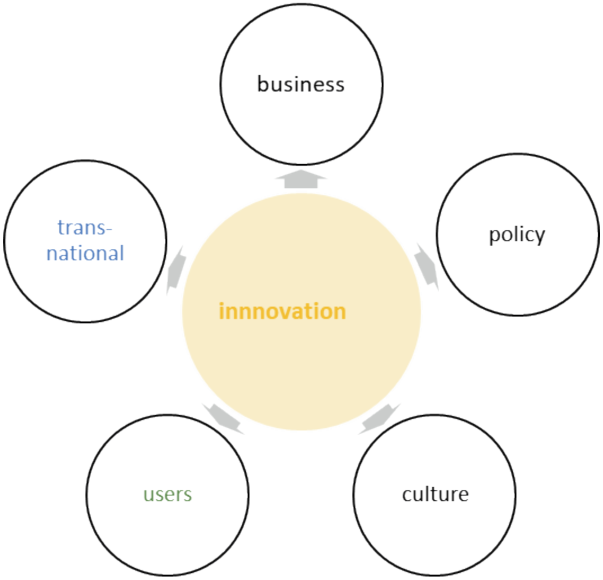

Figure 3. Relevant environments for innovations (adapted from Deuten et al., 1997: 134).

Objectives and Methodology

The paper considers the current situation of ST-transitions in the EVRCI scenario, highlighting latest developments against the backdrop of initial findings of a small scale research study into the potential impacts of EVRCI roll out. The objectives of the study were to pilot the sampling and synthesis techniques for a larger, ongoing study, highlighting potential gaps in reasoning, conflicting data and thematic attribution. This paper provides an outline of the collected preliminary research data whilst further aiming to clarify relevance to the outlined theoretical frameworks, in particular data is configured according to the five "environments" outlined in the SEF.

Qualitative data was collected anonymously from 16 "expert" participants, through online questionnaire. The experts were selected from countries across four different regions: - Asia, Oceania, North America, and Europe and were made up from expertise in eight related areas including Environment, Design, Finance, Management, Planning, Policy, Society, and Technical. Participants were provided with six open questions, relating to Investment Risk, Societal Risk, Governmental Policy, Potential Conflicts, Design Requirements and Technical Requirements and their responses coded and analysed through an inductive approach to thematic analysis based on Braun & Clarke's Six-phase Framework (Braun & Clarke, 2013).

Findings

Participants qualitative data was coded through a number of iterations and themed into the five environments related in structure to those of the SEF being: - "Civic / Culture"; "Business/ Market"; "Policy / Regulation"; "Global / Transnational"; and "User / Access. A total of 24 Themes were developed as outlined in Table 1 below and expanded upon in the subsequent text.

Theme Name	Description of Theme	# of PARTICIPANTS Responding	# of REFERENCES Provided
BUSINESS / MARKET		**16**	**83**
B1 Delivery Best Practice	Contributions on how to roll out infrastructure to address various issues	6	11
B2 Financial Positioning	Business case for investments within economic environments	8	11
B3 Investment Risk	Are such investments necessary or too risky?	10	20
B4 Planning Against Obsolescence	Futureproofing concerns for civic investment and rollout (also potentially business risk)	12	31
B5 Time Manifestation	What aspects can be envisaged to become problematic in the future?	7	10
CIVIC / CULTURE		**16**	**157**
C1 Competition for Limited Urban Space	Is sufficient space available for charging functions, especially in dense urban cities	11	15
C 2 Design & Appearance	What should infrastructure look like and how should it be integrated visually	15	32
C3 Environmental Impacts	Outline of environmental pollutants	5	7
C4 Equity & Accessibility	Implications when public space is utilised for undertaking the charging of private vehicles.	10	26

Table 1. REnvironments and Themes highlighting potential impacts in EVRCI.

Theme Name	Description of Theme	# of PARTICIPANTS Responding	# of REFERENCES Provided
CIVIC / CULTURE		**16**	**157**
C5 Integration & Adaptation	Integrating infrastructure with multiple functions and flexible approaches	11	25
C6 Positioning & Safety	Considerations and Implications for localised spatial positioning	15	39
C7 Societal Health Risk	Are there unaddressed health aspects to wider society to be considered?	9	13
POLICY / REGULATION		**16**	**103**
R1 Conflicting Policies & Directions	Wider policies, laws and standards may conflict with EV transition	14	24
R2 Considered Strategies & Approaches	Approaches to developing and regulating the transition	16	42
R3 Enablers to Transition	Use of incentive and disincentive schemes	11	16
R4 Standards & Guidelines	Establishing technical and industry standards as a tool to consolidate approaches and accelerate change	6	9
R5 Structural & Contextual Factors	Localised or embedded structures that dictate responses	8	12

Table 1. REnvironments and Themes highlighting potential impacts in EVRCI.

Theme Name		Description of Theme	# of PARTICIPANTS Responding	# of REFERENCES Provided
GLOBAL / TRANSNATIONAL			**16**	**41**
T1	Degree of Importance	Respondents stress the importance or unimportance of this factor in the societal embedding issues	6	7
T2	Drive to Decarbonisation	Alignment with the larger decarbonisation policy environment	11	16
T3	Political Factors	Macro level influences to embedding outside of the area of technical change	6	8
T4	Supply Chain Factors	International supply chains influence on the technology transition	5	10
USERS / ACCESS			**13**	**48**
U1	Distribution & Access	Considerations for users in the city wide deployment of infrastructure and implications for transition.	8	22
U2	Equipment Safety & Security	Technical issues relating to the installation of infrastructure	9	20
U3	User Conflict & Personal Safety	Potentially problematic human elements related to users of infrastructure	5	6

Table 1. REnvironments and Themes highlighting potential impacts in EVRCI.

In summarising the findings of Experts responses, the building of a future-ready EV charging network requires harmonising the technical, economic, urban, regulatory, and human factors set out in Table 2 below. The nature of ST transitions is the continual flux and interaction between these environments.

Environment	Core Focus	Key Challenges	Strategic Priorities
Business / Market	Financial viability & operational safety	High upfront costs, variable usage, maintenance risks, tech obsolescence	Safety-by-design, phased investment, modular systems, public-private partnerships
Civic / Culture	Urban integration & social equity	Space competition, visual clutter, accessibility, community disruption	Compact, multifunctional design; equity-focused siting; community engagement
Policy / Regulatory	Policy alignment & governance	Conflicting goals (e.g., EVs vs. public transit), lack of standards, slow adoption without mandates	Integrated transport policy, clear standards, incentives for shared/active mobility
Global / Transnational	Geopolitical & supply-chain dynamics	Battery mineral dependency, uneven global progress, geopolitical risks	Supply-chain diversification, international standards, aligning local rollout with global climate goals
Users / Access	Equity, safety & user experience	“Charging deserts,” reliability issues, physical/digital safety hazards	Equitable siting, robust safety protocols, reliable hardware, inclusive access

Table 2. Integrated Summary of EVRCI Responses.

Further Discussion

Theoretical frameworks suggest that ST-transitions, such as that being evidenced in the current societal embedding of EV's, are complex, contextual and unpredictable; being multi-faceted rather than simply binary supply and demand scenarios. Systems thinking is essential in the provision of EV infrastructure, a charging point is not just a piece of hardware; it is a nexus of technology, urban space, policy, and human behaviour. Effective strategies must treat it as such—promoting interoperable standards, flexible designs, equitable access, and policies that incentivise shared and active mobility alongside electrification. The small sector study bears this out, with respondents highlighting issues within five positioned environments of the SEF. Interestingly, the Civic/Cultural domain elicited the largest number of responses and concerns (Fig. 4), yet this is the area where the least amount of both research is being un-

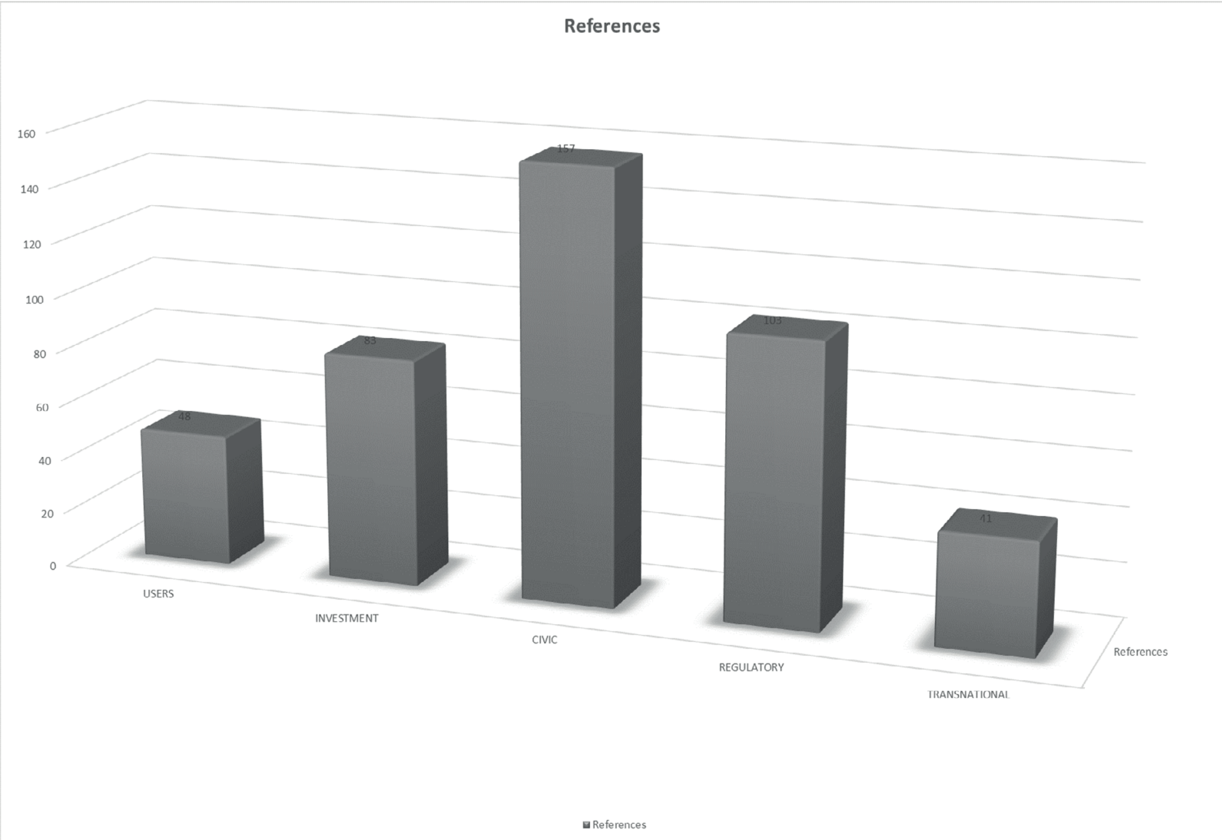

Figure 4. Expert Respondence by quantity within five environments of a Societal Embedding Framework

dertaken and influence is being exerted in roll-out. Experts were able to suggest multiple societal approaches focused on mobility integrated roll-out programmes. Responses particularly addressed selective site positioning, emphasising the importance of the EV transition as part of wider decarbonisation approaches together with co-ordinated transport strategies that promote public transport at the heart of policy. In dense urban environments, mobility solutions such as cycling and walking should be prioritised above facilities for car use and space not compromised for EV charging infrastructure or safety implications. Public funding should support foundational civic enablers and share the risk with private sector, ensuring design is considered, context-sensitive and aesthetically integrated. The key areas of concern highlighted are in terms of positioning, appearance, and obsolescence (Fig.5), yet these are not themes yet

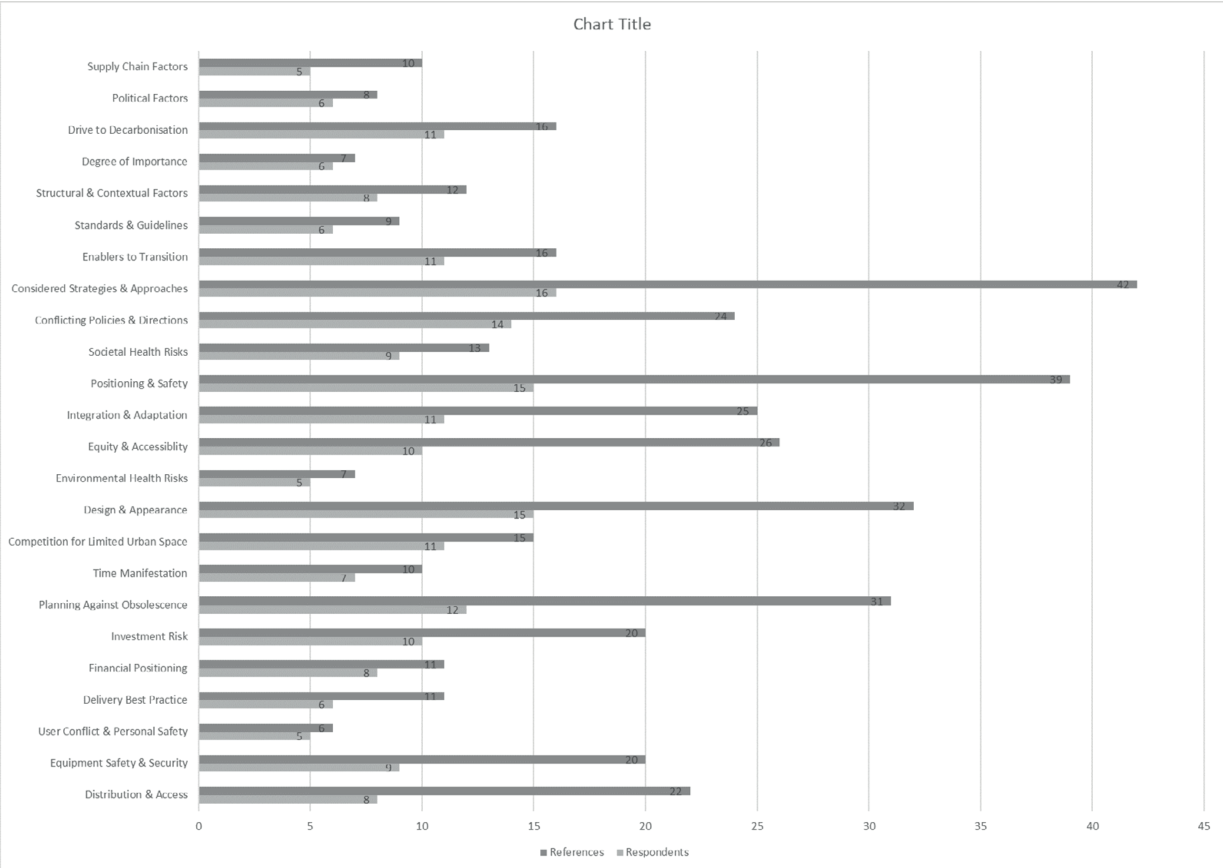

Figure 5. Quantity of Expert Responses by Theme

being generally well evidenced globally, where the physical design of infrastructure is still supply and demand functional and the appearance not considered in terms of its modularity, flexibility, and interoperability.

Follow-up Research

Further studies, to deeper consider the diffusion of innovation in the EV charging environment beyond the normal business case, which is typically focused on policy and economics alone, is necessary and may substantiate that Macro level impacts of new innovation are typically only perceived and accounted following mainstreaming. Piloting research often fails to adequately address diffusion at this level, being unable to react at the necessary depth and speed.

Following further data collection, the researcher plans to develop a Contextual Impact Model (CIM) for evaluating the significance of environmental and social impacts of EVRCI roll-out. Such an impact assessment methodology may then be adopted at the formative phase of innovation diffusion in order to illustrate the interdependencies of levels in the MLP and SEF and to explore the possible changes in ST transition scenarios that might occur. The CIM can be retrospectively applied to a wide variety of existing EVRCI situations, including those in London, Shenzhen and Hong Kong.

References

[1] Abernathy, W. J., & Clark, K. B. (1985). Innovation: Mapping the winds of creative destruction. Research Policy, 14(1), 3-22. https://doi.org/https://doi.org/10.1016/0048-7333(85)90021-6

[2] Berkheimer, J., Tang, J., Boyce, B., & Aswani, D. J. (2014). Electric Grid Integration Costs for Plug-In Electric Vehicles. SAE International Journal of Alternative Powertrains, 3(1), 1-11. https://doi.org/https://doi.org/10.4271/2014-01-0344

[3] Braun, V., & Clarke, V. (2013). Successful qualitative research: A practical guide for beginners.

[4] Budnitz, H., Meelen, T., & Schwanen, T. (2022). Residential Neighbourhood Charging of Electric Vehicles: an exploration of user preferences. https://EconPapers.repec.org/RePEc:osf:socarx:fsv7n

[5] Calvillo, C. F., & Turner, K. (2020). Analysing the impacts of a large-scale EV rollout in the UK – How can we better inform environmental and climate policy? Energy Strategy Reviews, 30, 100497. https://doi.org/https://doi.org/10.1016/j.esr.2020.100497

[6] Chen, T., Zhang, X. P., Wang, J., Li, J., Wu, C., Hu, M., & Bian, H. (2020). A Review on Electric Vehicle Charging Infrastructure Development in the UK. Journal of Modern Power Systems and Clean Energy, 8(2), 193-205. https://doi.org/10.35833/MPCE.2018.000374

[7] City of Berkeley. (2017). Residential Curbside Electric Vehicle Charging Pilot. . www.cityofberkeley.info/EVcurbside/.

[8] City of Berkeley. (2020). Berkeley Electric Vehicle Roadmap https://www.cityofberkeley.info/uploadedFiles/Planning_and_Development/Level_3_-_Energy_and_Sustainable_Development/City%20of%20Berkeley%20Electric%20Mobility%20Roadmap_2020.pdf

[9] CN. CIPA. (2020). China Charging Infrastructure Development Report. http://en.caam.org.cn/Uploads/File/2020-09-10/5f59ce29d1d17.pdf

[10] Deuten, J. J., Rip, A., & Jelsma, J. (1997). Societal embedding and product creation management. Technology Analysis and Strategic Management, 9(2), 131-148. https://doi.org/10.1080/09537329708524275

[11] Elzen, B., Geels, F. W., & Green, K. (2004). System innovation and the transition to sustainability : theory, evidence and policy. Edward Elgar Pub.

[12] Funke, S. Á., Sprei, F., Gnann, T., & Plötz, P. (2019). How much charging infrastructure do electric vehicles need? A review of the evidence and international comparison. Transportation Research Part D: Transport and Environment, 77, 224-242. https://doi.org/https://doi.org/10.1016/j.trd.2019.10.024

[13] Geels, F. W. (2012). A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. Journal of Transport Geography, 24, 471-482. https://doi.org/https://doi.org/10.1016/j.jtran-

geo.2012.01.021

[14] Geels, F. W., & Penna, C. C. R. (2015). Societal problems and industry reorientation: Elaborating the Dialectic Issue LifeCycle (DILC) model and a case study of car safety in the USA (1900–1995). Research Policy, 44(1), 67-82. https://doi.org/https://doi.org/10.1016/j.respol.2014.09.006

[15] Geels, F. W., Sareen, S., Hook, A., & Sovacool, B. K. (2021). Navigating implementation dilemmas in technology-forcing policies: A comparative analysis of accelerated smart meter diffusion in the Netherlands, UK, Norway, and Portugal (2000-2019). Research Policy, 50(7), 104272. https://doi.org/10.1016/j.respol.2021.104272

[16] Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. Research Policy, 36(3), 399-417.

[17] Gerard, D., & Lave, L. (2007). Experiments in technology forcing: comparing the regulatory processes of US automobile safety and emissions regulations. International Journal of Technology, Policy and Management, 7(1), 1-14. https://doi.org/10.1504/ijtpm.2007.012236

[18] Hall, D., & Lutsey, N. (2017). Emerging best practices for electric vehicle charging infrastructure. https://theicct.org/sites/default/files/publications/EV-charging-best-practices_ICCT-white-paper_04102017_vF.pdf

[19] Hardinghaus, M., Löcher, M., & Anderson, J. E. (2020). Real-world insights on public charging demand and infrastructure use from electric vehicles. Environmental Research Letters, 15(10), 104030. https://iopscience.iop.org/article/10.1088/1748-9326/aba716

[20] He, S., Luo, S., & Sun, K. K. (2022). Factors affecting electric vehicle adoption intention: The impact of objective, perceived, and prospective charger accessibility. Journal of Transport and Land Use, 15(1), 779-801. https://doi.org/10.5198/jtlu.2022.2113

[21] He, S. Y., Kuo, Y.-H., & Sun, K. K. (2022). The spatial planning of public electric vehicle charging infrastructure in a high-density city using a contextualised location-allocation model. Transportation Research Part A: Policy and Practice, 160, 21-44. https://doi.org/https://doi.org/10.1016/j.tra.2022.02.012

[22] He, S. Y., Kuo, Y.-H., & Wu, D. (2016). Incorporating institutional and spatial factors in the selection of the optimal locations of public electric vehicle charging facilities: A case study of Beijing, China. Transportation Research Part C: Emerging Technologies, 67, 131-148.

[23] Hu, X., Wang, K., Liu, X., Sun, Y., Li, P., & Guo, S. (2018). Energy Management for EV Charging in Software-Defined Green Vehicle-to-Grid Network. IEEE Communications Magazine, 56(5), 156-163. https://doi.org/10.1109/MCOM.2018.1700858

[24] Hurst, D. (2020). Electric vehicles and infrastructure. https://researchbriefings.files.parliament.uk/documents/CBP-7480/CBP-7480.pdf

[25] Ji, Z., & Huang, X. (2018). Plug-in electric vehicle charging infrastructure deployment of China towards 2020: Policies, methodologies, and challenges. Renewable and Sustainable Energy Reviews, 90, 710-727. https://doi.org/https://doi.org/10.1016/j.rser.2018.04.011

[26] Kanger, L., Geels, F. W., Sovacool, B., & Schot, J. (2019). Technological diffusion as a process of societal embedding: Lessons from historical automobile transitions for future electric mobility. Transportation Research Part D: Transport and Environment, 71, 47-66. https://doi.org/https://doi.org/10.1016/j.trd.2018.11.012

[27] Kemp, R., Rip, A., & Schot, J. (2001). Constructing Transition Paths Through the Management of Niches. In (pp. 283-313). Psychology Press. https://doi.org/10.4324/9781410600370-19

[28] Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M. S., . . . Wells, P. (2019). An agenda for sustainability transitions research: State of the art and future directions. Environmental Innovation and Societal Transitions, 31, 1-32. https://doi.org/10.1016/j.eist.2019.01.004

[29] Liu, L. (2025). National Energy Administration: as of the end of November 2025, the total number of electric vehicle charging infrastructure (gun) in China reached 19.32 million, an increase of 52.0% year-on-year Shenzhen Securities Times Co., Ltd. Retrieved 23 December from https://www.stcn.com/article/detail/3553098.html

[30] Meijer, I. S. M., Hekkert, M. P., Faber, J., & Smits, R. E. H. M. (2006). Perceived uncertainties regarding socio-technological transformations: towards a framework. International Journal of Foresight and Innovation Policy, 2(2), 214-240. https://doi.org/10.1504/ijfip.2006.009316

[31] Morton, C., Anable, J., & Brand, C. (2014). Policy making under uncertainty in electric vehicle demand. Proceedings of the Institution of Civil Engineers - Energy, 167(3), 125-138. https://doi.org/10.1680/ener.14.00006

[32] Mylan, J., Morris, C., Beech, E., & Geels, F. W. (2019). Rage against the regime: Niche-regime interactions in the societal embedding of plant-based milk. Environmental Innovation and Societal Transitions, 31, 233-247. https://doi.org/https://doi.org/10.1016/j.eist.2018.11.001

[33] Renaud-Blondeau, P., Boisjoly, G., Dagdougui, H., & He, S. Y. (2022). Powering the transition: Public charging stations and electric vehicle adoption in Montreal, Canada. International Journal of Sustainable Transportation, 1-16. https://doi.org/10.1080/15568318.2022.2152403

[34] Schot, J. (1992). Technology in decline - a search for useful concepts - the case of the dutch madder industry in the 19th-century. The British journal for the history of science, 25(84), 5-26.

[35] Song, Y., Zheng, Y., & Hill, D. J. (2017).

Optimal Scheduling for EV Charging Stations in Distribution Networks: A Convexified Model. IEEE Transactions on Power Systems, 32(2), 1574-1575. https://doi.org/10.1109/TPWRS.2016.2568746

[36] Sovacool, B. K., Lovell, K., & Ting, M. B. (2018). Reconfiguration, Contestation, and Decline:Conceptualizing Mature Large Technical Systems. Science, Technology, & Human Values, 43(6), 1066-1097. https://doi.org/10.1177/0162243918768074

[37] Systra. (2018). Plugging the Gap : An Assessment of Future Demand for Britain's Electric Vehicle Public Charging Network. https://www.theccc.org.uk/publication/plugging-gap-assessment-future-demand-britains-electric-vehicle-public-charging-network/

[38] Turnheim, B., & Geels, F. W. (2012). Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997). Energy Policy, 50, 35-49. https://doi.org/10.1016/j.enpol.2012.04.060

[39] UK. Government. (2022a, 5 April). Apply for local electric vehicle infrastructure (LEVI) pilot funding https://www.gov.uk/guidance/apply-for-local-electric-vehicle-infrastructure-levi-pilot-funding

[40] UK. Government. (2022b, 5 April). On-Street Residential Chargepoint Scheme guidance for local authorities https://www.gov.uk/government/publications/grants-for-local-authorities-to-provide-residential-on-street-chargepoints/grants-to-provide-residential-on-street-charge-points-for-plug-in-electric-vehicles-guidance-for-local-authorities

[41] UK. Government. (2022c). Public Electric Vehicle Charging Infrastructure

[42] Deliberative and quantitative research with drivers without access to off-street parking. Department of Transport. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1061865/public-ev-charging-infrastructure-research-report.pdf

[43] US. California PUC. Zero-Emission Vehicles. State of California. Retrieved April 23 from https://www.cpuc.ca.gov/zev/#Infrastructure

[44] US. NRDC. (2020). Scaling Up Electric Vehicle Charging Infrastructure: Lessons from China and the United States for the Indian Context. https://www.nrdc.org/sites/default/files/charging-infrastructure-best-parctices-202007.pdf

[45] Zheng, R. Z., Jack. (2025). China tops our Index as it continues to enhance its impressive e-mobility ecosystem. EV Charging Index 2025. https://www.rolandberger.com/en/Insights/Publications/EV-Charging-Index-2025-Expert-insights-from-China.html