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A transition to battery electric vehicles without V2G: an outcome explained by a strong electricity regime and a weak automobility regime?

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Abstract

Background A sustainability transition in mobility is dependent on a transition away from a fossil fuel-based automobility regime. Smart charging, in the form of vehicle-to-grid (V2G) has been presented as one—or even the—key technology in facilitating a sustainability transition in the automobility regime. With the large global increase in battery electric vehicles (BEVs) combined with a rapid increase in the production of wind and solar energy, V2G may indeed become a key technology to enable the balancing of electricity grids worldwide. Thus far, however, the large-scale introduction of BEVs in Norway has been implemented without the use of commercial V2G systems; indeed, it has only recently been implemented in commercial smart charging stations, and then only in the less-radical form of grid-to-vehicle (G2V) systems. The Norwegian experience is contrary to expectations in the sustainability transitions literature and, therefore, merits further investigation. This article details how and why this outcome unfolded and considers the relative strength of the automobility and electricity regimes as a possible explanation. Specifically, it asks: can the absence of commercial V2G charging in Norway be explained by the structure of the existing regimes? And, if so, is this generalisable?

Results To answer the research question, the study employed an exploratory two-stage case study approach, drawing on 36 expert interviews. The first stage included 27 interviews with key actors, including stakeholder organisations. These were followed by nine in-depth interviews with key actors in smart charging. The interviews were analysed using a multi-level perspective (MLP) framework. The study finds that the relative strength of the involved regimes influences how the challenge is framed and which solutions are presented. Cases in point: regime actors use smart charging (G2V) as an add-on to their existing services, while start-ups without the same ties to the established regime present and promote solutions that conflict with the existing regime.

Conclusions This article finds that the solutions presented by regime actors have thus far been more commercially successful, compared with solutions presented by start-ups. This finding is in line with previous research that suggests that actors with strong ties to the existing regime present less-radical solutions with lower transformational potential, while niche actors without these ties present more-radical solutions. Still, the absence of V2G and the relative low market penetration of other advanced smart charging solutions have not prevented the introduction of BEVs from reaching the acceleration phase. This means that V2G is not necessary for large-scale BEV introduction, in all

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cases. By extension, this suggests that V2G mainly addresses issues with the electrical grid, highlighted by BEVs. BEVs may be successfully introduced at scale, where the pre-existing grid is well-developed, with sufficient balancing capacity. If this precondition is not met, the transition to BEVs may be contingent on smart charging or costly grid extensions. This can be the case at specific locations in Norway, but it may be more prevalent in other locations.

Background

Introduction

The major sustainability transition in mobility is arguably a transition away from private cars driven by internal combustion engines (ICE) [1] and the emergence of battery–electric vehicles (BEVs). Research shows that such a transition is possible through both reconfiguration and technological substitution pathways [2][1]

Smart charging is an emerging technology associated with the reconfiguration and technological substitution pathways. It facilitates the replacement of ICE vehicles with BEVs. There are three main types of smart charging: unidirectional grid-to-vehicle (G2V), bidirectional vehicle-to-grid (V2G) and bidirectional vehicle-to-other applications (V2X). The latter two have generated the most interest in the literature on charging. Although a recurring issue in V2G literature, there is minimal literature on the societal context and uptake of the technology [3]. Studies suggest that V2G smart charging may be the tipping point for the adoption of BEVs, based on survey data, modelling and theoretical reasoning [4–6]. Nevertheless, in Norway, where more than 71.9% of new private vehicles in the summer of 2021 were BEVs [7], V2G still has no commercial presence.

This raises the following research questions: *can the absence of commercial V2G charging in Norway be explained by the structure of the existing regimes?* If so, are these dependent on context-specific factors, or is this a generalisable observation?

This article addresses these questions using a multi-level perspective (MLP) framework to analyse how a niche technology—smart charging—is used in the context of an ongoing sustainability transition in mobility. This relates to the call in the broader transitions literature [8] for research on the role of businesses and industries in sustainability transitions and mechanisms operating at the firm level associated with technological change. Thus far, studies have largely been conducted using historical cases, with only a few studies focusing on the future and upscaling potential of niche innovations [9].

This article reports on study findings demonstrating how smart charging is used differently by established industry actors and start-ups. The study finds that the way in which the challenges and market opportunities are perceived is linked to a company's background. Nevertheless, the overall transformative performance of the technology is likely to depend on the relative strength of the involved regimes: in this case, Norwegian energy and automobility regimes. However, the study also shows that the physical and geographical context is difficult to separate from the institutional and cultural components of the regime.

Smart charging is a solution to the barrier to the introduction of BEVs presented by local capacity limitations in the electrical grid. In addition, smart charging has a range of other potential applications relating to the more efficient utilisation of the electrical grid and introduction of the flexible capacity offered by BEVs to the balancing markets [10]. Consumer-level benefits include a fire-safety aspect, smart homes, potential economic benefits and pre-heating in winter [11].

Though the potential of smart charging has long been acknowledged [12, 13], smart charging only emerged as a commercial technology in the Norwegian market in 2017—and only in unidirectional G2V, its least radical form. In other words, the rapid growth in BEVs in Norway clearly shows that the absence of smart charging and V2G solutions has not been a major barrier to electrification. This contrasts with claims by de Hoog et al. [14] and Chen et al. [4], who suggests that V2G is a precondition for the up-scaling of BEV use.

The article is structured as follows: the remainder of this section presents the Norwegian case; section "Methods" details the study's research design; the results and analysis are reported in section "Results"; and a discussion of the study's findings comprises section "Discussion", followed by a conclusion in section "Conclusion".

Empirical context

Norway was an early adopter of BEVs and has the highest proportion of BEVs in the world [15]. This was through the use of a number of strong supporting incentives [16–18]. Most of these incentives were introduced in the early 1990s, with the primary aim of supporting domestic industries [19]. In the early stages, there was a limited production industry in Norway focusing on BEVs.

[1] A transition along a dealignment and realignment pathway is also possible, but this requires major changes in culture and behaviour; it also requires more changes to the regime and is further away from realisation [2].

The main actors were the Think and Kewet, which later traded as Buddy. Both of these companies were small independent vehicle manufacturers. Think produced a series of small cars between 1995 and 2011, with a total production of approximately 2500 units. Buddy produced BEVs in Norway between 1998 and 2013, having failed to launch its cars in Denmark and Germany; its total production was approximately 1500 units [20]. Domestic BEV production stopped when the first major global car manufacturer launched BEVs on the Norwegian market in 2012–2013.

When the policy measures supporting BEVs were initiated in the 1990s [19], climate change mitigation was largely absent from the discourse surrounding BEVs. This has gained importance in policy legitimation, but the policy measures remain largely unchanged. Today, support for zero-emission vehicles is generally rooted in a climate-change mitigation narrative.

Norway's promotion of BEVs as a sustainability transition policy must be understood within a context in which the private car is the main mode of mobility, in terms of number of trips and number of passenger kilometres [21, 22]. At the same time, greenhouse gas (GHG) emissions from fossil fuel-burning private cars comprise nine per cent of national GHG emissions. In total, road traffic contributes 17.5% [23]. Norway's electricity consumption per capita is the second highest in Europe, behind Iceland, and 3.7 times higher than in Germany [24]. Furthermore, the main electrical grid is well-developed. In Norway, electricity is mainly produced from renewable sources, predominantly in the form of hydropower (93% of the total) [25].

In Norway, the electrification of the private vehicle fleet has more GHG-emission reduction impact and lower associated costs, compared to other European countries. As BEVs are being introduced large-scale early on, Norway is likely to experience the challenges associated with this transition before other countries. These include challenges around integrating mobility and energy systems, where smart charging is seen as a key technology. The challenges surrounding the electrification of the vehicle fleet may well turn out to be smaller in Norway, due to particularities of the case, but they are likely to emerge at an earlier point in time.

Methods

Theory: conceptualising smart charging in a mobility transition

The relation between the development of smart charging as a technology and a sustainability transition in mobility is complex. To conceptualise how the interplay unfolds, this article uses an MLP framework [26–28]. This framework is useful, as it combines concepts, such as the development of 'niches' with dynamic stability through the institutional and stabilising elements of 'the regime', and the influence of a broader context through 'the landscape' level.

Within an MLP framework, transitions are typically understood as regime changes. These can result from developments at the niche, regime or landscape level, or a combination thereof. The relative strength of the actors and importance of events at the different levels help determine how transitions unfold and which 'pathway' the transition follows [29]. In this context, 'pathways' refer to specific sequences of events, as defined by Geels and Schot [29]. Of particular relevance is the *transformation pathway,* where there is moderate pressure at the landscape level, but no obvious alternative technology ready; the *de-alignment and re-alignment pathway*, where there are large and sudden landscape changes and no obvious niche alternatives; and the *technological substitution pathway*, where there is landscape-level pressure in combination with available alternative technologies. In the MLP, actors at the regime and niche levels make choices influenced by the context and a series of regulatory and normative rules provided by the landscape, which works as an exogenous context.

The MLP can be combined with the 's-curve' associated with the process of socio-technological transformation [30] and the stages of development [31]. The s-curve is created by tracing the technologies that were successful in reaching the regime level back to their niche origins. As highlighted in the MLP literature [32], this creates a positive bias (Fig. 1).

In the context of the introduction of BEVs in Norway, the pre-development phase (i.e., Phase 1) can be regarded as the period before 2013. Phase 2, the 'take-off' phase, commenced in 2013, when global car manufacturers began offering BEVs to the Norwegian market, including a design and battery capacity that enabled the vehicles to function as ordinary cars. Phase 3, the acceleration phase, arguably started in 2017, when BEVs accounted for five per cent of the private vehicle fleet [34]. During this phase, friction relating to the scale of BEV adoption was increasingly recognised. That these frictions were not present in earlier phases is likely a result of favourable conditions in the Norwegian energy system compared to other European contexts: heating in Norway was largely electrified, which necessitated the development of a strong transmission grid and large-capacity hydropower plants.

Skotland et al. [35] find that even the large-scale introduction of BEVs will have a modest impact on the Norwegian electricity supply, suggesting that 1.5 million BEVs would result in a 3% increase in electricity consumption. Uncoordinated charging, however, may

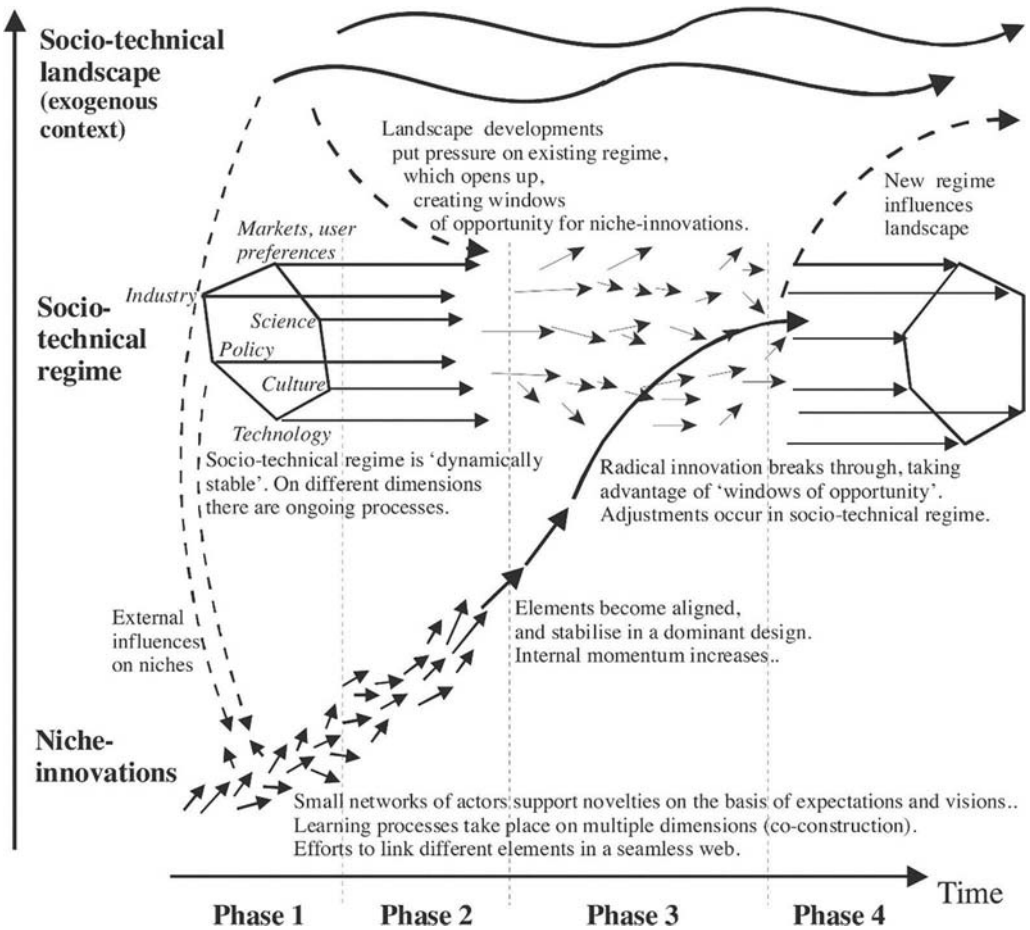

Fig. 1 Multi-level perspective—combined with the stages of development adapted from Geels [33]

present significant challenges locally [14, 36], highlighting smart charging as a potential solution.

The acceleration phase is characterised by increasing shares of BEVs as both the proportion of new vehicles and total proportion of the private vehicle fleet. A full transition to a new stabilised situation has yet to occur. Key policy documents—such as the National Transport Plan [37]—state that from 2025, only zero-emission vehicles will be sold. Presently, BEVs represent the only realistically available technology, as both hydrogen and biofuels lack infrastructure.

MLP analyses of mobility typically find that the transport sector is dominated by a few mode-centric regimes, such as automobility, public transport and others, depending on context [2, 38–40]. Transition analyses of mobility also commonly state that while the ICE-centred automobility regime is strong and stable, it is under increased pressure: on a landscape level, due to increased environmental awareness; and a niche level, due to pressure from innovations, such as BEVs, multimodal travel (e.g., mobility as a service [MaaS]) and emerging practices, such as car sharing [41, 42].

For a transition to occur, the regime must be influenced by the external pressure represented by landscape- and/or niche-level developments, or the regime will simply reproduce itself [29, 38]. Furthermore, the strength of a regime indicates how resistant it is to change. In the context of charging in Norway, smart charging is particularly interesting, as the technology connects a sector that is undergoing a sustainability transition (mobility) with a sector that is not. This is the case, since unlike most other European countries, the electricity sector in Norway faces little short-term landscape pressure to change, as it is already mainly based on renewable forms of energy. In this context, the mobility regime is under pressure from both the landscape level, with increasingly pressure to reduce GHG emissions, and the niche level. The Norwegian electricity regime, on the other hand, is mainly under pressure from a niche technology. This contrasts the wider European setting, where the electricity regime is under landscape-level pressure both from transitioning to new electricity sources, such as solar and wind, and from increased demand on electricity from other sectors—including heating and mobility, where electrification is a major component of the sustainability transitions.

Smart charging connects two regimes

Smart charging as a technology connects two sectors: the mobility sector and the energy sector. Within the mobility sector, it can be argued that there are two major established regimes relating to private cars and public transport, and a patchwork of minor (and in part overlapping) regimes relating to other mobility solutions.

The Norwegian automobility regime is interesting, as it is somewhat different from the automobility regimes that are typically studied in the transitions literature [38, 39, 43, 44]. Unlike Germany, France, the United Kingdom and Italy, Norway's automobility regime is not strongly influenced by domestic car manufacturers. The core components of the Norwegian automobility regime are focused on building roads and importing vehicles as the primary economic activity [45]. At the same time, the rules, regulations, culture and norms are very similar to what is found in other European countries. Norwegian society is affluent and automobility is culturally dominant. However, the automobility regime is dominated by many small and independent actors who conduct minimal research and development but are often quite active as early adopters of new transport technology [45, 46].

Although the Norwegian electricity market has been liberalised, the grid is still regulated as natural monopolies [47]. In this respect, the transmission system operator (TSO), who regulates and operates the central high voltage grid, and distribution system operators (DSOs), who regulate regional and local electricity grids, hold key roles in the regime—together with the regulating body (the Norwegian Water Resources and Energy Directorate). Production is dominated by strong domestic suppliers, mainly in the form of hydro and wind (93% and 4% of the total supply in 2019) [25]. There are also a number of smaller actors and a supporting industry. The regime can be characterised as robust and stable; it has a high capacity for dealing with flexibility in the form of large hydropower reservoirs functioning as energy storage, low electricity prices[2] in a European context and high reliability for consumers.

[2] This has changed with the 2021 energy crisis and the 2022 war in Ukraine, which have resulted in parts of Norway experiencing electricity prices comparable to those in the EU.

While Norway's electricity system has already been decarbonised and the landscape-level pressure is less severe than in other European countries needing to include technological phase-outs (e.g., of coal power plants [48]), the regime is under some pressure, as the set climate targets will require more electricity to be generated from renewable sources. A 40% cut in GHG emissions by 2030 and 80–95% by 2050 will involve electrification across sectors. Wind and solar power are the main candidates globally. This is also the case in Norway, together with an expansion of and new small-scale hydropower [49]. The climate targets also entail a need for new technologies and infrastructure.

Research design

This study employed a two-step design, with this article focusing on the more analytical second step (Fig. 2). The first step included an initial round of scoping, focusing on identifying mobility-related innovations that have been developed in Norway in the context of the support mechanisms for BEVs. The second step followed a comparative case study design, which looked at smart charging. The comparative case study used a diverse case strategy [50], in which cases were selected to maximise variance. The independent variable was how actors provide smart charging.

The data were collected through two rounds of semi-structured interviews using open-ended questions. This approach was deemed most suitable to answer the request questions, since smart charging is an emerging phenomenon that has only recently been introduced to the market.

First, a round of interviews with key actors (including stakeholder organisations) was conducted to obtain an overview of the relevant technologies and cases, and to map the relevant innovations. These 27 interviews are documented in [46].

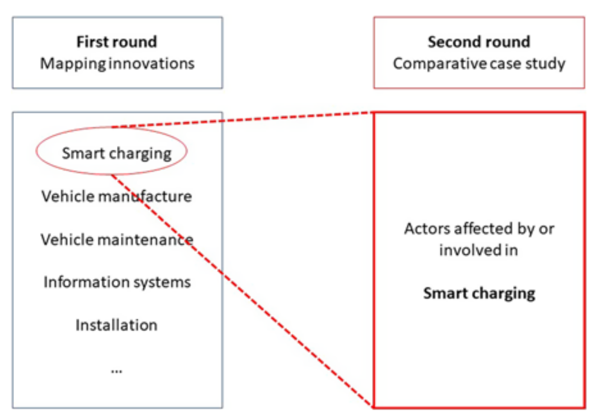

Fig. 2 Mapping and comparative case study—a two-step approach

The preliminary analysis of these interviews indicates that smart charging is one of the few technologies to have both been developed domestically and reached a market, following Norway's massive push towards the electrification of its private vehicle fleet. Most of the domestic economic activity associated with BEVs is related to maintenance and installation [51]. Though industry support is an important driver for initiating the support mechanisms, the small domestic car manufacturing industry was heavily impacted by the entry of global car manufacturers into the Norwegian market.

The second round of interviews focused on smart charging and the relationship between the mobility and energy systems, seen from the perspective of smart charging companies, TSO, DSOs, regulatory authorities and BEV users. The interviewees were selected based on suggestions from the scoping interviews and the mapping of actors in the relevant market using the Norwegian Register of Business Enterprise, as well as by snowballing. This approach was selected to utilise the broader perspectives of national agencies, to ask the specific market actors more precise questions (see appendix). In this round of interviews, nine actors were interviewed. All 36 interviews were recorded and transcribed verbatim.

Results

Smart charging can be provided through different approaches

Smart charging technology interacts with two different systems, the electricity system and the mobility system. In Norway, the transition in the automobility regime from ICE to BEVs took place with a minimal amount of conflict between the niche technology and the existing regime. Figenbaum [16] explains this by highlighting three factors. (1) The Norwegian ICE regime is relatively weak in that Norway lacks a strong automotive industry. (2) BEV technology has been incorporated into the ICE regime. In addition, (3) leading ICE regime actors also had a strong presence in the emerging BEV regime.

A contributing factor to the relative ease of this transition is that most BEVs are used in areas, where the electrical grid has been well-developed, with ample opportunity for home charging. This latter was initially used by people whose BEVs constituted a second vehicle in their household, but recent data show that 50% of new BEV owners do not own an additional vehicle [52]. Research also indicates that there have been limited consequences for DSOs as a result of the introduction of BEVs [53]. This is mainly explained by available grid capacity.

Although the concept of smart charging and many smart charging components have been in existence since at least 2010, smart charging only emerged as a commercial service in Norway in 2017, when the number of BEVs reached five per cent of the total number of vehicles [34]. The first use of BEVs complemented or was an alternative to grid expansion by the local distribution network, by providing smart charging in a communal garage [54]. BEVs comprise more than 10% of the total number of cars, but smart charging in the form of V2G has still not taken off commercially.

Based on the interviews, four different approaches to for providing smart charging were identified:

1. smart charging as a two-sided platform
2. smart charging as a complement or alternative to grid expansion
3. smart charging as a solution to rapid charging
4. smart charging as added value to home charging

All of these are varieties of unidirectional G2V, and none of them (thus far) offer V2G or V2X. Actors representing three of the four approaches were interviewed. Norwegian actors representing smart charging as added value to home charging were invited but were unable to participate in the interviews. The actors representing users and regulatory authorities referred to and commented on the actors in all four categories.

The most radical approach to providing a smart charging service is the *two-sided platform.* In this approach, smart charging is provided, such that the flexibility offered by the solution is sold to private vehicle owners and the TSO/DSOs. The actors providing these solutions have an organisational form that is close to that of a sectorial platform [55]. In this respect, the technology is used to create value in the form of flexibility that can be traded, as well as avoiding charging during peak periods. Customers become prosumers, purchasing electricity and selling flexibility. This can be achieved with G2V, V2G and V2X charging solutions.

The least radical and earliest introduced form of smart charging is to use it as a *complement or alternative to grid expansion*. In this solution, the main customers are property developers who can reduce the cost of a grid connection by reducing the peak load for that connection. The main economic incentive for smart charging in such cases does not relate to the operation of a charging facility, but to its installation. Actors who provide this service typically offer grid extension and the installation of charging boxes, or combine installation with the operation of the charging facilities. In the latter case, the installation cost can be distributed among the users of the charging facility on a per-kWh basis, as opposed to the owners.

Smart charging as a solution *for rapid charging* uses smart charging technology to address the issue of the lack of grid capacity for rapid chargers. These differ from conventional chargers in that they require greater installed capacity and are typically required at locations along main road networks between cities—locations that are typically not well-served by the existing electricity grid. These charging stations also often have a very uneven usage pattern, as they are used for weekend commuting and leisure trips. Thus, these chargers are in high demand for a few hours, a few days per week, but remain inactive most of the time. As they are subject to a tariff structure with maximum demand charges (MDC), the cost-of-service provision for these charging stations is quite high, though revenue is relatively low. Smart charging solutions can reduce peak power demand through load balancing and the installation of batteries, thereby increasing the profitability of rapid charging stations in areas with uneven demand.

The final form of smart charging, *added value to home charging*, incorporates smart charging technology into charging boxes to allow vehicles that do not directly support smart charging to be 'smart charged'. Smart charging companies sell physical products and digital services, while their customers receive lower electricity bills. The financial benefits of this solution for customers are likely to increase, as smart meters became mandatory in Norwegian households in 2019 and a new tariff structure was implemented in 2022. They allow households to monitor their temporal electricity consumption and are a prerequisite for peak power tariffs to be introduced to households. Moreover, companies offering smart charging are rapidly expanding their customer base (Table 1).

Smart charging companies differ in a number of ways related to the products or services they offer. However, from the point of view of the mobility system, these companies offer a highly similar service: charging for mainly private BEVs. The main consequence of the variance in their business approach is related to how they interact with the energy system.

Smart charging approaches face different barriers

In describing their experience of smart charging, one interviewee states that while the company initially believed they were providing mobility services, as the business developed, they realised that they are actually providing an energy service—and adapting energy logic to the mobility sector. This illustrates that although the niche companies initially perceived what they were doing as innovation in mobility, the main innovative component of their services related to their interaction with the energy system.

When asked to identify barriers to the introduction of their smart charging solutions, the one major barrier described by the actors that is directly related to the automobility regime is the absence or underdevelopment of standards related to communication formats between vehicle and charger. This leads to the development of parallel charging systems, whereby certain vehicles can only be charged using specific charging points. A consequence of this is that smart charging companies must create specific solutions for specific vehicles, on a model-by-model basis, adding costs and complexity to the software needed. Another consequence is the development of parallel infrastructures, whereby different makes of vehicle can only use certain charging stations. Both consequences reduce the utility value of BEVs and work as a barrier towards the development of more advanced charging solutions, particularly V2G.

A further barrier is that payment is not standardised across charging operators [56, 57], meaning consumers must have multiple memberships with different charging point providers, and that some of the charging points will be unusable. Consequently, some charging points can only use a given range of software, which then limits competition in the smart charging software market or creates lock-ins for given solutions.

Table 1 Key characteristics of smart charging companies and the services they provide (no interviews with actors representing 'added value to home charging' were conducted)

Approach	Private consumers	Balancing grid	Physical installation	Own software	Included in interviews
Two-sided platform	Yes and No	Yes	No	Yes	Yes
Complement or alternative to grid expansion	No	No	Yes	No	Yes
Solution to rapid charging	Yes	No	Yes	Yes	Yes
Added value to home charging	Yes	No	Yes	Yes	No, but mentioned[a]

[a] Actors representing this business approach were contacted, but no interviews were conducted

Table 2 Summary of barriers to smart charging

Barriers to smart charging	Automobility regime	Electricity regime
The development of industry standards	Communication between vehicle and charger	Communication between vehicle and charger
Standards for payment	Partly	Roaming services
Industry structure	N/A	Which solutions are allowed?
Underdeveloped markets	N/A	Flexibility and balancing
Lack of incentives	N/A	Tariff structures
Industry culture	Yes, but not important in Norway due to weak regime	Minimal focus on customer needs
Bureaucracy	N/A	DSO—municipalities
Time lag	N/A	TSO—DSO—municipalities

Regarding the electricity regime, the list of barriers is longer and includes:

- A different business logic, creating a cultural difference between start-ups and established actors. Start-ups have smart charging as their core activity and perceived future revenue stream, whereas established actors such as DSOs use smart charging to complement their core activities for grid operation.
- A vested interest in existing technologies, particularly in the use of hydropower as an energy source to balance the grid, or alternatively the use of gas-powered backups.
- Industry standards and requirements unsuited to non-hydropower-based flexibility: i.e., certification includes elements of turbine design. Such standards and requirements cannot be met by actors who provide flexibility using batteries.
- High entry barriers to the balancing markets in the form of minimum capacity restrictions.
- Culture of energy companies not engaging with customers. As one respondent states: *'Energy companies have not spoken to the customers ever, in the history ... I mean it's all about selling energy. Their only interaction with the companies and users is the invoices'*. Consequently, the respondent argues that energy companies are not responding to market needs. Similar statements can also be found in Inderberg [58].
- Long time lag from identification to installation. Investment funding is readily available but municipal and DSO bureaucracy limits the pace of investment. One respondent argues that although there is political pressure for subsidising charging stations, subsidies are not needed. Instead, he points to the simplification of the process towards DSOs on one hand and municipalities on the other as critical. Private funding is readily available (Table 2).

The identified barriers to smart charging relate to both the automobility and electricity regimes. Most of the barriers relate to the electricity regime. Communication standards relate to both automobility and electricity, as the standards relate to the interface between these sectors. The same applies to payment standards.

The barriers are associated with different transition pathways

Apart from communication standards, the identified barriers mostly relate to the various components of the electricity regime. These do not equally affect the business approaches (see Table 3).

Table 3 Approaches, challenges and pathways

Approach	Challenging existing regimes		Pathway	
	Car regime	Electricity regime	Car regime	Electricity regime
Two-sided platform	No	Yes, very	Complements technological substitution	Dealignment and realignment (SWE)
Complement or alternative to grid expansion	No	No, complements	Complements technological substitution	Transformation
Solution to rapid charging	Partly	No, complements	Complements technological substitution	Transformation
Added value to home charging	No	No, complements	Complements technological substitution	Transformation

The only smart charging approach that challenges the automobility regime is the *solution to rapid charging*. This approach is parallel to and in potential conflict with two attempts from the automotive industry. The automotive industry is offering to produce a similar charging infrastructure focusing on a single manufacturer (Tesla) or a group of manufacturers (IONITY[3]), as opposed to the smart charging solution, which aims to make rapid charging a commodity across vehicle manufacturers. All the other approaches to smart charging do not significantly challenge the actors in the automobility regime. In mobility, the introduction of BEVs in Norway can be seen as mainly following a technological substitution pathway, and all the smart charging solutions complement this.

However, the platform solution challenges the electricity regime by including flexibility trading as a component of smart charging. This means providing an alternative source of flexibility beyond the solutions in the presently regulated markets.

Regarding the electricity regime, there is, in turn, a difference between the *two-sided platform* and the other solutions in how they relate to the transition pathway typologies. With the two-sided platform being closer to a dealignment and a realignment transition pathway, the approach requires major changes to the established regime. The other solutions offer add-ons to the established regime and are thereby associated with a transformation pathway.

Different approaches to smart charging have been introduced by different technology developers. V2G is not being offered at present. The arguments against its inclusion include conflicts with both the automobility and electricity regimes. The conflict with the automobility regime is linked to the fact that few car models are designed with V2G as a standard option. Moreover, insurance policies do not presently cover the risks associated with V2G, with fire and reduced battery life mentioned as particularly challenging areas. The electricity regime includes all the barriers to smart charging for grid balancing and also the lack of a suitable tariff structure that would incentivise use. This will change following the introduction of a time-of-use (TOU) pricing system for residential consumers. Presently, the main beneficiary of V2G in Norway would be society at large, in the form of improved flexibility in the distribution grids. The main benefactor would be private individuals connecting their vehicles to the grid, as this currently entails increasing risk and offers very little, if any, financial compensation. V2X may be easier in relation to the electricity regime, as it is associated with going off grid, but has the same conflicts as V2G with the automobility regime. However, as one informant states: 'Why would you want to go off a perfectly functioning grid? It will just be more expensive and riskier'. These statements are similar to the findings in Parsons et al. [59] and Lin and Sovacool [60], but partially contrast Noel et al. [61]: the latter use a stated preference approach as opposed to interviews about experience, and find a positive willingness to pay for V2G, in the Norwegian case.

Discussion

The rapid introduction of BEVs in Norway indicates that charging and the charging infrastructure have not been a major barrier to the electrification of mobility. That is not to say that charging has not been a barrier for specific user groups and trip purposes, as shown by Ydersbond and Amundsen [62]. The incentive structure for private individuals to adopt BEVs was in place before the technology (i.e., suitable vehicles) was available. As vehicles for different needs have become available, the transition towards BEVs has picked up pace. The size of the BEV fleet and usage patterns have resulted in the charging infrastructure becoming a minor barrier to overall electrification. Smart charging partly addresses this.

Looking at smart charging, the market adopts different approaches. These range from actors (e.g., Tibber and Meshcraft) that present business cases outside the established solutions in the automobility and electricity regimes, to regime actors (e.g., Elvia and BKK) that present their own solutions, adding smart charging to complement their DSO services.

This analysis suggests that G2V smart charging as a technology only partially challenges the automobility regime. If anything, it looks complementary. This is based on the observation that the pre-existing actors in the automobility regime in Norway can largely continue their business as before. Vehicles are imported, and roads are built. At a global scale, traditional vehicle manufacturers are challenged by new manufacturers, but these generally operate within the same regime. They (mostly) produce and sell vehicles; smart charging is (mainly) deployed by actors independent of the traditional automobility regime. Thus, smart charging by itself presents a less-radical solution to the decarbonation of mobility—representing a transition through technological substitution, where major components of the regime remain unchanged, while a key technology is substituted (ICE to BEV). Though this substation includes the development of some new technologies (such as smart charging), the institutions, industry, policy and culture surrounding automobility remain largely unaffected.

[3] Jointly owned by the Volkswagen Group, BMW, Ford Motor Company, Hyundai Motor Group and Daimler AG.

However, smart charging challenges actors in the electricity regime, for example, in the existing approaches to G2V and V2G. Smart charging offers supply, capacity and flexibility through alternative mechanisms to those that exist in the present regime. This means changing technology, policy, institutions and culture, as well as adding to the industry.

The smart charging approaches that are the least challenging to the electricity regime are those that are presently on the market. They offer value creation primarily by reducing installation costs, and their main customers are communal garages. The more-radical forms of smart charging that are more at odds with the electricity regime seem to have greater transformative potential in the context of value creation and a societal sustainability transition. However, they also face stronger structural opposition from the established regimes in the form of rules and regulations that are in direct conflict with the business approach of the more-radical smart charging solutions.

In contrast to Chen et al. [4], this study finds no interdependency between V2G smart charging and BEV adoption. BEVs have been adopted on a large scale without V2G. This may partially be due to the particularities of the Norwegian energy system, with a relatively strong local and regional electricity grid, high flexibility and low carbon intensity.

Several of the interviewees stated that their technologies would likely be more interesting in a Dutch or German setting, with more decentralised energy production, higher electricity prices and weaker electricity grids. These findings are in line with Després et al. [63], who highlight that V2G will likely happen at a later stage.

However, the absence of V2G may also be explained by the relative strength of the pre-existing energy regime and the fact that it is better coordinated. This is supported by Meckling and Nahm [64], who suggest that political coordination, such as that typically found in industries in the Nordic countries, results in policies that support incumbent companies. It also faces relatively weak landscape-level pressure. Stronger landscape-level pressure in the form of increased demand for capacity in the flexibility markets—resulting from increased interconnectedness between the Norwegian and the European grids, increased use of wind and solar power, and increased energy prices—may well result in increased pressure to change.

The outcome in the Norwegian case is likely due in part to a relatively weak automobility regime that did not oppose the introduction of BEVs [19]. And that the electricity regime was not challenged by the introduction of BEVs before these were combined with smart charging. In response to smart charging, some DSOs have chosen to utilise the technology, thus providing within-regime solutions to some of the barriers to BEV adoption presented by the electrical grid. Thereby following a reconfiguration pathway. This approach has in particular been used in urban areas, where joint ownership parking has been a challenge for BEV adoption.

The more-radical smart charging solutions have faced opposition, including both the two-sided platform approach with G2V and V2G. These approaches are associated with a dealignment and a realignment pathway in the electricity regime. As there is presently only limited landscape-level pressure on the existing regimes, this is not likely to succeed. However, incidents such as the 2019 droughts (when the hydropower-based capacity in the flexibility markets was exhausted [in Sweden]), the 2021 energy crisis and the 2022 war in Ukraine may well provide sufficient landscape-level pressure to change this.

The time frame used by the electricity regime is at odds with the rapid adoption of BEVs. The current electricity regime uses months to years to provide a grid extension, and years up to a decade to provide changes in the transmission grid. Changes in the distribution grid have a time frame that is between the two, in contrast to the rapid introduction of BEVs. This provides a window of opportunity for smart charging G2V in less-radical forms. Similar transitions in other sectors may create more landscape-level pressure to include the opportunities for energy storage offered by an ever-increasing fleet of BEVs.

Norwegian experience shows that smart charging and V2G is not a prerequisite for a technological substitution of ICE by BEVs. However, this is a case in which the electricity regime has not been challenged by this transition. In the Norwegian case, the consumption of energy by BEVs is not likely to challenge the production or distribution capacity on a national level. Skotland et al. [35] argue that 1.5 million BEVs would amount to approximately 3% of energy consumption. Wangsness, Halse [53] also find that the introduction of BEVs has little impact on grid costs. Wangsness et al. [65], however, argue that when the electricity sector is heavily dependent on intermittent generation or has a sharp peak in demand, BEV charging and V2G become crucial. As long as electricity production relies on hydropower with storage capacity, this is not that important. However, with ever-increasing demand, this may well change.

Conclusion

Actors with strong connections to a relatively robust electricity regime have been successful in addressing some of the challenges created by smart charging within the structure of the existing regimes. More-radical solutions using new business models or more-complex smart charging solutions, such as V2G, are being presented by niche-level start-ups and entrants to the mobility system. Thus far, these have proved difficult to implement. This does not negate the potential of these solutions in a sustainability transition context, but given the present context, V2G solutions have not been successful. These findings are in line with Meckling and Nahm [64], who suggest that less-radical or incremental innovations are more likely to be introduced by established actors and implemented at an early stage in a transitions context. More-radical innovations are less likely to emerge and face stronger opposition from existing regime actors.

The absence of smart charging and V2G has not been a barrier to BEV implementation reaching the acceleration phase in Norway. The absence of V2G can be explained by both the barriers to V2G and the risk–incentive structure that customers currently face. This is in line with findings, such as [3, 60, 61]. The socio-technical barriers are present in both the automobility regime and the electricity regime. However, in the Norwegian case, barriers to V2G are more visible in the electricity regime than the automobility regime. G2V smart charging is facing fewer barriers, and these are mainly linked to the electricity regime.

That fact that V2G has not yet been successfully implemented in the Norwegian case may be explained by both the strength and structure of the domestic electricity regime. A strong regime with a high level of legitimacy that presents few barriers to the adoption of BEVs does not need to change, though the technology is available. In other contexts, with less-available flexibility and higher electricity production costs, this may be markedly different.

A key policy implication of this research is that it is important to take extant regime structures into consideration when introducing new technology. In the case of Norway, the transition towards BEVs is relatively unproblematic in terms of the mobility regime; however, it faces numerous barriers related to the electricity regime. This highlights the role of supporting policies across regimes in sustainability transitions. Furthermore, findings suggest that pointing to Norway's 'uniqueness' risks undervaluing the transferable lessons that can be learned from the introduction of BEVs in the Norwegian market—namely, the relative ease with which it is associated—and that the real barriers presented by regimes adjacent to mobility may be overestimated.

The main limitation of this research is that it is a single-case study. Findings regarding the importance of the regimes in explaining the introduction of BEVs would be clearer, if they were replicated in other locations, where there is a strong electricity regime, a weak automobility regime and large-scale introduction of BEVs. This will likely be possible to do in the future, as BEVs are introduced in other contexts.

Although this article finds that barriers to the introduction of BEVs from the absence of V2G smart charging are small, this does not mean that V2G is likely to remain unimportant. A higher number of BEVs and increasing use of BEVs in city centres and rural areas suggest an increasing role for V2G. However, this will also be influenced by increasing the vehicles' battery capacity.

Appendix—list of in-depth interviews

The interviews were conducted using a semi-structured approach using Teams/Zoom and were recorded and transcribed verbatim (Table 4).

Table 4 List of in-depth interviews (second round)

Actor	Type	Title	Duration	Date	ID
Smartgrid	Consultancy	Advisor	1 h	06 June 20	1
NVE	Public authority	Advisor	1 h 30 min	18 June 20	2
NVE	Public authority	Advisor	45 min	18 June 20	3
Statnett	Grid operator	Senior Advisor	1 h	25 June 20	4
Nodes	Private company	Senior Advisor	1 h 30 min	26 June 20	5
Elbilforeningen	Interest organisation	Senior Advisor	1 h 30 min	20 June 20	6
Tibber	Private company	Developer	1 h	11 Nov 20	7
Recharge Infra	Private company	Developer	1 h	12 Nov 20	8
Ladeklar	Private company	Developer	1 h	30 Nov 20	9

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Availability of data and materials
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Declarations

Ethics approval and consent to participate
The study has been approved by the NSD—Norwegian Centre for Research data.

Consent for publication
Not applicable. This is included in the NSD approval.

Competing interests
The author declares no competing interest.

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