PNAS RESEARCH ARTICLE | SUSTAINABILITY SCIENCE OPEN ACCESS

How policies and actor strategies affect electric vehicle diffusion and wider sustainability transitions

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Edited by Frank W. Geels, The University of Manchester, Manchester, United Kingdom; received May 6, 2022; accepted November 8, 2022 by Editorial Board Member William C. Clark

Implementing electromobility is a central component in the de-carbonization of personal mobility. In recent years, the absolute number of electric vehicles (EVs) and their market share has increased sharply in many countries. This paper focuses on Norway, a pioneer market for EVs that other countries can learn from. The analysis highlights how a combination of local and national policies over a 30-y period, which targeted both industry development and vehicle demand, were important drivers of this development. It also highlights the importance of advocacy groups and strong networks in promoting EVs, as well as changes in user preferences. The paper demonstrates how the EV diffusion has been driven by alignments of multiple processes across different levels, involving interactions between multiple actors and social groups with different interests and views about desirable futures as described by the multi-level perspective (MLP). Building on the MLP, the study of EV diffusion in Norway illustrates how niches are often sustained through demonstrations, experimentation, strategic alliances, and actors securing favorable political and economic conditions. Further, it shows how local or national niches may depend on international regime actors, such as the car manufacturing industry and policies developed abroad. The paper also explores how the introduction of EVs has opened for wider effects, including innovation within production-consumption systems beyond mobility. Based on this analysis, we argue for a nuanced perspective on the relationship between incremental, regime-internal innovation, and wider transformative changes, where the merits of societal learning and experience with battery electricity for transportation are highlighted.

electric vehicles | multi-level perspective | policy | transformative change | sustainability transitions

Significance

This research deals with the emergence, development, and deployment of one sustainable innovation intended to promote sustainability transitions, the electric car. It gives an in-depth processual understanding of this relatively far progressed case of transition related to one of the key strategies for climate change mitigation; the reduction of emissions from person mobility. As such, this research illustrates how diverse and sometimes competing societal interests can converge around a policy strategy to decarbonize the transport sector and thus give important insight for future sustainability pathways and acceleration within transport and electricity systems.

The electrification of personal transport plays a key role in decarbonizing mobility globally (1). About 16% of all global greenhouse gas emissions can be ascribed to the transport sector, a majority of which can be traced back to road transport (2). The work to decarbonize the sector has been challenging, not least because push-back from incumbent automakers that want to maintain existing regimes rather than change them (3). Yet, over the last decade, much has happened, both in terms of technological development, changes in industrial structures, and market creation. In 2021, 6.6 million electric vehicles (EVs) were sold globally, which is more than double compared to 2020 and numbers continue to grow steeply in 2022 (4).

In this article, we use the development in Norway, one of the world's leading EV markets, to discuss the multi-level and multi-actor dynamics that have resulted in a market where most new vehicles sold are EVs. The share of EVs in Norwegian new vehicles sales in 2021 was 64.5% [86% if counting both battery EVs (BEVs) and plug-in hybrid vehicles (PHEVs)], which means that the largest transition challenge ahead in the country lies in substituting the remainder of the car fleet, which should account for around 96% of all vehicles by 2050 to be in line with 1.5-degree climate scenarios (5). This is a contrast to comparable markets in the EU where the EVs (BEV + PHEVs) share in 2021 was 17%, with the largest market shares found in Iceland (72%), Sweden (43%), Denmark (35%), and the Netherlands (30%). The shares are much lower in China (16%) and the USA (4.6%) (4), among private customers (in contrast to leasing or cars bought by commercial actors). Given the rapid global increase in EV sales, the Norwegian experience provides valuable insights into other countries over the coming years.

There are multiple explanations for the sharp increase in EV-shares that can be observed in Norway. Most acknowledged is the fact that Norway has implemented strong incentives for buying EVs. The country also has characteristics that makes it an especially good fit for electrification. Norway can be characterized as a mass-motorized country (6), that is wealthy, with high living standards, partly due to revenues from and oil and gas. It has an electricity system where 98% of electricity production is based on renewables, primarily hydropower

This paper is part of a Special Feature on Sustainability Transitions in Consumption-Production Systems. The collection of all PNAS Special Features in the Sustainability Science portal is available here: https://www.pnas.org/sustainability-science.

Author contributions: M.R. and T.M.S. designed research; performed research; analyzed data; and wrote the paper.

The authors declare no competing interest.

This article is a PNAS Direct Submission. F.W.G. is a guest editor invited by the Editorial Board.

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Published November 13, 2023.

[see, e.g., Skjølsvold et al. (7)]. This has historically served the country with abundant and cheap energy providing low operating costs for EVs due to inexpensive electricity and a robust and steadily expanding electricity grid infrastructure. Here, electricity is also used for space heating, including space heating of homes. Thus, the electricity system in Norway was already quite dense and did not need many initial upgrades to introduce EVs compared to other countries. In early phases of the EV introduction, this electricity system secured instant access to charging through the existing infrastructure as EVs could be plugged into existing electricity outlets and wall sockets to charge. As the EV transition increased in scope, installing dedicated domestic chargers for everyday use became the norm and specialized infrastructure for fast and convenient EV charging has gradually expanded (8). Further, EV technology has steadily improved, and the satisfaction of early adopters and further learning by using processes has facilitated the uptake of EVs by the broader population. Throughout the period, new advocacy groups have served an important role in the political legitimation of EVs. In sum, a series of policy strategies and instruments, combined with the work from a range of actors working within an already favorable set of conditions, have pushed EVs from being a niche technology to a mainstream element in the Norwegian automobility regime

Conceptual Framework

Our analysis builds from a socio-technical understanding of transitions anchored in the multi-level perspective (MLP). This perspective operationalizes consumption-production systems across three levels: niches, regimes, and landscapes, which loosely correspond to the micro-meso-macro-distinction of most social theory. Regimes (meso) refer to the stable rules and institutions that guide incumbent actors and undergird existing systems, while niches (micro) are smaller with less stabilized rules. The landscape (macro) is exogenous and difficult to influence. Within this perspective, socio-technical transitions have primarily been analyzed as regime change or regime transformation, where niche innovations either grow into new regimes, or become part of and change existing ones (9). Studies within this perspective tend to differentiate between different phases of transitions. Phase 1 (experimentation) is characterized by trial-and-error learning. Phase 2 (stabilization) involves innovations gaining a market foothold and consolidation in a clearer direction. Phase 3 (diffusion) entails uptake in mainstream markets, while phase 4 (institutionalization) entails the replacement of parts of the old consumption-production systems, including norms, habits, and standards (10).

The MLP provides us with a broad theoretical lens to analyze how policies, product technologies, industry, markets, consumer behavior, infrastructure, spatial arrangements, and cultural meanings work together across levels (11) to understand the process of shifting to electromobility in Norway. Specifically, our analysis zooms in on a) how a combination of policies has worked over time and b) the role of EV users and the work and strategies conducted by intermediary actors to advance this transition. To address this, we take cues from two distinct, related literatures.

The literature on the role of policies in transitions has tended to be framed through the concept of policy mixes. Rogge and Reichardt (12) note how policy mixes consist of a) concrete policy instruments (e.g., economic instruments such as subsidies), b) policy strategies (e.g., emission reduction targets for 2050), and c) policy processes, characterized as a cycle of problem-solving attempts. In our analysis, we will highlight how the Norwegian EV transition has been shaped by instruments, strategies, and processes implemented and enacted over time, both at niche and regime levels in Norway and other countries.

The research on technology users has over the last years shifted from focusing on the processes that make users adopt new technologies, to focusing on how different forms of technology use might also be a resource for transitions. Schot et al. (13) have noted how different stages of transitions tend to attract, and need, different types of users. In early stages of transitions, user-producers might tinker with radical new technologies, while user-legitimators and user-intermediators provide meaning and provide spaces for appropriation and enroll new users. Further on, user-citizens engage in regime-shift politics by lobbying for a specific technology before user-consumers adopt products and make them part of their everyday practices. The literature on intermediaries (e.g., ref. 14) further highlights how actors that can mediate information, interests, and insights between systems, sectors, actors, or levels are central for advancing transitions. In what follows, we mobilize these perspectives to describe the dynamics and mechanisms of the Norwegian EV transition.

Research Design

The paper makes an integrative or synthetic analysis of data collected across past research projects on EVs that the authors of this article have been involved in. It combines this with a close reading of key secondary sources and historical accounts. Research methods in those projects were mainly qualitative interviews with EV users, surveys of EV users, and key EV stakeholders, observations, and qualitative analysis of written sources (e.g., policy documents, industry reports, and gray literature). More than 100 qualitative interviews with owners of EVs have been conducted, and we have used data from a survey of 16,000 EV owners (selected among members of the Norwegian EV Association that were conducted in 2016 and 2017 (3,422 in 2016 and 12,665 in 2017)). More than 20 key stakeholders were interviewed, and the stakeholder interviews include stakeholders in EV-related industries representing national and local authorities, governmental organizations (GOs), and non-governmental organizations (NGOs) working to promote electrification of transport such as EV manufacturers and mobility agents (see ref. 15 for details). Interviews also covered those holding positions as "intermediaries" in the EV transitions, such as technical advisors or technical mangers, electricians, and leaders of housing boards (see ref. 16 for a more detailed account). The synthetic analysis has also been informed by contemporary innovation studies' analysis of the Norwegian EV industry from the 1990s until today.

Analysis

Many descriptions of the Norwegian EV transition depict it as the sole result of demand-side policies (17), but in this section, we will analyze the current "success" as an outcome of a long process involving multiple types of actors, policies, and sites across levels and scales. First, we discuss the role of policies, infrastructure, experimentation, and strategic alliances between local, regional, national, and international actors in securing favorable political and economic conditions for EVs to develop and diffuse, before highlighting the role of users and advocacy groups in supporting the transition. Lastly, we will discuss how the EV diffusion may contribute to broader societal changes, e.g., through enabling a culture of innovation with respect to electrification of new sectors. Following the four-phase dynamics described through earlier MLP studies, Norway is currently in a phase of rapid EV diffusion. The dynamics in play, however, also currently take the form of institutionalization, as EVs, associated infrastructure, use-patterns, and routines are increasingly normalized and an integrated element of Norwegian society (Fig. 1).

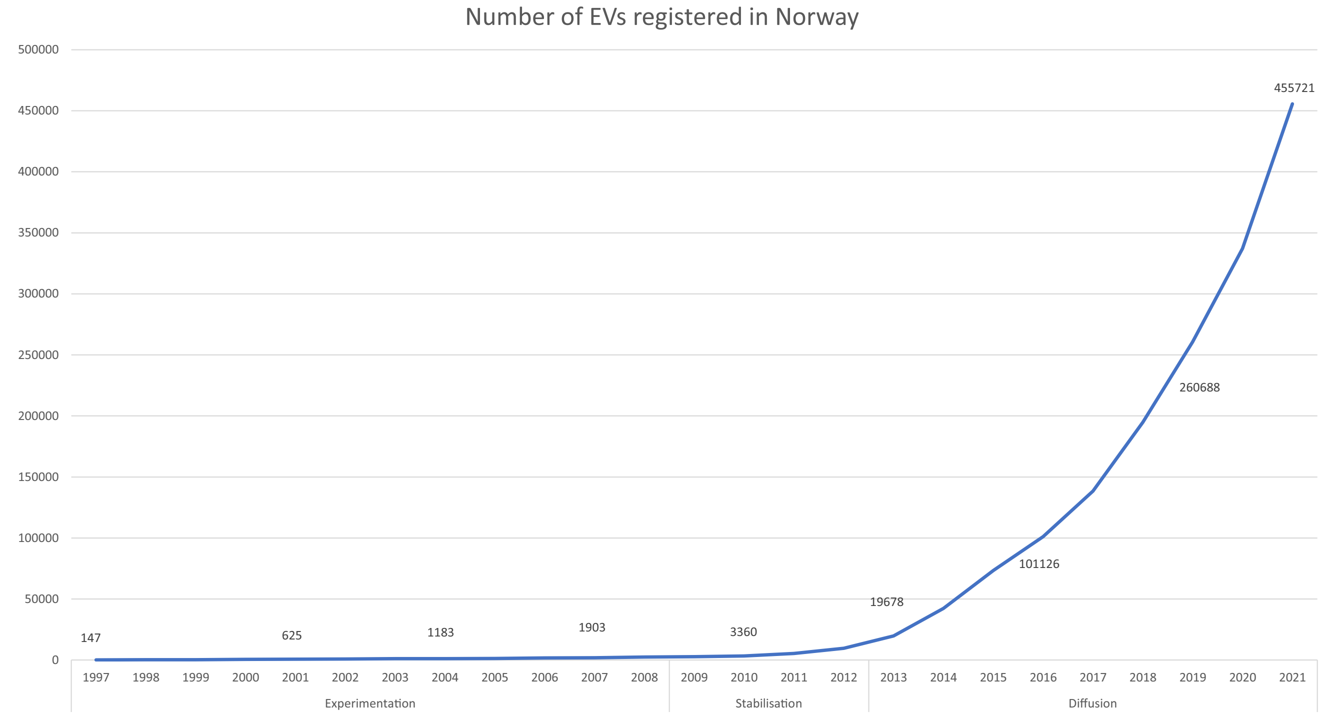

Fig. 1. Number of EVs registered in Norway.

The Role of Policies, Experimentation, and Strategic Alliances. The current Norwegian electric mobility transition has been nurtured through a combination of local and national policies over a period of 30 y. However, it also has a prehistory dating back to the early 1970s. Aspehjell et al. (18) have described how the oil crisis of 1973 triggered a Norwegian interest in nurturing an EV industry. Importantly, Bakelittfabrikken AS, a plastic industrial firm, started to develop a small prototype EV, which they hoped would decrease the country's dependency on global oil value chains. The oil crisis was an example of what the MLP describes as a landscape shock (19), which opened a small window of opportunity for niche innovators. As the oil crisis faded however, this early EV development did not take off (20).

The story is slightly more than a historical curiosity. In the early 1990s, the first Norwegian EV policy strategy targeted the development of a domestic EV niche industry (21). The major actor to act on to this policy strategy was the same plastic factory from the 1970s, who once again wanted to produce a line of small, urban EVs. The primary goal of early policy instruments of this era was to nurture and shield niche innovation activities such as these. Examples of such early nurturing instruments were subsidies granted through a national industrial fund. The activities were also supported by incumbents of the electricity regime, who considered EVs to be a potential expansion of the electricity market (22). In subsequent years, the Norwegian EV innovation trajectory can be characterized by experimentation within niches, i.e., protected spaces that allow experimentation with the coevolution of technology, user practices, and regulatory structures while emphasizing "learning, networking, visioning and the relationship between local projects and global rule sets that guide actor behaviour" [ref. 23: 537]. The Norwegian EV industry began by developing local projects that aligned actors working together to connect, network, share experience, and replicate, eventually forming an increasingly "cosmopolitan" or global niche (24, 25).

As noted, the network of actors that developed the Norwegian EV during the early 1990s were anchored in the plastic industry and nurtured by incumbents in Norwegian hydroelectricity. Hence, they represented a break with dominant automobility regimes. Several prototypes were produced during this era under the moniker of "Personal Independent Vehicle" (PIV), a lightweight vehicle intended for urban use developed by the company PIVCO. The first edition (PIV1) was tested in 1993, and the next year 13 vehicles of the second-generation prototype ("CityBee") were publicly tested as part of the vehicle fleet used during the Lillehammer Winter Olympic Games. These efforts can be described as "niche experiments" (26), where the goal was partly to achieve visibility and public engagement to illustrate the viability of an alternative to the dominant automobility regime.

The early attempts at nurturing a Norwegian EV industry also attracted interest from other regimes, abroad. The first commercial order of 50 CityBee vehicles came from San Francisco, where the Bay Area Rapid Transit (BART) light rail system would allow select companies in the area to use the EVs as what we today would call last-mile transport (27). This early venture into the Californian scene, however, was problematic and never became much of a success. PIVCO was also struggling with raising capital and was in the end declared bankrupt in 1997 (27). Policy strategies in California, however, later came to be important for further Norwegian developments, as the Californian strategy to reduce transport emissions was operationalized as a policy instrument in the Zero Emission Vehicle legislation (28). This policy instrument established a credit system where car manufacturers had to earn credits from the sale of non-emission vehicles to legally be able to continue producing petrol cars (29). It was at this time that PIVCO was acquired and thereby saved by Ford Motor Company, who wanted PIVCO and its vehicles as a tool to be able to meet the requirements of the new California legislation (27). By the late 1990s, PIVCO was rebranded as Th!nk, hence becoming part of the traditional automobile production regime. Later, under leadership of Jac Nasser, Ford, however, undertook a radical reorientation toward what we would now call Mobility as a Service. Once Nasser was deposed, the strategy was returned to business as usual, and Th!nk was one of the victims (30).

This brief narrative about the rise of a Norwegian EV industry illustrates both the importance of a domestic policy push by policy instruments on the production side in Norway, as well as a policy pull from demand-side policy instruments abroad. Demand-side policies abroad also stimulated the forming of strategic alliances with transnational regime actors such as the American car industry. To stimulate the development of the EV industry, Norway steadily implemented a series of policy instruments to develop a domestic market for PIVCO and other EV producers during the 1990s. This included exemption from registration tax (1990), experiments with free parking for EVs (1993), reduced annual license tax (1996), and exemption from road-toll fees (1997).

Today, however, Norway is not known for an EV industry, but for a thriving EV market. As the Norwegian EV niche actor Th!nk became exposed to the selection mechanisms of the international automobility regime, they soon went bankrupt (31), as did their predecessor PIVCO. The policy instruments implemented to stimulate a domestic market, however, had started working, and the demand for EVs in Norway was rising. When Th!nk went bankrupt in the USA around the year 2000, there was a shortage of EVs in Norway. To meet this demand, another Norwegian company bought the entire fleet of EVs from Ford Motor Company and imported it for sales in Norway, a fleet that Ford had originally decided to scrap (20).

While the EV-industrial ambitions in Norway came to a halt with Th!nk, the policy instruments which were introduced to create a domestic market for that industry remained intact and were also strengthened by the introduction of the exemption from value-added tax (25%) for EVs from 2001. Meanwhile, policy strategies in Norway were re-oriented to target climate emission reductions rather than new industry formation. This is another example of how landscape developments can open new routes for policy development and innovation. Since the Norwegian energy system is largely based on renewable hydropower, the attention was first turned to the transport sector, where electrification became one of the key strategies of Norwegian climate policies (32).

We should note, however, that the policy instruments of this era were not enough in themselves to propel EVs: EVs did not take off before significant developments were made in the auto-industry, and a series of new car models were introduced in the late 2000s. Arguably, the Norwegian policies here served as a technology-pull mechanism, accelerating the EV innovation among international automakers, hence laying the ground for new EV markets.

As part of the reorientation toward implementing EVs as domestic climate mitigation measures, a series of new policy instruments such as access to driving in bus lanes and free passage on ferries were implemented (21). The ambitions became part of national policy strategies in 2012, where it was decided that the comprehensive EV incentives should be kept until 2018 or until 50,000 cars were sold. Further, the goal was that all new cars sold by 2025 should be either zero or low emission (33). Thus, our narrative corroborates claims in the literature highlighting that strong, consistent, and stable policies that are necessary to create wide adoption and EVs penetrating automobile markets (34, 35). In the Norwegian case, this strategic push over time was secured by a broad alliance of politicians across the political spectrum. In this way, the government signaled a strong national interest, created market interests, and ensured availability of vehicles (36). Such broad political coalitions may be harder to achieve in more polarized, bi-partisan countries such as the USA.

The active nurturing of EVs through progressive tax system has made most EV models equal in price or cheaper to buy compared to a similar petrol model in Norway. In addition to these monetary incentives that made EVs more affordable for consumers, the Norwegian government also supported investments in the charging infrastructure. The goal of the government was to provide at least one fast-charging station for every 50 km of main roads (8). Norway's first support scheme for public charging infrastructure took place in 2009 to 2010 when about five million euros were spent supporting the installation of slow charging stations, resulting in 1,800 charging points to be built (8). In later years, the subsidies shifted to support fast-charging stations, and there are now over 5,000 fast chargers available. In total, these policy measures increased the number of fast-charging points from zero to over 15,000 over the course of 10 y (37). Although most people own their own houses (82%), live in houses or detached houses (77%) that enable charging at home and that most EV drivers (88%) daily charge their vehicle at home (8), the widespread net of charging stations has contributed to increase the utility of EVs as it has enabled EV drivers to drive for longer distances and to use the vehicle for all purposes such as longer leisure trips (3). The fast-charging network is mainly used for longer trips but serves as a "safety net" for daily EV use.

In sum, the result has been a formidable growth in registered EVs over the last decade. The EV development did, however, not only happen due to actions taken by policymakers and firms but also involved a range of other actors and processes that contributed to keeping the policies and the momentum of transitions to EVs alive.

The Role of Advocacy Groups and Users. Advocacy groups and interest organizations forming strong networks for promoting electromobility (15) have been particularly important for the Norwegian EV transition. Actors promoting EVs began coordinating and organizing their action in a targeted way in the early 1990s, thus fulfilling the role as intermediaries (14) in the early experimental phase of the EV transition. Later, they were key in coordinating efforts to enroll the Norwegian public as participants in the EV transition. One example is the EV user organization NORSTART (later Norsk Elbilforening or Norwegian EV Association), founded in the early 1990s. The organization became central as disseminators of information, working to recruit EV drivers through free test drives. Later, they facilitated knowledge transfer between early adopters and to prospective EV buyers through online platforms. Thus, the EV interest organization both performed the role of user-legitimators and user-intermediaries (13). They shaped values and provided meaning and rationale for niche actors by producing narratives and vision and worked to create spaces for the appropriation of EVs, at the same time as shaping and aligning different elements of the production-consumption system. The small Environmental NGO Bellona was also a crucial user-intermediary, important for raising awareness of the benefits of EVs, and in their effort to secure favorable incentives and conditions for EV use in Norway. As an example, Norwegian Architect Harald Røstvik together with Bellona mobilized national pop stars such as the group A-ha, to attract attention to the cause, serving as very visible user-legitimators (18). These endeavors did not happen without contestation and struggle. Civil disobedience such as parking illegally, not paying for toll roads, and refusing to pay fines was used strategically to create media attention and put the authorities under pressure to secure more favorable conditions for EVs in Norway and after intensive campaigning the struggle eventually paid off. User-intermediaries, such as the Environmental NGO, Zero, also hosted EV rallies to demonstrate that EVs were a future-oriented alternative to diesel and petrol cars (18). Thus, many of these activities that intermediaries undertake to promote EVs (motor races, rallies, test drives) resemble activities that earlier were performed by car manufacturers seeking to create a market for automobility (38).

In later stages of the transition, other types of actors have been central in advancing the growth of the EV market. As recognized by sustainability transitions scholars, ordinary user-consumers, buying the product can contribute to transitions and to the shaping of the transition dynamics (13) as they embed new technologies in everyday life. This has been the case in the Norwegian EV transition where users and user preferences from a growing number of EV drivers have been an important factor that have contributed to shaping and accelerating the transition.

Throughout the different phases of EV adoption in Norway, EV drivers have reported high levels of technology satisfaction (36, 39, 40). Such positive user experiences have been crucial for the uptake of EVs, as the perception of and culture around EVs have shifted from being associated with an alternative technological choice of a few early adopters to becoming a mainstream element of the automotive culture (41). The fact that even early adopters enjoyed EV conveniences such as easily available home-charging, free parking, and bus lane driving and experienced that the cars (even the small and simple first models such as Th!nks and Buddy) had good driving abilities that filled most mobility needs were important factors that turned idealistic early adopters into user-legitimators (41). Many also highlighted the merit of fossil guilt-free driving as an important asset. Combined with the comprehensive package of incentives, this catered to the needs of different user-groups who satisfied a variety of mobility needs through using different EV models (36).

EV diffusion is, however, not only about adoption. It is also a process of learning in which users develop new skills, new practices, and beliefs. Such learning-by-using processes have been important in the Norwegian EV transition, particularly with regard to overcoming concern for so-called range anxiety, namely the fear that EV driving ranges are insufficient to meet the needs of drivers, and how EVs changed from being a secondary vehicle to the first car.

Research on EV users indicated that the driving range of the EV was seldom considered a significant problem by experienced EV drivers (41, 42). Thus, range anxiety, which has typically been seen as one of the dominant barriers to EV adoption in other countries (43), was seen as less of a problem by most experienced EV users who quickly learned to adjust and internalize driving practices that was a better fit for EVs (38, 41, 44). One interesting observation, however, was that the limited driving range made the materiality and resource use associated with transportation needs more noticeable, and that therefore, many users (64%) reported a heightened awareness of energy use (39) an unexpected surge in pro-environmental values and considered in installing solar panels in their houses (25%) (36, 44).

It is also interesting to note that, although the EV was acquired as a "second car" that typically was not expected to cover all transport needs of the household, many users reported that the EV, in most instances, transformed into being "the number one car" of households (39). Thus, EVs were used for most trips, replaced 82% of the use of a petrol or diesel car, as the ICE car was reduced to being employed for more special situations such as weekend trips, holidays, or as the "workhorse" vehicle, for instance used for towing (44, 45). Over time this specificity of EV use has diminished with new and larger electric car models being launched on the market (with larger engines, 4WD, longer driving range, and possibilities for towing). In fact, EV owners have become more like other car owners, and they also adopt the EV as a second car less frequently than before (46).

User-citizens, backed by intermediary organizations, were soon to engage in work to keep the favorable EV policies that made more consumers adopt EVs as the technology developed, cars grew, and their driving range extended. Thus, we clearly see how different stages of transitions tend to attract, and need, different types of users as described by Schot et al. (13).

Wider Systemic Impacts from the Broad Implementation of EVs. Until recently, the Norwegian EV transition has primarily received attention as a demand-side success story, where the focus has been on what has been done to make Norwegians replace their internal combustion engines with electric cars. This has been reflected in academic work, where EV implementation has often been described as a form of simple technology substitution (e.g., ref. 47). Over the last years, however, the diffusion of EVs has become so substantial that it has spurred a series of new second-order challenges and opportunities at the intersection of the mobility system and the electricity system (see e.g., refs. 48 and 49 for related discussions). On the one hand, EVs can produce local electricity grid congestion challenges (16, 50), but on the other hand, they might also constitute an aggregated source of flexibility in the grid. As sustainability transitions become more complex, Markard (49) notes that there tends to be a shift in the emphasis of policy strategies, moving from attempting to stimulate the early adoption of new technologies, to integrate and embed new technologies within existing systems, as well as to coordinate and alleviate systemic impacts of new technologies across sectors.

In late stages of the Norwegian electromobility transition, local electricity peak load challenges have become an issue. At first, these challenges were particularly visible, e.g., at islands with a high share of vacation homes combined with a weak mainland grid connection (51). Later, similar dynamics have become noticeable at substation level in urban neighborhoods, where electricity grids, e.g., in condominiums with shared garages were badly equipped to deal with the influx of EVs (16). Initially, these developments often resulted in local conflicts when individuals or organized early adopters of EVs demanded access to charging points. In this phase, the housing boards and managers of shared garages were hesitant to implement charging infrastructure, citing both costs and fire safety as arguments against shared charging infrastructure as well as the installment of private chargers. This resulted in heated debates in the media. As policymakers gradually became aware that this could potentially slow down further EV adoption, policy instruments were made, which effectively makes access to charging infrastructure in such garages a mandatory right.

Over the last years, the EV-rollout has been accompanied by significant innovation activities at the intersection of the smart grid and electromobility. Most prominently, this can be seen in the work to advance demand management technologies and price mechanisms intended to shift the timing of electricity consumption, often referred to as smart charging (52, 53). Research on development of smart charging processes has highlighted the importance of intermediary actors in charging infrastructure upgrades. Especially, electricians who installed dedicated chargers in the early phase of the EV transition, soon recognized what they understood to be the emergence of a form of "infrastructure anarchy" around the private charging of EVs. To alleviate this metaphorical anarchy, electricians later worked with car dealers and local neighborhood boards to promote automated demand-side management in the form of smart charging (16, 53). These developments have arguably resulted in an increased public understanding of the electricity system and its constraints (16, 54, 55). Large electricity producers and distribution grid companies have exploited this while communicating ideals of

Table 1. Key dynamics of the Norwegian EV transition

Phase	Key policy and actor dynamics	Impacts
Experimentation	Policy strategy to establish an EV industry: policy instruments to stimulate EV demand. High profile experimentation and alliance building across hydroelectricity regime and new industry.	New international market opportunities. Domestic early adopters gaining EV experiences. EVs gaining visibility in Norway.
Stabilization	Policy strategy to mitigate climate change; stronger policy instruments to stimulate EV demand. Technology development builds on traditional auto-industry. User-intermediaries and user-legitimators central.	The establishment of a slowly growing domestic market of EVs, primarily based on charging through existing infrastructure.
Diffusion	Policy strategy to mitigate climate change, policy instruments to stimulate EV demand and develop dedicated EV infrastructure.	Rapidly growing market shares for new EVs. Local conflicts over the establishment of charging infrastructure.
Institutionalization	Policy strategy to mitigate climate change, policy instruments to stimulate broad transport electrification and integration with electricity system.	EVs normalized and dominate new cars sales, strong secondhand market. Charging infrastructure prevalent. National identity as 'EV nation.' Focus on innovation in related fields such as battery production, electric maritime transport.

smart energy consumption in households more broadly, leveraging new public insight into peak load electricity charging. Hence, demand-side management is now gradually becoming part of the electromobility regime in Norway, hence blurring the boundaries between energy and mobility production-consumption systems. Over the coming years, that might also become the case for vehicle-to-grid technologies intended to feed electricity from EV batteries back into the grid. This, however, is still mainly a piloted niche technology in Norway (56).

Beyond the direct developments at the intersection of EV implementation and smart grid functionality, the Norwegian EV experience has arguably also been central in cultivating a broader culture of innovation around transport electrification. Electrification has become a pillar of the Norwegian de-carbonization efforts, partly because it allows for the combination of industrial policy and climate policy strategies (57, 58). This is visible across several domains. EVs are often hailed as the first steppingstone in a future where mobility is shared, connected, and autonomous (e.g., ref. 59), while bus operators in most large cities are rapidly moving toward battery electric buses as a standard. Further, large initiatives including mission-oriented policy instrument packages have been launched to facilitate the electrification of ferries and other maritime vessels (60). For instance, by 2022 more than 60 ferry routes along the western coast of Norway will be electrified. This work also entails significant infrastructural and regulatory transformations, for instance as ports upgrade their energy provision, implement demand management, and often begin producing renewable energy on site (e.g., refs. 61 and 62). Similar developments are unfolding in the construction industry, where policy instruments are pushing for innovation with electrification as an end-result (63). While these developments, like the EV transition, are largely reliant on technology imports, Norwegian authorities are currently nurturing large industrial initiatives in both the North and South of Norway seeking to build battery factories and hence more actively profit from electrification. Norwegian zero carbon hydropower here serves as a sort of industrial pull mechanism for international battery producers who are increasingly seeking to become net-zero producers.

While it is difficult to directly establish a link between Norway's EV transition and subsequent strategies of transport electrification, EVs have arguably played an important symbolic role in showcasing the potential in battery technology as an alternative to fossil fuels. To us, these recent developments serve as a warning against drawing narrow system boundaries when analyzing transition processes. While the early policy strategies and mechanisms for transport electrification arguably resulted in what Smith et al. (64) described as a "fit and conform" pattern of change, i.e., primarily the replacement of a combustion engine with an electric engine, the transition has gradually become much broader. Today, electrification is increasingly seen as a cornerstone of national innovation and industrial ambitions. In sum, thus the transition strategy has shifted toward dynamics similar to what Smith et al. (64) called a "stretch and transform" pattern, where multiple regimes, systems, and actor strategies are changing simultaneously through its dynamics. What started out as an ambition of building EVs and replacing internal combustion engines is gradually transforming the infrastructural fabric of Norwegian society, potentially paving the way for further innovation in adjacent sectors and among international actors (Table 1).

Conclusion

In this article, we have discussed the transition dynamics around the introduction of EVs in Norway, a process which has resulted in a near-complete stop in the sales of new internal combustion vehicle engines in the country, and which is now having broad cascading effects in adjacent systems. The article illustrates the central role of policy in fostering such a process, but also serves as a cautionary tale against quests to find catch-all policy instruments. Instead, the Norwegian experience has been fostered by a policy mix combining what Rogge and Reichart (12) called policy strategies that have shifted over time, and a set of policy instruments targeting both the production and the demand side. Moreover, the case illustrates how transitions within territories such as a country are strongly linked to local conditions. In the Norwegian case, certain traits can intuitively be linked to the success of EVs (hydropower-based electricity system and supportive regime, wealthy nation), whereas other traits intuitively come across as barriers (low population density, large distances, few, and small metropolitan centers). The distinct Norwegian traits have become interlinked with policy and practice developments in other places in the world, illustrating the virtues of analysis with broad system boundaries. Our case also illustrates that nurturing niches is crucial for bringing about regime shifts, but as noted in the MLP (9), such niches need strong links to ongoing external processes to come to fruition (23).

Through our discussion, we have also highlighted the role of actors serving as intermediaries in the process of transition, as well as the role of users not only in adopting vehicles, but in driving the transition further. To us, this also hints at some interesting policy opportunities over the coming years. While policy mechanisms for advancing transitions have tended to focus on stimulating the production and demand of technologies through financial mechanisms, the Norwegian case suggests that there could also be merit in stimulating and nurturing the emergence of new interest organizations, new institutional configurations, and new practices. In sum, we have argued for a nuanced perspective on the relationship between incremental, regime-internal innovation, and wider transformative changes, where the merits of societal learning and experiences from battery electricity for mobility have been highlighted.

Data, Materials, and Software Availability. Data are available from authors upon request.

ACKNOWLEDGMENTS. We would like to acknowledge the comments to improve this manuscript and editing the special issue by Frank Geels, Florian Kern, and William C. Clark. Moreover, we would like to thank the participants of a February 2022 workshop intended to improve early drafts. Special thanks to Toon Meelen, William C. Clark, and Peter Wells for thorough feedback, as well as to two anonymous peers for providing insightful and constructive comments. The work has benefited from funding by the Norwegian Research Council through the Norwegian Centre for Energy Transition Strategies, grant no. 296205.

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