

Article

The Risk of Dissolution of Sustainable Innovation Ecosystems in Times of Crisis: The Electric Vehicle during the COVID-19 Pandemic

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Abstract: Innovation ecosystems evolve and adapt to crises, but what are the factors that stimulate ecosystem growth in spite of dire circumstances? We study the arduous path forward of the electric vehicle (EV) ecosystem and analyse in depth those factors that influence ecosystem growth in general and during the pandemic in particular. For the EV ecosystem, growth implies outcompeting the less sustainable internal combustion engine (ICE) vehicles, thus achieving a transition towards sustainable transportation. New mobility patterns provide a strategic opportunity for such a shift to green mobility and for EV ecosystem growth. For innovation ecosystems in general, we suggest that a crisis can serve as an opportunity for new innovations to break through by disrupting prior behavioural patterns. For the EV ecosystem in particular, it remains to be seen if the ecosystem will be able to capitalize on the opportunity provided by the unfortunate disruption generated by the pandemic.

Keywords: innovation ecosystem; innovation strategy; sustainability; electric vehicle; dominant design; crisis; pandemic



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1. Introduction

The green economy can become an engine for economic recovery after COVID-19 [1], and the electric vehicle (EV) ecosystem is one of the central pillars in the quest for reducing our reliance on fossil fuels. Only about 17,000 electric cars were on the world's roads in 2010, but by 2019, that number had swelled to 7.2 million, 47% of which were in the People's Republic of China. However, electric cars only accounted for 2.6% of global car sales and about 1% of global car stock in 2019. At the same time, only nine countries had more than 100,000 electric cars on the road, and only about 20 countries reached market shares above 1% [2]. Like most other new technologies, EV sales grow along a traditional S-curve [3,4] and they are still in the stage of slow start with oversupply [5]. It is not clear when the EV market will enter in the next life-cycle stage, with a fast growth and supply sometimes unable to keep up with demand, since the automotive industry is a sector that has never had to deal with truly disruptive changes regarding its products, processes, or value network structure [6].

The automotive industry has been considered as an innovative industry driven by strong competitive pressure and constant technological progress, typically with huge investments [7,8]. Nevertheless, this innovation has been incremental rather than breakthrough or radical because it has been focused on optimizing existing products for existing customers and processes [9]. It has been during the last 15 years that this situation has started to change due to the rise of different car engine alternatives to the internal com-

bustion engine (ICE) and new complementary technologies, e.g., artificial intelligence for autonomous driving [10].

The industry is currently in the process of being disrupted additionally by connected, autonomous, and shared driving, causing an unprecedented technology and business model transformation. Competition thus no longer takes place only between firms, but also between entire innovation ecosystems, in which loosely connected entities interact and coevolve to generate and profit from innovation [11–13]. The new competition dynamics in the automotive industry are not limited to a zero-sum game where all competitors compete for a market of a given size [14,15], but are instead focused on how each one of these ecosystems can meet customer and social needs [15,16]. The sustainable innovation ecosystem of the EV is hence trying to outcompete the less sustainable ICE ecosystem. Competition between innovation ecosystems can therefore drive internal competition within firms that produce both ICE vehicles and EVs. On the other hand, firms that compete in some arenas might also collaborate in others, e.g., by influencing policy or strengthening supporting infrastructure [3].

Amid this transformation, the COVID-19 outbreak has put additional stress on the industry [17]. Quarantined workforces, widespread shutdown of business, disrupted global supply chains, and decreasing demand have undermined the viability of the automotive industry [18]. Due to the supply-chain disruptions related to COVID-19, many important firms in the automotive industry, e.g., Tesla, Toyota, Hyundai, and Volkswagen, had to cease operations in several production plants, thus leading to the further compromising of the automotive industry [19]. Such multinational enterprises can play a major role in leading entire innovation ecosystems towards more sustainable practices [20] and can thus foment EV emergence. However, the pandemic has brought the aspirations and main projects of the major automobile companies to a grinding halt [21]. The COVID-19 pandemic will affect global EV markets, although to a lesser extent than the overall passenger car market, which was estimated to contract by 15% in 2020 relative to 2019. The International Energy Agency expects that the EV sales for passenger and commercial vehicles will remain broadly at 2019 sales levels and will represent 3% of global car sales in 2020 [2]. These predictions can change due to the effects of the second and third waves, which will slow and weaken the expected economic recovery [22]. According to Eurometal, the second wave of COVID-19 could drive the recovery of the automotive sector into 2022 instead of the mild recovery currently forecast for 2021 [23]. These predictions and the evolution of the third wave are expanding the uncertainty that car manufacturers are facing. For the participants of this ecosystem, it is difficult to know how long the recovery will take and predict what the next normal will look like. The pandemic is accelerating and reconfiguring existing trends in the economy [24].

Nonetheless, the pandemic has not only caused the emergence of new threats, but also new opportunities that the sector must analyse carefully [25]. Both types of influences lead to profound changes in the macroeconomic and microeconomic environment of this ecosystem; they are driving the emergence of, for example, new consumer behaviours, new regulatory trends, and new technologies. For this reason, it is vital to identify additional factors that are directly affecting the current trends of the ecosystem. In this paper, we therefore ask which factors associated with a severe crisis influence the evolution of innovation ecosystems.

2. Methodology

We seek the answer to this research question through a detailed inductive case study, which aims to identify relevant factors [26]. The inductive case study method is a qualitative research method particularly suitable for identifying unknown factors or mechanisms, which is what we aim to do in this article [27]. This method is therefore adequate for the analysis of emerging fields, e.g., innovation ecosystems, where qualitative research is needed to identify mechanisms and relationships before these can be tested quantitatively [28]. We follow the current tendency to use secondary data when studying innovation

ecosystems [29,30]. This is warranted by the analysis of complex relations involving a multitude of actors, which requires multiple data sources.

The studied case is the evolution of the EV innovation ecosystem during the crisis generated by COVID-19. The considerable impact of the pandemic on EV evolution makes this particular innovation ecosystem suitable for identifying factors that may affect ecosystems in general. In the following section, we analyse the evolution of the EV innovation ecosystem. We then examine factors affecting this evolution related to the pandemic. Finally, we discuss these findings and their impact on research, policy, and practice.

3. Results

3.1. *Barriers to the Evolution of the EV Sustainable Innovation Ecosystem*

Even though the EV has many advantages compared to ICE vehicles, e.g., sustainability, simplicity, reliability, compact dimensions, and fewer moving parts of electric motors requiring less maintenance, whether or not EVs are superior to ICE vehicles throughout their entire life cycle is still subject to debate [31]. More research is necessary to understand the energy performance of EVs [32]. There is still a divergence of opinions and assumptions that confuse the consumer, and above all, there is a lack of compelling business cases that can be presented to the consumer. Additionally, it is necessary to make this comparison from the perspective of a life-cycle assessment to avoid problem shifting or rebound effects and to quantify the environmental impact from raw-material extraction to the end-of-life [33]. According to this view, it seems that EVs have already reached cost parity with ICE cars from a total cost perspective, including upfront payment, maintenance, depreciation, and fuel costs. The performance of the EV is not robust enough and depends on a great variety of interconnected factors, such as duty cycles of the electric engine, driving conditions, and traffic situations [2]. Moreover, the environmental performance of EVs changes greatly depending on the electricity sources.

Another impediment to EV diffusion is that the industry has not yet converged towards a dominant design of the electric car that would lay down a co-aligned structure within the EV ecosystem to set shared technological compatibility standards [15,34,35]. For example, there is not yet convergence on core powertrain design of the EV. There are different battery-cell designs with different geometries, along with multiple chemical compositions, and there is a large variance in the design approach for thermal management with four battery-cooling solutions. The lack of a dominant design reduces incremental innovation to refine the product [36]. Due to this lack of a standardized and shared design and architecture, there is a great variability of EV performance attributes between the different design solutions that have been developed and adapted in parallel. For example, the environmental performance of EVs is strongly influenced by the size of the battery, the energy required in the battery production phase, and how that energy is produced [37–40].

The EV is not an isolated product, which makes its performance dependent on a combination of several factors that have a distinct nature and exert a greater or lesser influence. These factors are controlled by public and private participants of the EV ecosystem, producing different effects in terms of not only the performance of the electric car, but also the degree of acceptance of the EV by the consumer. This expresses the co-dependence that exists within this ecosystem and between these actors and stakeholders, brought about by their mutual co-specialization [41–43]. For example, since the performance of EVs depends on driving styles, weather, traffic, infrastructure, etc. [32], it is necessary to add in the EV's complementary services of support to the driver. These services may include navigation services, vehicle support services, advanced charging services, shared mobility services, or insurance. For instance, beyond delivering a car with superior performance-as-developed, the EV ecosystem also entails the emergence of sufficiently robust complements, e.g., charging infrastructure [3]. Thus, in addition to the battery performance and the charging time, the availability of charging infrastructure is somewhat associated with the driving range performance, which is one of the attributes that influence the adoption of EVs [44,45]. In this sense, fast and smart charging stations are expected to propel the growth of electric

vehicles; the slow charging times of the EV are viewed as a liability when compared with the simplicity of filling up at a gas station [46]. In addition, the inclusion of different pricing and technical charging options of time-of-use pricing will encourage consumers to move their charging from peak to off-peak periods.

The rise and fast development of new technologies with in-vehicle systems and applications are constantly transforming the value propositions brought by the EV. This is due to the rise of the affordability and quality of the properties of these new technologies, which are emerging through the new interactions between drivers, EVs, and these technologies [47]. These major innovations are driving automotive firms into more disruptive innovations that are game changing in the sector and are creating new businesses, new models, and major new categories that are completely redefining the competitive environment [48,49]. For example, the advances in communication and digitalization have transformed EVs into mobile digital devices or platforms that enable and foster new kinds of interactions with the Internet, people, other cars, road infrastructure, etc., by integrating different hardware and software systems as well as support devices such as sensors, cameras, and radar for different purposes (e.g., active safety, driving assistance, and entertainment). The application of these developments is improving and adding new product and service attributes to EVs and delivering new experiences to both drivers and users. These new features are transforming the concept of a car and demand new kinds of co-specialization and collaborative arrangements within and outside the ecosystem with other related ecosystems that also require new forms of governance and new structures. This also generates new opportunities for firms and entails an underlying competition. For example, the global race to be the first company to bring a fully autonomous vehicle to the marketplace depends on a number of components and subsystems coming together that need to be integrated [50]. These new technologies also allow the creation of new business models with new complementarities, such as car sharing services, which are more cost effective and beneficial to society since they reduce traffic and decrease the demand for parking [51,52]. The introduction of these services is driving different usage patterns of car sharing and private EVs. For example, within these new systems of car-sharing services, new technologies allow firms to introduce pay-per-use systems.

The introduction of these radical innovations and new perspectives is shaking up the established order of the automotive ecosystem and is introducing disorders that are constraining the ability of all actors to achieve a clear, deep, and immediate understanding of the new and upcoming complex problems, challenges, or situations that are about to emerge in the transformation of this ecosystem. The constant development and implementation of these changes are now transforming all ecosystem participants, their relationships, and value-creation processes. These new drivers of ecosystem interaction are blurred by the traditional perception of these ecosystem participants of their environment, hence amplifying the value gap and generating a blind spot in the ecosystem [53]. These blurred perceptions also inhibit the gathering of all actors' insights, especially through intuitive apprehension and a lack of understanding of the upcoming crucial relationships within the ecosystem. At the same time, the evolution of the traditional automotive ecosystem is typically viewed as the evolution of more traditional, linear value chains [3,12,35], which has implied a supply- and production-centric perspective to value creation, where the role of the end user is generally reduced to that of a more or less passive recipient buying the system-level orchestrated offering [54]. Thus, the evolution of the EV sustainable innovation ecosystem is altering and disrupting the structure of the car industry, while at the same time questioning century-old assumptions of technological supremacy as the sole differentiator [55].

Table 1 summarizes the barriers to the development of the EV sustainable innovation ecosystem that have been identified in this section, together with the level of innovation required to overcome each barrier. Issues regarding a lack of standardization, infrastructure, efficient business models, and ecosystem structure all require ecosystem-level

innovation, and thus need to be solved through widespread collaboration and coevolution of ecosystem participants.

Table 1. Main barriers hindering the evolution of the EV sustainable innovation ecosystem.

Barrier	Title 2
Price	Firm
Performance	Firm
Standardization	Ecosystem
Infrastructure	Ecosystem
Business model	Ecosystem
Ecosystem structure	Ecosystem

3.2. The impact of COVID-19 on the EV Ecosystem

Before 2020, the EV innovation ecosystem was already struggling to achieve a dominant design and widespread diffusion of the EV. We have identified a number of trends associated with the pandemic that have influenced this struggle (Table 2).

Table 2. Trends associated with the pandemic that have influenced the evolution of the EV innovation ecosystem.

Trend	Impact on EV Evolution
Work from home	Decreased mobility and less need for vehicles
Private transportation	Increased need for private vehicle ecosystem
Decreased spending	EVs are considered too expensive
Active travel	Decreased need for vehicles
Technology adoption	Increasing inclination to adopt EVs
Changing mobility patterns	Uncertainty about future mobility needs
Stimulus spending by states	Higher adoption through lower purchase costs

3.2.1. Working from Home

During the period of the pandemic, automotive consumers and users, as all humans, have been subjected to unprecedented psychological and survival pressures and environment-imposed constraints [56] that have led them to learn and improvise innovative forms to cope with new and blurred boundaries of work, leisure, and education. This has resulted in less commuting to work and other activities. It is quite probable that after the pandemic situation, many meetings will also be held online instead of in person. Thus, there might be a decrease not only in the private demand for vehicles, but also the demand associated with business travel [25].

3.2.2. Private Transportation

During the COVID-19 pandemic, there has been a tendency for people to switch to a different transport mode that reduces the risk of infection, but the exact shifts largely depend on their pre-COVID-19 habits [57]. There is a significant shift from public transport to private transport and non-motorized modes [58,59]. For example, people who own a private vehicle will use it increasingly, while those who previously relied on public transport might switch to another mode, such as biking or walking. Some governments encouraged people returning to work to travel by active means or private car instead of using public transport. According to a survey of the consultancy firm McKinsey [57] about the current consumer sentiment and the anticipated future behaviour related to mobility as economies find a next normal, one third of consumers value constant access to a private vehicle more than before COVID-19, especially amongst younger consumers.

Due to the lockdown, internet searches for used cars for sale in the UK have increased [60], and prices have risen to record levels. [61]. Even if there is no clear guarantee that such results will translate into actual purchases, at the very least they suggest a shift in

opinion [62]. People are more concerned about using private vehicles to travel to/from work, contradicting pre-COVID policy to encourage a modal shift towards more sustainable active and public modes of transport [63].

3.2.3. Decreased Spending

People are inclined to spend less on their car, due to economic effects of the COVID-19 pandemic situation [64]. This can delay the switch to EVs, since the consumer wants to take fewer risks. However, planned spending on vehicles has increased across all geographies vs. previous waves, and this indicates that in some cases EVs may be financially preferable where there are subsidies and tax exemptions in place due to the pandemic effects [64].

3.2.4. Active Travel

Many people have switched to new forms of active travel like walking and cycling, alone or with members of a single household. Active travel encompasses all healthy journeys that demand some form of physical exertion on behalf of the individual [65]. Despite their offering a healthy break during the lockdown, they are also feasible alternatives to the private car or public transport for short journeys [63]. This has been taken as a great opportunity by public authorities to rapidly reconfigure and redesign transportation infrastructures in towns and cities, at relatively low cost, to accommodate active travel in order to improve public health and deliver cleaner air [66]. Active travel is the most sustainable form of transport. It does represent a threat to the EV, but cycling is not accessible to all, and inclement weather and cultural and social barriers continue to limit the number of cyclists who are women and ethnic minorities [67,68].

3.2.5. Technology Adoption

The pandemic has strengthened the role of new technologies as vital complementarities within the EV. Due to the pandemic, consumers have had to rapidly learn to use and adopt new technologies, thus positively affecting their perceptions and acceptance of new technologies and their added value within the EV as modular offerings that encompass inputs from different sources [35,69]. Such acceptance of improved technology due to the pandemic means that EVs are becoming more relevant and competitive. For example, the autonomous and connected EV, if approved for on-road use, could see higher-than-expected demand, since these vehicles enable physical distancing [70]. Some consultancy firms like Accenture consider that the adoption of the megatrends in the automobile sector (connected, autonomous, shared, and electric driving) will remain unchanged as trends will continue to drive the industry's evolution going forward, but the speed of adoption might slow down due to the pandemic [17].

3.2.6. Changing Mobility Patterns

Individual mobility, compared to public transport, leads to higher consumption of natural resources. Hence, there has been a recent trend toward more sustainable behaviours through the use of public transportation, like trains or buses. This is important since sustainable behaviour is not only vital on an institutional level, but also on an individual level [71]. Behaviour during the pandemic is a sign that people adapt quickly to new mobility and driving needs, constraints, and patterns [57,72]. For example, government measures for combating the pandemic, such as movement restriction regulations [73] and their side effects, like panic buying and its time interventions and pressures, have affected consumer behaviours [74]. The population has learned a new skill, i.e., staying at home, which has interfered with individual needs for autonomy, connection, and competence [73]. Faced with this new equilibrium, the consumer has had to adapt by developing and adjusting to new mobility and driving routines, for example, using new routes, new schedules, new mobility purposes, and new destinations. For example, in the UK, "click to car" has become the latest pandemic-friendly way to shop [75]. During this time, the consumer has been experiencing and evaluating these new routines and has been adapting

them to their needs and convenience. We do not know which of these new routines and spatial and temporal changes in mobility [73] will remain as the new normal or if new ones will arise as a result of those that have emerged during the pandemic.

3.2.7. Stimulus Spending by States

As indicated earlier, planned spending on vehicles has increased, and due to the pandemic effects, governmental programs have provided financial support towards the purchase of EVs. Hence, with subsidies and tax exemptions in place [64], a higher adoption through lower purchase costs might also foster EV diffusion. Lower prices might also attract entrepreneurial action, with further competition in the future [76].

For instance, Germany has now overtaken, in terms of EV sales, California, the home of Tesla, due to recently introduced state-funded subsidies [77].

3.3. Long-Term Influence of the Crisis

McKinsey believes that policy makers react differently across regions, since some might view the crisis as an opportunity to reconfigure future transport policy and practice for the benefit of the global environment and individual citizens alike, while others might loosen regulatory mandates to prop up their automotive industries [70]. For example, if physical distancing continues, governments might relax regulations for private mobility, at least over the short term, because people feel less vulnerable to infection in individually owned vehicles [70]; this contradicts pre-COVID-19 policies about the sustainability of public modes of transport. On the contrary, due to the new human mobility behaviours, policy makers might also revise the local mobility regulations to give more space to pedestrians and cyclists. Governments should analyse and develop localised movement policies and regulations [73]. The design of incentives, e.g., green mobility incentives, should also be aligned with such regulations and policies. Previous approaches and policies to mitigate transport noise, emissions, congestion, etc., such as smart mobility, active travel initiatives, and tax reductions, on their own will be inadequate in a post-COVID-19 world because they don't take into account the relevant knowledge about the new needs and customs within individual and corporate travel behaviour [63].

3.3.1. The COVID-19 Pandemic as a Strategic Opportunity

The COVID-19 shutdown is an opportunity to reconfigure future transport policy and practice for the benefit of the global environment and individual citizens alike [63]. EV firms should now focus on resource optimization and standardization, new growth segments, and cost rationalization to overcome slowdown [78], and this will facilitate their transition to the mass market. As an additional strategic opportunity, the pandemic represents a testing ground for EV firms and governments alike, as they can measure the effects on consumers' perceptions of the different decisions made in terms of the introduction and further development of new technologies within the EV, the design of new regulations, and incentives for EVs. This will enhance the framing of more reliable strategic visions and more appealing value propositions for the consumers of EVs, which can accelerate the transition to EVs over ICE vehicles.

3.3.2. Automotive Supply Chain Resilience to the COVID-19 Outbreak

The countermeasures against the pandemic have caused increased border restrictions and complete nationwide lockdowns, leading to important disruptions to international trade and global supply chains [25], especially in the automobile markets. For example, the number of EV models might be reduced to cut costs. Previous strategies related to global supply-chain efficiency have made the supply chain vulnerable to this disruption [17]. These negative consequences have pushed firms to rethink their strategies regarding supply chain resilience (SCR), which refers to the supply chains' ability to prevent and absorb changes as well as regain or improve the initial performance level after an unexpected disturbance [79]. The pandemic has revealed that many companies were focused only

on the quantification of the resilience level and the resulting consequences, rather than the development of both response and recovery strategies [80–82], thereby limiting the capacity of recovering from disruptions [82]. The global analytics firm Crisil has identified the automobile industry as having been highly impacted by the COVID-19 pandemic due to the industry's low resilience [83]. Industry firms can now reconfigure their supply chain resilience strategies in order to predict, be prepared for, and understand the extent of the impact of a future disruption by devising adequate strategies to respond to and cope quickly with the consequences of a disruption and reconfiguring their resources to strengthen competencies and adapt to the consequent effects [21,84]. Such resilient post-COVID-19 strategies require increasing organizational frugality and adapting strategy processes to the new normal [76]. While the resilience of the automobile supply chain has attracted significant attention in recent times, the existing literature lacks empirical investigation into building predictive, receptive, and preventative supply chain resilience strategies and has not addressed the global supply chain impact [85,86].

4. Discussion

When analysing the case of the EV ecosystem during the pandemic, we find that a crisis can serve as an opportunity for new innovations to break through established barriers by disrupting prior behavioural patterns. In the case of the EV, these patterns are mainly related to mobility, but other industries may experience similar disruptions to other patterns. Ecosystem innovation requires aligning ecosystem participants, and a crisis can serve as the necessary impetus that motivates actors towards a joint objective. While posing many challenges, a crisis also offers opportunities. A thorough analysis of the interactions within the ecosystem will render the opportunities presented by this disruption applicable for other innovation ecosystems. Future research can also quantitatively measure and test the factors identified in this study.

The coronavirus pandemic has highlighted the importance of further developing current and new product attributes in response to the new trends and personal protective issues generated with the advent of the pandemic [17]. For example, EV manufacturers are encouraged to shift towards health and wellness solutions in vehicles as part of the new value propositions [78]. Vehicle manufacturers are reconfiguring the internal layout of seats and circulation spaces on buses, taxis, etc., and are installing contactless door sensors and hand-sanitizer dispensers as well as clear screens between seats to provide a physical barrier to airborne aerosols [87]; however, the efficacy and levels of public acceptance of these new configurations are unknown [63].

The COVID-19 pandemic is affecting oil demand and supply, since it has helped trigger a dramatic fall in oil prices due to coordinated massive production cuts to offset the collapse in oil demand [88]. As a consequence, previously planned oil exploration and production may be abandoned on cost grounds and the perceived weakness or uncertainty of demand. The forces of the pandemic will permit slow recovery of the oil demand, thereby curbing major oil price rises for at least three or four years [88]. Some experts have suggested that this could hinder the perceptions of drivers regarding EVs as they look to capitalise on the cost savings associated with lower fuel costs [62]. These factors slow down the pace of transition to more sustainable modes of transportation.

The pandemic has reconfigured the demand for, as well as the role and mobility of, light commercial vehicles (LCVs) due to their role during COVID-19. Panic buying in supermarkets was quickly replaced with overwhelming demand for online food ordering and delivery and retail deliveries as consumers tried to avoid going outside [89]. For some logistics providers, this might mean increasing the number of LCVs in their fleet to cope with a greater number of deliveries. COVID-19 has become a sudden catalyst for change within strategic fleet management because logistic operators have been conveyed to reconfigure and renovate their value propositions. This is a great opportunity for EV manufacturers that can extend their product portfolios to new models of electric LCVs. It

is fundamental that these companies collaborate with logistics companies and with rental companies for commercial fleets.

There is an apparent contradiction between the post-COVID priorities of economic growth needed for a fast economic recovery and the environmental safeguarding and protection priorities through top-down interventions [63]. Restarting the global economy will inevitably require the increased mobility of people and movement of goods, but this contradiction generates a knowledge gap, since all actors in an ecosystem need to align themselves in order to find a delicate new equilibrium and shared new vision; this is not easy to configure between strategic demands and within a period of transition to a wider and mass technological acceptance. This coherent shared vision among participants may therefore reduce the gap of uncertainty and lower the threshold of complements necessary to invest in this emerging ecosystem of the EV [54,90]. New business models, e.g., for car sharing, indicate the additional potential of the EV for less costly and more sustainable modes of ownership and transportation. Future research could push this line of investigation further by developing and testing even more sustainable models, such as those based on a circular economy, with recycling and repurposing of vehicles and their parts [91].

Political action is fundamental for EV uptake since, if policy support is lacking, EV sales will slow down [92–94]. EV adoption requires policy interventions as it is a technological change that is faced with market, system, and institutional failures [95]. Current EV adoption rates are generally low in countries with no or weak policy interventions in this area and higher in countries with strong policies [93,96,97], which suggests that policy interventions can contribute to changing behaviour [98]. The policy environment provides an important set of contextual factors for consumers [99], and even if it does not affect consumer EV adoption directly, it interacts with psychological factors, moderating their relationships with EV adoption [100]. For example, perceived behavioural control may lead to high EV purchase intentions only when financial policy instruments sufficiently reduce the price gap between EVs and ICE vehicles [101]. There is still an important research gap regarding empirical analysis on the effect of policies on EVs [102]. It has been suggested that the hybrid data-driven models that combine both macroeconomic and microeconomic variables are preferable to other methodologies (e.g., agent-based) that have delivered biased predictions; however, there is no unanimity on which method is the most appropriate [103].

Innovation policy can support the investment of research and development funds and the improvement of innovation capabilities for entire innovation ecosystems [102]. The “double credit policy” uses different reward and punishment mechanisms simultaneously to block the development of the ICE vehicle industry and promote the development of new energy vehicles [103]. Another possibility, especially for emerging countries, is public investment in the domestic automotive industry, such as favourable financing or requiring local manufacturing to qualify for subsidies; this has proven effective in the development of EVs that meet the needs of domestic populations [104].

The effectiveness and efficiency of different policy instruments may be similar depending on their design and robustness from a purely economic viewpoint, but also on their political feasibility and their effects on public opinion [105]. Pull policies, e.g., subsidies, attract more public support than push measures, e.g., fuel taxes and travel restrictions. In addition, there is considerable political room to manoeuvre for more ambitious pull measures, such as the large-scale expansion of public charging infrastructure.

5. Conclusions

A crisis tends to foment the emergence of a dominant design in science-based industries [106]. However, we have analysed factors and circumstances that both support the EV innovation ecosystem as a whole, and slow down ecosystem growth. To increase the pace of transition to EVs, countries with key markets must shape and implement jointly common and synchronized policy packages to enhance policy synergies and effects between

countries [107]. Although different prediction models have been designed for the diffusion of the electric car at the national level, no truly global diffusion model has been agreed upon and developed to investigate EV uptake [107]. The identified factors demonstrate that this sector still lacks a full perspective, structure, and ecosystem governance, since the coordination of policies requires cooperation not only from different public national and international authorities but also between the different stakeholders and participants in the ecosystem. These negotiations require the full commitment of the global players, including governments and EV manufacturers. An extended charging infrastructure for EVs is thus equal in importance to the institutional infrastructure supporting the resilience of the EV innovation ecosystem. Finally, the sustainability of the EV innovation ecosystem depends on whether it's fuelled by green energy. Carbon-intensive electricity sources imply little improvement compared to ICE vehicles, and the use of climate-friendly energy, e.g., biogas and biomass, is crucial to make the EV ecosystem part of climate action [108]. The support of such underlying energy infrastructure hence defines the climate impact of the EV ecosystem.

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