



Innovation based on the co-evolution of institutions and firms: An integrative literature review of the electric vehicle transition

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ABSTRACT

Innovation is a key driver of economic growth, transforming industries and reshaping competitive advantage. This process, usually led by firms, often drives research toward pollution-intensive directions due to path dependence and lock-in around existing technologies and incumbent business models.

Given the societal impact of road transportation, the decarbonization of mobility became a priority for governments, leading the transition to electric vehicles. This paper argues that the electric vehicle transition is not solely a firm-led technological innovation, but a co-evolutionary innovation shaped by institutions and firms.

Using an Integrative Literature Review, the study reviewed this transition to explore how formal institutions (e.g. regulation, industrial policy), informal institutions (societal values, expectations), and firms' strategies interact over time to produce sustainable innovation. The study identifies five distinct phases, each characterized by different institutional roles, corporate strategies and societal attitudes.

This research offers a significant contribution to both co-evolutionary theory and innovation management, particularly in the context of sustainability transitions, by advancing a new co-evolutionary innovation framework with a mission-oriented perspective. The proposed multi-phase model provides an analytical lens for policymakers and business practitioners to examine how institutional pressure evolves toward market-based competition as innovation diffuses, highlighting how effective collaboration between public institutions and private firms can enable sustainable innovation.

1. Introduction

Innovation is a key driver of economic growth, transforming industries through “creative destruction”, whereby new technologies replace older ones and reshape competitive advantage [1]. This process, usually led by firms and entrepreneurs, disrupts equilibrium and triggers business cycles, occasionally leading to industrial revolutions. Such breakthrough innovations bring profound social and economic change, creating opportunities and risks as they reshape customer attitudes and sector structures, forcing firms to revise and adapt their business models [2]. Evolutionary theory argues that innovation trajectories are rarely neutral: path dependence and lock-in around existing technologies, infrastructures, and incumbent business models drive research toward pollution-intensive directions [3]. National industrial policy plays a pivotal role in innovation; by imposing specific policies, governments can redirect technological innovation in line with societal expectation toward a sustainable path [4] and facilitate the emergence of new industries [5].

Due to the societal consequences of air pollution and the significant contribution of road transportation, which accounts for nearly one quarter of global CO₂ emissions [6], the transition toward emission-free mobility has become an urgent necessity. Although technological innovations in the automotive sector have reduced emissions from traditional internal combustion engine (ICE) vehicles, the rapid expansion of the global vehicle fleet continues to outpace these efficiency gains [7]. As a result, alternative powertrain solutions are required, and battery-electric vehicles (BEVs) have emerged as the most widely endorsed technological pathway for decarbonizing road transportation [8,9]. At the same time, achieving truly zero-emission mobility requires complementary systemic actions, including the decarbonization of electricity generation, sustainable battery production and lifecycle management, and the smart integration of electric vehicles into energy systems and power grids [10,11].

This paper aims to review the innovation process related to the BEV technology, arguing that the transition to emission-free battery electric vehicles cannot be considered solely as a technological innovation driven by firms' strategies but rather as a broader transformation shaped

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Abbreviations

BEV	Battery Electric Vehicle	MNE	Multi-National Enterprise
CARB	California Air Resources Board	METI	Japan's Ministry of Economy, Trade and Industry
EEA	European Environment Agency	MITI	Japan's Ministry of International Trade and Industry
EU	European Union	MLP	Multi-Level Perspective
EV	Electric Vehicle	NEV	New Energy Vehicle
ICCT	International Council on Clean Transportation	NGO	Non-Governmental Organizations
ICE	Internal Combustion Engine	OEM	Original Equipment Manufacturers - Car Manufacturers
IEA	International Energy Agency	PHEV	Plug-In Hybrid Vehicle
ILR	Integrative Literature Review	R&D	Research and Development
IPCC	Intergovernmental Panel on Climate Change	SLR	Systematic Literature Review
LEV	Low-Emission Vehicle	US EPA	United States, Environmental Protection Agency
		USDE	United States, Department of Energy
		ZEV	Zero-emission Vehicle

by regulatory actions and societal demand [12,13]. This process, wherein institutional regulations, firms' strategies and societal expectations continuously influence each other's trajectories, makes the EV transition a textbook case of co-evolution theory [14] and an outstanding example of innovation driven by the co-evolution of institutions and firms. National governments impose cleaner vehicles to achieve emission-free road transportation, meet climate commitments, reduce energy import dependence, and lower healthcare costs [15,16]. Firms and organizations are developing capabilities to achieve viable technological innovations. Consumers, meanwhile, are revising their mobility preferences based on environmental expectations, while policy incentives are creating new value propositions such as lower usage costs and smoother urban driving [17,18].

Despite the growing relevance of electric vehicles in the global sustainability agenda, the EV transition has received limited attention from a co-evolutionary perspective [19]. This represents an important research gap, as the interaction between institutional forces and corporate strategies plays a pivotal role in shaping the pace, direction, and outcome of technological innovation. These reflexive dynamics influence firms to develop new capabilities and adapt their business models but also impact the effectiveness of policy frameworks designed to steer the transition. A deeper understanding of this interplay is essential for explaining how innovation trajectories unfold and under what conditions institutional alignment and strategic firm action converge to enable a successful transition.

This study explores how formal institutions (such as government regulations) and informal institutions (societal values, norms, and expectations) shape firms' innovation strategies, based on the transition to battery electric vehicles (BEVs), using an Integrative Literature Review (ILR) approach. The research begins by identifying key phases of the EV transition as evidenced in the existing literature, with the aim of illustrating how large-scale innovations emerge through the continuous interaction between institutional pressures and corporate responses. Building on the foundational work of Rodrigues and Child [20], the study advances a new co-evolutionary framework derived from the EV transition, which enables a deeper understanding of the mutual influence among institutions, firms, and society, and how these reciprocal interactions shape the trajectory, nature and success of co-evolutionary innovations. This subject is relevant far beyond the automotive sector.

The primary objective is to uncover how institutional forces not only promote the adoption of emerging technologies but also influence the strategic choices firms make in response. Rather than viewing the BEV transition as a linear, technology- or market-driven process, the study adopts a more holistic perspective, emphasizing the complex, reciprocal dynamics through which regulation, social expectations, and corporate innovation co-evolve. In addition, it offers insights into how innovation systems can be steered toward sustainable outcomes.

This study makes a significant contribution to both co-evolutionary theory and the field of innovation management, particularly in the

context of sustainability transitions. First, it advances a new co-evolutionary innovation framework with a mission-oriented perspective. Based on the work of Rodrigues & Child [20], this new framework positions innovation not as a by-product, but as a central outcome of the reciprocal relationship between institutions and firms, emphasizing how government policy, societal pressure and strategic firm action collectively influence technological pathways. Secondly, the proposed multi-phase view provides a useful analytical framework for understanding how institutional pressure evolves into market-based competition as innovation diffuses, offering valuable insight into the dynamic nature of technology adoption and industrial transformation. Thirdly, the study demonstrates how effective collaboration between public institutions and private firms can enable sustainable innovation, helping to overcome path dependence and avoid technological lock-in, conditions that typically constrain transitions to cleaner alternatives. Furthermore, the case of the electric vehicle transition represents a complex, multi-sector, multi-country phenomenon that is rarely addressed in such an integrative way in co-evolutionary studies [21]. By synthesising this case, the research contributes to broadening the empirical base of the theory's applicability to large scale, cross-national innovation systems. The study makes a significant contribution to theoretical understanding and provides practical implications for how institutions and firms can work together to shape systemic innovation in response to urgent societal challenges, such as climate change and industrial decarbonization.

2. Theoretical background

2.1. Co-evolution theory

Co-evolution theory explains the reciprocal and dynamic relationship between firms and their environments, drawing from biological evolution, where adaptation and selection shape populations over time. In a business context, this perspective posits that firms do not evolve in isolation but co-develop alongside institutional, technological, and socio-political environments [22,23]. Organizational adaptation, as proposed by March [24], occurs through both exploration and exploitation, reflecting a mutual influence between firms and their external environment.

According to Hannan and Freeman [25], Darwinian mechanisms operate in competitive environment, where only firms with suitable characteristics survive changing market conditions. Rodrigues and Child [20] describe three strategic firm responses to environmental change: inertia due to internal limitations, reactive adaptation following external triggers, and proactive shaping of the environment. The latter reflects true co-evolution, where firms seek to influence external conditions through lobbying, stakeholder engagement, or regulatory change [26,27].

Volberda and Lewin [28] identify a multi-level co-evolutionary

framework that links firm-level strategies to industry dynamics and macro institutional factors. Environmental forces shape firm behaviour, but firms can also shape these forces, especially when political, regulatory, and cultural dimensions are considered [20]. Institutions evolve alongside firms, with institutional changes often being slow but significant, particularly when driven by shifts in political power and economic policy [29,30].

Rodrigues and Child [20] developed a framework illustrating how firms co-evolve with institutions during transitions from highly institutionalised environments to liberalized markets. Drawing upon a Brazilian telecommunications case, they demonstrate that, even in the context of stringent regulatory constraints, managerial agency can exert influence over change through engagement with networks, civil organizations, and political structures. By analysing interactions across macro (societal), meso (sectoral), and micro (firm) levels, the framework effectively captures the dynamics of firm–institution co-evolution and the shift in firm strategy from a regulation-driven environment to competition-driven market conditions [20]. The framework is of significant value in the representing the roles of different actors and their interconnections.

The co-evolutionary perspective applied in this research incorporates both formal institutions (laws, regulations, and rules) and informal institutions (norms, cultures, and ethics) as proposed by the Institution-based view [31]. Informal institutions, such as societal norms, values, and culture, interact in a triangular relationship with firms and formal institutions, where public opinion can shape government policy, and governments can, in turn, influence societal values [32,33].

In conclusion, co-evolution theory provides a robust theoretical framework for understanding the reciprocal relationship between firms and their environments. This framework underscores the dynamic interplay between firms and the external forces that shape their evolution, including technological, institutional, and socio-political factors. It is imperative for firms to adopt proactive, adaptive strategies in order to thrive and build long-term competitive advantage in complex, evolving contexts.

2.2. Co-evolution theory and innovation

Co-evolution theory offers a framework to comprehend innovation as the consequence of reciprocal, continuous interactions between firms and institutions, providing a synthesis of Schumpeter [1] theory, which considers firms and entrepreneurs as the driving force of innovation, and evolutionary theory, which emphasizes the role of institutions and national industrial policy in steering innovation trajectories. Economic growth is considered a dynamic, multidimensional process driven by the interaction and mutual adaptation of technologies, firms, industry structures, and supporting, governing institutions [34].

Institutions exert influence over competition through regulation and innovation policy [5]. While evolutionary theory highlights the tendency for innovation to follow pollution-intensive paths due to technological and institutional lock-in, targeted interventions, such as regulation, research incentives, and stakeholder engagement, can redirect development toward sustainable alternatives [4]. Current major global challenges (pollution, sustainability, energy and raw material sourcing) have a negative effect on incumbent firms, as lock-in around existing technologies and incumbent business models make them reluctant to develop radical innovations. However, consumers, civil organizations, and lawmakers can apply pressure to drive innovation that serves the collective interest of society and avoids path dependence [35].

The multi-level perspective (MLP) has become one of the most influential frameworks for analysing sustainability transitions. Developed by Geels [14] and refined in subsequent work [35,36], the MLP conceptualizes transitions as the outcome of interactions across three analytical levels: niches (spaces for radical innovation), socio-technical regimes (dominant technologies, rules, and institutions), and the

landscape (broader macro-structural trends such as climate change, geopolitics, or cultural values). These levels interact dynamically, with transitions emerging when niche innovations gain momentum, landscape pressures destabilize incumbent regimes, and new socio-technical configurations begin to form.

These interactions vary across industries and regions, producing multiple evolutionary paths shaped by geographic and historical conditions [37,38]. Governments play a critical role in this process by aligning industrial policy with national interests, using reliable data to craft flexible policies that evolve from directing innovation to supporting it as systems mature [39,40]. It is evident that firms do not merely adapt to institutional change; they also have the capacity to actively shape such change. Due to the accelerating rate of innovation and global market integration, particularly within technological sectors, the external environment of a firm becomes increasingly complex and challenging [41], offering more opportunities for organizations to influence their macro environment (policies, regulations, and norms), thereby supporting the co-evolutionary theory [42]. In the context of globalization, where value chains, product cycles and the technological evolution of specific industries are interconnected, the role of the national and firm-level innovation strategies in shaping industry evolution requires greater attention in strategic management research [43]. In cases where an appropriate national strategy and corresponding government policies are in place, the reciprocal relationship between national innovation policy and MNE (multi-national enterprise) strategy can lead to the establishment of new industries based on technological innovation. In the absence of adequate government policy or supportive industry conditions, firm innovations may migrate from the home country to contribute to the development of another national economies [44].

The interplay among government policy, corporate innovation, and customer adoption creates a dynamic system in which societal responses can influence the reshaping of institutional priorities and regulatory approaches [35].

As presented in Fig. 1, which was developed by the authors, formal institutions (government policy) and firm interactions contribute to the development of innovations. The adoption of innovations by customers provides firms with invaluable feedback, highlighting areas for further innovation and progress. Concurrently, the attitudes of customers and the diffusion of innovation contribute to the evolution of society, which in turn exerts an influence on the evolution of formal institutions.

The co-evolution framework is especially pertinent in the context of

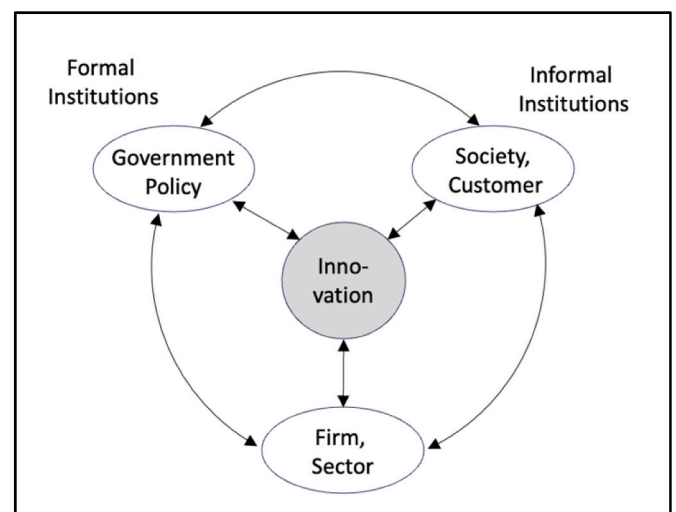


Fig. 1. Innovation based on co-evolution of formal institutions, firms, and society.

Source: Authors' own construction

large-scale transitions, such as the shift to zero emission mobility, where innovation depends not only on technological breakthroughs but also on system-wide coordination and institutional alignment. Innovation emerges through the interaction between firms and institutions, where public policy steers investment and R&D (Research and Development), firms transform knowledge into technologies and products, and consumer adoption generates feedback that shapes both markets and regulatory frameworks [14,45]. Public expectations, media narratives, and societal norms further influence firm strategies and policy trajectories, underscoring the mutual reinforcement between technological and institutional change [36].

Integrating the multi-level perspective with the co-evolution theory provides a more granular explanation of how and why institutional and corporate actions change over time. Whereas multi-level perspective describes structural pressures and windows of opportunity, co-evolution explains how firms develop new capabilities, experiment to redesign business models, and engage in strategic actions to influence institutional responses [26]. This reciprocal influence is essential in sectors where regulatory mandates, infrastructure, environmental and socio-cultural factors, and firm-level technological innovation co-evolve.

Innovation is therefore a multi-actor, multi-directional process, in which formal institutions (e.g., laws, regulations, mandates, infrastructure investment) and informal institutions (e.g., norms, culture, social movements) interact with firms to co-create the future. It is no longer sufficient to conceive the innovation as a linear process from scientific discovery to market uptake. Instead, in the current context, where priorities are shaped by global challenges such as climate imperatives and energy sourcing, innovation is increasingly driven by recursive and interdependent dynamics between firms, formal institutions, and society [46]. It is essential to understand this dynamic if we are to design effective policy, build adaptive firms, and navigate transitions in critical sectors such as transportation, energy, and healthcare [35,47].

In summary, innovation should not be viewed as an isolated outcome of firm strategy; rather, it emerges through the continuous reciprocal interaction of firms, industries, and institutions. This perspective is further supported by transition studies highlighting the interaction between innovation systems and socio-technical regimes [48], as well as empirical analyses of transition management approaches, which demonstrate both the potential and the political and institutional challenges of steering systemic change toward sustainability [49].

The success of sustainability-oriented innovations thus depends on an enabling institutional environment that evolves with market actors [50]. Recognizing and regulating this dynamic interplay is essential for fostering sustainable, competitive, and adaptive innovation systems [51].

3. Research gap and importance of the EV transition

Despite the application of the co-evolution framework in numerous case studies across various sectors, including the automotive, chemical, energy, and finance industries, as well as in multiple regions covering Europe, Asia, and the Americas, the academic literature still lacks a co-evolutionary analysis of the electric vehicle (EV) transition. Existing literature on the subject typically examines a single industry within a single institutional context, thereby leaving unaddressed the multi-level, multi-country, and path-dependent dynamics that characterize EV diffusion. Consequently, there is a significant gap in current scholarship regarding the co-evolution of formal (e.g., government regulations) and informal (e.g., societal expectations) institutions with firm level innovation in the EV transition. Understanding this gap is essential, as this transition represents a complex, globally interconnected process that unfolds through the simultaneous interaction of technological change, institutional adaptation, and societal transformation. A co-evolutionary perspective that captures this complexity can provide more detailed insights into the mechanisms of large-scale innovation, support more

context sensitive policymaking, and contribute to the development of more effective strategies for accelerating sustainable mobility transitions.

This study addresses the following research questions.

1. What are the key institutional, organizational, and societal levers that drive sustainable innovation and large-scale transition in the electric vehicle sector?
2. How do institutions and firms interact to overcome path dependence and technological lock-in during the electric vehicle transition?
3. How can the co-evolutionary dynamics observed in the EV transition be conceptualized into a generic framework applicable beyond the automotive sector?

4. Methodology

4.1. Research design

The present study explores the electric vehicle transition, with the aim to understand how innovation is driven by the co-evolutionary relationship of institutions and firms. The research was developed using a qualitative method, specifically the Integrative Literature Review (ILR), due to the exploratory nature of the study.

A Systematic Literature Review (SLR) demands a rigorous approach to the formulation of its search strategy. The Integrative Literature Review permits the incorporation of research articles, supplementary documents, and information published by experts and reliable organizations [52]. The integrative review methodology is a recognized qualitative approach in management studies for assessing emerging subjects that require an initial structured understanding and the identification of relevant concepts related to the topic [53]. The Integrative Literature Review was employed in this research to analyse and synthesize existing literature on the specific research subject, thereby enabling the conceptualization of new perspectives and frameworks [54].

4.2. Research Process

The subsequent research process was implemented based on Webster & Watson [55], as illustrated in Fig. 2.

- **Step 1 - Scope definition:** The primary goal of the research is to understand how the global automotive sector is transitioning from internal combustion engines (ICE) to electric vehicles (EVs) through the co-evolution of institutions and firms. Specifically, the study seeks to identify distinct phases of this transition, each characterized by a different combination of institutional roles, corporate strategies and societal attitudes. The systematic literature review therefore targets publications that analyse the interplay of regulatory, technological, and market dynamics in the automotive and broader mobility sectors, covering the period from the early 1970s to 2025.
- **Step 2 – Conceptualization:** The conceptual framework underpinning the research is the co-evolution theory, particularly in relation to innovation driven by the reflexive evolution of societal expectations, institutional regulation, industrial structure and firm capabilities. The EV transition is examined as a multi-level phenomenon involving macro-level (policy, regulation), meso-level (industry structures, market dynamics), and micro-level (firm capabilities, business models) interactions. These dimensions were mapped onto a timeline in order to identify distinct evolutionary phases reflecting shifts in institutional regulation, user acceptance, and firm strategy.
- **Step 3 - Literature search:**
 - o A systematic literature search was carried out using the Scopus database, as it provides an extensive list of articles from other databases, including WoS and Emerald [56]. The search criteria were defined as “Electric vehicle transition” and “Business

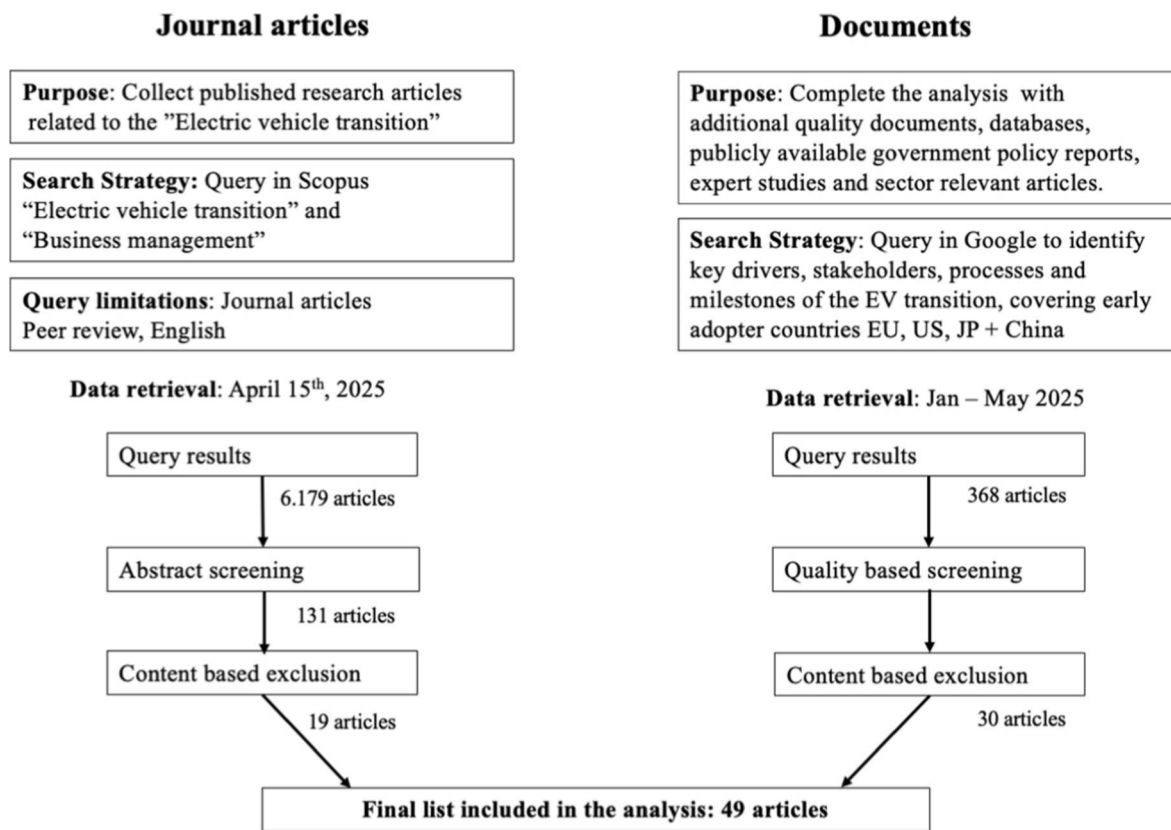


Fig. 2. The research process.

management" in order to ensure that articles and studies related solely to the field of engineering were excluded. The bibliographic data (i.e. the DOI, the year of publication, and the authors) were recorded for each article. The articles were then coded by system level (macro, meso, or micro) and by thematic relevance. The initial query produced 6179 records.

- o This step has been followed by an initial screening, involving a review of titles and keywords to verify topical relevance. Although the initial Scopus search was not time bounded, additional filters were applied to retain only peer-reviewed journal articles and conference papers published in English, in order to ensure the quality of the documents [57]. These criteria reduced the list to 131 documents.
- o Additionally, each abstract was examined in depth to confirm alignment with the study's subject and intended focus. During this phase, publications were excluded if they did not meet the pre-defined scope and quality requirements, in particular if they focused exclusively on technical, engineering, or battery chemistry aspects of electric vehicles without addressing institutional, organizational, strategic, or market dimensions, or if they lacked sufficient conceptual or empirical grounding relevant to the co-evolution of institutions and firms. This step narrowed the set to 42 documents.
- o Finally, a comprehensive review of the articles was performed through a detailed reading of the remaining papers. During the full-text screening, studies that did not sufficiently contribute to the analytical framework or empirical understanding of the co-evolutionary dynamics of the EV transition were excluded, leading to a final sample of 19 articles. The full list is provided in Appendix A.
- o Given the rapid pace and the complexity of the EV transition, this study adopted the Integrative Literature Review (ILR) methodology, which proposes to complete the list of peer-reviewed

academic articles resulting from the SLR by incorporating a variety of additional sources, including government policy reports, expert studies, sector-specific articles, and industry databases, in order to ensure a more comprehensive understanding and enhance the validity of the findings. The selection of additional documents followed clearly defined inclusion criteria to ensure analytical rigor and transparency. Documents were required to demonstrate direct relevance to institutional–firm interactions within the electric vehicle (EV) transition and to provide an explicit, evidence-based analytical contribution to understanding regulatory mechanisms, strategic firm responses, market evolution, or technological development. Eligible sources included publications issued by institutionally credible organizations, such as government agencies, international organizations, recognized research institutes, established industry bodies, as well as reputable international press outlets with established editorial standards, in order to ensure reliability and methodological soundness. Through this process, the analysis integrated documented firm-level and policy-level cases. All included documents were cross-validated against peer-reviewed academic literature or official data sources to ensure consistency and to avoid reliance on isolated or unsubstantiated claims. Sources characterized primarily by advocacy positions, opinion-based arguments, or lacking empirical or analytical grounding were excluded from the review. As Bowen [58] observes, the integration of supplementary documentation is essential for cross-validating information from diverse sources. The aim of this extended review process was to identify the key drivers, stakeholders, processes, and milestones, both accelerators and roadblocks, of the EV transition. The analysis focuses primarily on early adopter regions, namely the European Union, the United States (with focus on California), and Japan. Despite its later start, China has rapidly overtaken many early adopters and offers valuable insights into the dynamics of the EV transition, thus

justifying its inclusion. The process yielded a total of 30 additional documents, listed in Appendix B.

• **Step 4 - Literature analysis and synthesis:**

- o The relevant information was analysed using a structured qualitative coding process consistent with the Integrative Literature Review (ILR) approach. The literature was coded by thematic focus, concentrating on formal and informal institutional dynamics, firm-level strategies and capabilities, and interactions across macro, meso, and micro levels. Temporal markers and key events were also coded and integrated into a structured timeline to identify patterns of co-evolution between institutions and firms. The coding process followed a hybrid deductive–inductive approach, thus combined theory-driven categories derived from co-evolutionary and transition literature with inductive codes emerging from the reviewed material, allowing analytical flexibility while preserving theoretical coherence.
- o The research process included a historical reconstruction of the electric vehicle (EV) transition, which is intrinsic to the ILR methodology and enables the synthesis of heterogeneous sources of knowledge by tracing the temporal evolution of institutional, technological, and societal developments [52,54]. Reconstructing this sequence by synthesising evidence, was essential for understanding how co-evolutionary dynamics unfolded and for identifying gaps and inconsistencies in prior scholarship.
- o Distinct phases were identified by clustering coded events and mechanisms along the timeline, based on observable shifts in dominant institutional logics, firm strategies, and societal attitudes. Phase boundaries reflect qualitative changes in the configuration and relative influence of these actors rather than fixed chronological intervals. Based on this analysis, five distinct phases of the EV transition were identified and are discussed in detail in the Findings section.

- **Step 5 – Research agenda:** The synthesis points to important directions for future research: (1) Institutional adaptation, (2) Cross-sectoral co-evolution, (3) Emerging markets dynamics reshaping global sectoral structure, and (4) Business model innovation.

4.3. Validity and triangulation

To ensure the reliability of this Integrative Literature Review, the analysis followed a structured and transparent methodological procedure. First, the selection and coding of the 19 scientific articles and 30 expert documents were conducted using a predefined coding protocol grounded in established co-evolutionary theory and the existing literature on the electric vehicle transition, in line with recommendations for rigorous qualitative synthesis [52,54]. The coding scheme focused on institutional dynamics, firm strategies, societal responses, and their interactions across macro, meso, and micro levels and was iteratively refined during the analysis. This inductive process enabled the identification of recurring patterns and temporal sequences, which subsequently informed the development of the new co-evolutionary innovation framework.

Inter-coder reliability was strengthened through iterative cross-checks of the coding scheme: independent reviewers coded the sources, discrepancies were discussed, and the coding scheme was refined until conceptual saturation and consistency were achieved [59]. Methodological triangulation strengthened robustness by integrating evidence from peer-reviewed academic sources with industry reports, policy papers, and technical documents, enabling cross-validation of emerging themes and reducing single-source bias [60]. Additionally, negative or contradictory evidence was deliberately incorporated to avoid confirmation bias and ensure analytical neutrality [61]. Together, these procedures support a rigorous and credible synthesis of existing knowledge on the co-evolution of institutions and firms in the electric vehicle transition.

5. Findings

This section summarises the key findings of the study, as revealed by the Integrative Literature Review. These findings highlight the evolving dynamics of the automotive industry. Over the past two decades, the automotive industry has faced intensifying global competition, with established and emerging car manufacturers (original equipment manufacturers - OEMs) expanding into increasingly diversified product segments [62]. However, the shift toward electric vehicles (EVs), has introduced a profound structural transformation, embedding the sector in a new, highly institutionalised macro environment [63].

This new environment is shaped not only by formal institutional regulations, such as zero emission mandates, CO₂ standards, fleet policies, and subsidies, but also by informal institutional forces, reflecting shifting societal expectations around health, environmental sustainability, and urban quality of life [35,64].

Institutional measures have required firms to upgrade their capabilities, catalysing technological innovation leading to EV product. This progress has enabled the development of a wider and more attractive product offering, thereby fostering market competition. Consequently, consumer acceptance has increased, and EV diffusion accelerated, establishing new market norms [65]. Growing demand has intensified competition among OEMs, so that market forces, rather than top-down mandates, have begun to steer industry behaviour [66].

The study revealed five distinct phases based on the dynamics of these events, each defined by different and shifting roles, attitudes, and actions of the three key stakeholder groups: formal institutions, firms and society.

• **Phase 1.1970–1983: Institutional Strategic Shift**

Institutional pressure, Problem Identification and Agenda Setting.

• **Phase 2.1983–1997: Institutional Push for Firm's Innovation**

Institutional Push and Support, Early Firm Innovation and Societal Learning.

• **Phase 3.1997–2015: Innovation driven Market competition emerges**

Market Competition Emerges, Institutional Pressure Reduces, User adoption limited by technology constraints.

• **Phase 4.2015–2020: BEV upscaling, Firms Business Model shift**

Market Upscaling, Regulatory Recalibration, Institutional support to remove user adoption barriers, Emerging markets transform global sector structure, Aligning innovation with environmental and societal goals.

• **Phase 5.2020 –: Sector transformation drives Institutional policy change**

Global Industrial Footprint Shift, Strategic National Industrial Policy. Phase boundaries and transitions were defined based on significant events and turning points that produced qualitative structural shifts in the configuration of macro–meso–micro interactions within the EV transition, including.

- Observable changes in dominant institutional logics.
- Modifications in regulatory instruments or policy orientation.
- Significant technological or market breakthroughs.
- Reconfiguration of firm strategies, business models, and industry structure.

- Alterations in user adoption patterns and diffusion dynamics that prompted institutional recalibration.

5.1. Phase 1.1970 – 1983: Institutional Strategic Shift

The 1st phase began with the first public actions for a healthier environment (The 1st Earth Day). Mounting societal awareness, particularly of the impact of air pollution, prompted escalating influence of environmental movements on governmental institutions in the US, Japan and many European countries. This led to the establishment of the Environmental Protection Agency (US EPA) [67] and the Environmental Agency in Japan in 1971 [68].

These environmental concerns, together with geopolitical risks related to energy dependence, stimulated by the 1973 oil crisis [69] prompted governmental regulatory actions, which resulted in the 1970 Amendment of the Clean Air Act, authorizing for the first time in the US, federal and state regulations to limit emissions [67] and triggered the transition towards electric vehicles (EVs).

The Institutional Strategic Shift to cleaner transportation, included the definition of targets for the transition and the launch of early exploratory initiatives to engage stakeholders and identify potential roadmap. Government institutions, including the U.S. Department of Energy (US DE), Japan's Ministry of International Trade and Industry (MITI) and various European national agencies, played a central role in initiating R&D programs, offering subsidies, and coordinating pilot projects to stimulate EV innovation, including electric powertrains, and battery technology [70–72].

The Japanese government started in 1976 a long-term innovation plan targeting to develop zero emission vehicles by launching structured collaboration between public agencies, universities, local authorities, car manufacturers (OEMs), and automotive suppliers [68,73].

That time, automotive firms' engagement was still limited; EV projects have been marginal in R&D resource allocations, but some firms decided to launch exploratory initiatives, as a hybrid test vehicle based on Buick Skylark in 1972.

These initial steps, along with early stakeholder dialogues among government agencies, environmental NGOs (Non-governmental Organizations), academia, and the automotive sector allowed for the exploration of the feasibility and strategic implications of zero emission mobility [74,75] and helped define shared goals for achieving clean mobility. This phase established the normative and technological foundations that would later enable more systematic industrial transformation.

5.2. Phase 2.1983 – 1997: Institutional Push for Firm's innovation

The 2nd phase began with the launch of the revised EV plan by Japan MITI, which led in 1997 to the development of hybrid technology in 1997. This period underlines the deepening co-evolutionary relationship between institutions and firms, which was paramount in achieving the required groundbreaking technological innovation [76].

Institutional pressure increased, as evidenced by the California's ZEV (zero emission vehicle) Program mandate announced in 1990 by the California Air Resources Board (CARB), which defined ZEV sales mix targets glidepath for car manufacturers: 2% required in 1998, 5% in 2001 and 10% in 2003 [77].

These institutional actions prompted the development of firms' innovation capabilities, raised awareness for the large public about the targeted EV technology, and initiated the first real-world tests to measure customer acceptance and identify transition roadblocks. National governments collaborated with local authorities and car manufacturers to initiate pilot customer projects, such as the EV1 created in 1988 by General Motors [62,78]. These vehicles were not yet commercially viable for the mass market but allowed firms to test market fit and gather valuable real-world user experience, improving understanding of range

anxiety, infrastructure needs, and design limitations.

Product experimentation initiatives were accompanied by targeted communication strategies designed to raise awareness about the benefits of electric vehicles (EVs) and to address consumer concerns about range, safety and performance [79]. The notion of user acceptance played a crucial role in guiding both technological development and regulatory adjustments.

Despite significant investments, firms' R&D activity and cooperation with institutional organizations didn't yet succeed in developing a viable solution for the targeted BEV (battery-electric vehicles) technology intended to replace ICE (internal combustion engine) vehicles.

However, the Japanese flexible innovation process enabled the development of hybrid electric vehicle technology in 1997 [68], leading to the launch of the first mass produced hybrid vehicle, the Toyota Prius. This vehicle offered a more suitable solution for mainstream customers due to the limited availability of charging infrastructure [73].

This phase was marked by a strong co-evolutionary dynamic: firm strategies were influenced by institutional pressures and incentives, while innovation driven by firms, along with public responses, led to institutional learning and the adaptation of policy frameworks [74].

5.3. Phase 3.1997–2015: innovation driven market competition emerges

The 3rd phase began with the Kyoto protocol, the first international agreement addressing climate issues and actions. The protocol established global commitments for industrialized nations to reduce their greenhouse gas emissions, increasing institutional pressure to decarbonize mobility systems. Consequently, national governments climate strategies began to incorporate EVs to achieve emission targets, encouraging greater investment in EV technologies and supportive infrastructure. The protocol also recognized environmental regulation as a catalyst for innovation [80].

Hybrid technology became pivotal for Toyota, enabling to gain brand awareness and market leadership by 2008, which attracted other manufacturers to launch hybrid models. Market competition emerged, and low emission vehicle (LEV) sales increased significantly [81]. Hybrid technology proved to be an essential factor for the progress of the EVs [82], as its commercial success allowed a broader segment of the society to personally experience the advantages of vehicle electrification. Although their usage in electric mode proved to be very limited due to battery size and reduced range, at least users didn't face range anxiety [73].

In California, starting in the mid-1990s, OEMs legally challenged the ZEV mandate, arguing that battery electric vehicles could only serve an unprofitable niche market [66,83]. In 2000, CARB recognized the difficulty of achieving ZEV targets due to technical challenges and cost constraints and decided to delay them [79], shifting towards hybrid transitional technologies [77] while simultaneously launching customer purchase incentives [84]. These regulatory changes meant that, after the initial strict ZEV mandate, California temporarily weakened the institutional pressure, converting mandatory quotas into credit-based flexibility mechanisms. This approach aimed to achieve emission reductions based on car manufacturers' market commitments, offering a more enabling, market-supportive regulatory environment focused on accelerating EV technology and charging infrastructure development to improve customer usability [77].

A similar process occurred in Japan, where government policies shifted toward voluntary targets, tax incentives, and R&D support for battery technologies, aiming to further develop industrial capabilities [68].

In the European Union, prior to the introduction of binding CO₂ fleet standards in 2009, emission reduction efforts were largely pursued through voluntary manufacturer commitments and accompanying monitoring mechanisms, with limited regulatory enforcement [85].

The institutional strategy continued to seek viable BEV technology,

while newcomer firms' interest in entering the EV market increased, and more customer-oriented BEV pilot projects were launched. The arrival of Tesla as a disruptive force, along with established hybrid leaders such as Toyota, transformed the market by demonstrating that electric vehicles (EVs) could be high performance, attractive and competitive [86,87].

Technological innovation in batteries and other components led to improved performance and cost reduction, enabling the market introduction of the first electric vehicles, such as the Tesla Roadster (2008), Nissan Leaf (2009) and GM Volt (2011) [88]. Although BEV technology still offered limited performance compared to ICE models, it was already capable of fulfilling the needs of certain market segments.

Consumer expectations also began to evolve, shaped by advances in vehicle design, targeted marketing, and growing environmental consciousness. Consequently, the foundations of a viable EV market began to take shape, characterised by enhanced firm agency and increased institutional adaptability.

During this phase, the co-evolutionary dynamic shifted, with firms beginning to exert substantial influence over institutional frameworks. This influence took the form of lobbying for supportive incentives, regulatory credits, and infrastructure investments. In parallel, policy-makers adapted regulations to facilitate the broader diffusion of innovation [89]. Firms played an important role, using this more flexible regulatory landscape to experiment new technologies and business models. Transitions often experience periods of reduced policy pressure, which allow increased industry experimentation and capability building instead of strict regulatory enforcement [80].

This period ends with the Dieselgate, impacting public opinion and resulted in regulatory changes and the modification of firms' strategies to accelerate the EV transition [78].

5.4. Phase 4.2015 – 2020: BEV upscaling, Firms Business Model shift

The 4th Phase began with the Paris Agreement (2015), reflecting further societal pressure in developed countries and the institutional actions taken in consequence of the Dieselgate. In response to the Paris Agreement and growing climate urgency, governments recalibrated regulations to meet more ambitious targets, and cities introduced zero emission zones [90]. Major OEMs announced BEV transition strategies, including dedicated BEV platforms. Innovation in battery technologies enabled improvement in specifications, increased production, and cost reduction. Firms' expansion of hybrid and BEV product portfolios resulted in stronger competition.

As the market share of electric vehicles (EVs) gained momentum, a regulatory recalibration of long-term climate targets became necessary. Leading EV countries (Norway, the Netherlands, Sweden) began to announce bans on ICE vehicles with deadlines between 2025 and 2030 [91,92]. Simultaneously, governments expanded EV incentives for both manufacturers and consumers to stimulate innovation beyond early adopters toward mainstream consumers [93].

This phase represented the strategic upscaling of electric mobility, as these policy shifts encouraged car manufacturers to rethink their value propositions, invest in developing scalable EV platforms, reconfigure supply chains, align product strategies with mainstream customer expectations [94], and develop business model suited to a growing BEV share [95]. This phase reflected the search to define the "Innovation Trinity", ensuring customer fit, technological feasibility and a profitable business model. As part of their ongoing commitment to innovation, traditional car manufacturers collaborated with tech companies to explore new business models, including mobility services and sustainability-oriented solutions [96].

OEMs provided important market feedback to institutions about limited user acceptance and proposed delaying transition deadlines and adjusting ICE restrictions. One of the main barriers to user acceptance was the limited availability of charging infrastructure [97]. Consequently, government incentives were often accompanied by large-scale investments in charging infrastructure [98,99] and the localization of

battery supply chain [100].

China became the largest automotive market, launched the New Energy vehicle (NEV) strategy and imposed NEV mandate from 2020.

In this phase, the evolution of institutions and the role of firms in policy development became increasingly complex. Institutions began to play a more active role in facilitating second-generation innovation, while firms contributed to shaping the pace and adjustments of policy [101]. In the business world, there has been a convergence of public and private actions into mission-oriented innovation systems designed to align industrial and climate goals, including increased renewable energy sourcing [100,102].

5.5. Phase 5.2020 –: sector transformation drives institutional policy change

The 5th phase covers two important processes.

First, in the most advanced countries, EV adoption succeeded in reaching the mainstream customer segment and providing a viable user experience for daily usage. In the Norwegian market, BEV sales accounted for more than 50% of new car sales in 2020 and reached 79% in 2022 [103]. In several key markets, particularly Japan and some European countries, hybrid technology continues to serve as important transitional solution, especially where charging infrastructure, or user acceptance remain constraining factors.

Secondly, the emerging Asian markets reshaped the global automotive market, with China in particular succeeding in developing an accelerated innovation environment for the local EV industry, resulting in a significant challenge to the global industrial footprint.

China's remarkable economic growth has enabled the country to become the world's largest automotive market in 2009. If motorization were to reach the European Union (EU) average by 2050, this would result in an additional 500 million units [104], equivalent to the combined carpark of the US and the EU [105]. Considering the consequences of such a substantial increase of the car park on air pollution in metropolitan areas [106] and growing dependence on oil imports [107], China initiated a strategic shift toward e-mobility. This included, in a first step, customer incentives to EV purchase and, from 2020 onward, the introduction of a strict mandate for automotive manufacturers [86], combined with institutional measures to develop charging infrastructure, and the adaptation of the power grid to meet the increasing demand [108].

The central government defined the automotive industry as a strategic national industry and implemented policies to develop technological and industrial competitive advantage in the EV sector [109]. China became the largest EV market in 2020. Centralized institutional directive and incentives to create R&D centres, foster innovation and build industrial footprint with cutting edge technologies [110] lead to the emergence of significant number of Chinese EV manufacturers with production capacities far exceeding the local national needs. The national production capacity was sufficient to cover more than half of the global demand [111]. The Chinese government decided to use this additional capacity for international economic conquest and encouraged Chinese OEMs to export vehicles on a large scale. The measures included definition of targets, as well as guidance and subsidies with the objective of an economic expansion to achieve global EV dominance [109].

This process has led to intensified geopolitical competition between China, the EU, and the United States over battery value chains and leadership in the EV industry. The resulting dominant presence of Chinese manufacturers in the EV production and battery value chains created a significant threat to the automotive sector and national economies in North America, Europe, and Asia.

In response, Western governments have implemented protectionist economic policies, such as the U.S. Inflation Reduction Act, 2022 and the EU's Green Deal Industrial Plan. This policy recalibration aims to defend local economies by protecting employment and national industrial champions [90].

This new reality provides another example of the co-evolution of institutions and firms. Firms that previously adapted to the local institutional pressure are now proactively influencing it through geopolitical actions and lobbying. In addition, governments are using regulation not only to meet environmental targets but also to protect employment, national champions, and technological sovereignty. The EV transition is now embedded in broader debate over economic security, reindustrialization, and strategic national autonomy. This represents a new form of institutional–firm interaction shaped by the international political–economic context and technological and environmental imperatives, underscoring the increasing interdependence between sustainability objectives, competitiveness, and economic security.

The phases identified during the research are presented in [Table 1](#) (Phases 1–3.) and [Table 2](#) (Phases 4–5.) below. Each phase is accompanied by details of the institutional context and role, key events and policy milestones, firm level roles and innovation dynamics, and the relevant literature based on our research.

6. Discussion: the new co-evolutionary innovation framework based on the electric vehicle transition

A review of the extant literature indicates that the transition to electric vehicles (EVs) is precipitating substantial changes to the traditional business models of incumbent car manufacturers. The introduction of new powertrain technologies and the growing presence of digital revenue streams require firms to develop new capabilities and invest heavily in R&D, particularly in software and battery systems [62,63]. This transformation is further compounded by increasing supplier specialization and intensified pressure on value chain coordination, which reshapes profit distribution and competitive positioning within the industry [66]. Urbanization trends and shifting consumer preferences, such as declining interest in private vehicle ownership, are accelerating the development of alternative mobility services, thereby challenging traditional automotive value propositions and enabling technology firms and start-ups to enter the sector with disruptive service-oriented and platform-based business models [112].

In this increasingly complex environment and given the automotive industry's global industrial footprint and macroeconomic relevance for employment and GDP in both home and host countries, national institutions are compelled to align industrial policy with sustainability agendas [39,43]. Emerging market players, particularly from China and Southeast Asia, have leveraged institutional support, flexible innovation strategies, and the absence of legacy constraints to penetrate established markets with competitive EV offerings and novel business models [104, 108,110]. This evolution has introduced pronounced geopolitical dimensions into innovation policy and industrial competitiveness, intensifying strategic competition over battery value chains, technological leadership, and market access.

The EV transition exemplifies a co-evolutionary process involving informal institutions (e.g., societal values and public expectations), formal institutions (e.g., laws, regulations, and mandates), and firms (including their innovation strategies, capabilities, and alliances). These elements evolve interactively, influencing one another over time through recursive feedback loops that shape the direction, speed, and effectiveness of the transition [14], thereby facilitating technological progress and the adoption of disruptive innovations. The process also incorporates external influences, such as the entry of firms from other sectors and broader international developments, reflecting the inherently global nature of these dynamics. A deeper understanding of this reciprocal interplay is essential for designing policy frameworks that not only foster sustainable innovation but also enable systemic transformation across the entire value chain.

At the same time, the EV transition does not follow a linear or frictionless trajectory; rather, it is characterized by structural tensions, setbacks, and contested dynamics. Early attempts at battery electric vehicle (BEV) commercialization in the 1990s were constrained by

technological limitations and high costs, leading to regulatory recalibrations such as the postponement of the California ZEV mandate. Discontinuous, or “stop-and-go” policy approaches have also affected firms' long-term capability development and investment strategies, illustrating the fragility of early transition phases and the sensitivity of policy trajectories to technological and market conditions. The persistence of HEV and PHEVs technology in key markets also reflects the non-linear and path-dependent nature of the transition, where multiple technological trajectories coexist and compete under evolving institutional and market conditions. Regulatory conflicts between environmental ambition and industrial-economic objectives have further shaped strategic responses, while incumbent firms have occasionally engaged in lobbying efforts that influenced regulatory trajectories. Moreover, the transition involves significant structural trade-offs, including tensions between industrial policy intervention and global trade frictions; between ambitious electrification targets and constraints in grid capacity and renewable energy supply; and between the expansion of battery value chains and increasing dependencies on critical raw materials and associated geopolitical risks. In addition, financial incentives such as purchase subsidies and tax credits entail a risk of disproportionately benefiting higher-income consumers, raising important considerations for the inclusivity and pace of the transition. From a co-evolutionary perspective, these tensions are not anomalies but integral features of systemic transformation.

Based on the research findings, a new framework the “Co-evolutionary Innovation Framework” has been developed (see [Fig. 3](#)) to represent the co-evolution between firms and institutions, which leads to innovation. This new Co-evolutionary Innovation Framework captures these recursive dynamics by situating innovation at the centre of macro–meso–micro interactions, highlighting how institutional recalibration, firm strategy, and societal response continuously reshape one another under conditions of technological change, industrial competition, and sustainability imperatives. This new framework is grounded in the work of Rodrigues and Child [20, p.2139] and proposes significant evolutions. Compared to prior co-evolutionary frameworks (e.g., Refs. [20], [22], [28] [41]), which primarily focus on firm–environment adaptation, industry–institution dynamics, and organizational form evolution, this framework explicitly positions innovation at the centre of the process as a recursive and structuring variable. Furthermore, at the macro level, unlike earlier models that treat institutional forces in aggregated form, this framework separates formal and informal institutions, as defined by Peng [31], and describes their reflectively influencing mechanism. It also incorporates users and diffusion dynamics as endogenous feedback mechanisms. Finally, by integrating cross-regional and geopolitical feedback loops, the framework reflects the mission-oriented and globally competitive nature of contemporary sustainability transitions. In doing so, it extends co-evolutionary theory toward a mission-oriented innovation framework applicable to systemic technological transformations.

The framework operates across three levels between the macro (societal), meso (sectoral) and micro (organisational/user) levels. While the structure proposed by Rodrigues and Child [20] focused on form, objectives, processes, and performance at each level, the main focus of our framework is mission-oriented transformation, emphasizing how interactions across these three levels can drive technological innovation and lead to broader systemic transformation.

6.1. Macro level: societal pressure, economic treat translated into strategic shift and policy changes

At the macro level, societal awareness of environmental degradation and the impact of the oil crisis of the 1970s began to alter public discourse, creating pressure from informal institutions on political structure. This shift, combined with energy security concerns, modified political priorities and imposed a strategic shift, translated into regulatory policies by formal institutions such as national governments and

Table 1
The co-evolutionary phases (1. – 3.) of the EV transition.

Phase	Key characteristics	Key events and policy milestones	Formal Institutional role and actions	Informal institutions (Society attitude)	Firm-level role and innovation dynamics	Related literature
Phase 1. 1970–1983 Institutional Strategic Shift	<ul style="list-style-type: none"> - Institutional pressure - Problem Identification - Agenda Setting 	<p>1970: Funding of U.S. EPA institutionalisation of environmental governance.</p> <p>1970: U.S. Clean Air Act authorizing federal & state institutional regulations to limit emissions</p> <p>1971: Funding of Japan Environmental Agency</p> <p>1973: Oil Crisis, exposed the geopolitical vulnerability of oil dependence</p> <p>1976: US Congress: Electric and Hybrid Vehicle Research, Development, and Demonstration Act to push the development of new technologies including batteries, powertrain, and other hybrid-electric components.</p> <p>1976: JP MITI 1st plan to EV development: identify barriers, exploratory development</p>	<p>Emerging awareness of climate change</p> <p>Institutions react to air pollution, urban degradation</p> <p>Institutions face the impact fossil fuel dependence on society and economy</p> <p>Institutions introduce first measures for strategic shift</p>	<p>1970: 1st Earth Day - engage the public to push environment issues to the national agenda</p> <p>Increased cost of car usage</p>	<p>Limited strategic engagement by firms</p> <p>EVs marginal in R&D portfolios</p> <p>Exploratory developments</p> <p>1972: hybrid based on Buick Skylark</p> <p>Battery: in-house lead-acid batteries w limited energy density and range</p>	<p>[67], [68], [69], [70], [71], [72], [73], [74], [75]</p>
Phase 2. 1983–1997 Institutional Push for Firm's Innovation	<ul style="list-style-type: none"> - Institutional Push and Support - Firm Early Innovation - Societal Learning 	<p>1983: JP MITI revised 2nd plan</p> <p>US DOE and EU demonstration projects</p> <p>1990: California Air Resources Board (CARB): first Zero-Emission Vehicle requirement (mandate)</p> <p>1990: Norway introduced tax exemption fiscal incentive for EVs</p> <p>1997: Launch of 1st mass production hybrid car</p>	<p>Shift from framing to experimentation and early co-development</p> <p>Institutional initiatives: demo projects, subsidies and education campaigns to prepare the public for behavioural and infrastructural changes</p> <p>State-funded EV pilots and regulatory exploration</p> <p>Targeted communication: raise awareness and benefits of EVs and to address consumer concerns</p>	<p>1985 - 1990 Rise of environmental NGOs and media focus on air pollution</p>	<p>1988: GM commits R&D to develop EV</p> <p>1996: Launch of GM EV1, first modern EV by OEM battery: lead-acid, later NiMH/Panasonic - limited energy storage</p> <p>1997 - 1999: Other OEMs EV R&D (Toyota, Nissan, Ford, Chrysler, etc..)</p> <p>1997: Launch of Toyota Prius, first hybrid mass production battery NiMH/Panasonic, improved energy management</p>	<p>[62], [63], [68], [73], [74], [76], [77], [78], [79], [92]</p>
Phase 3. 1997–2015 Innovation driven Market competition emerges	<ul style="list-style-type: none"> - Market Competition Emerges - Institutional Pressure Reduces - User adoption limited by technology constraints 	<p>1997: Kyoto Protocol</p> <p>2001: Norway introduce user incentives (free public parking, and bus lane usage)</p> <p>2009: Norway launch EV infrastructure program to support EV charging network development</p> <p>2009: US American Recovery & Reinvestment Act: funds R&D EV batteries and related technologies.</p> <p>US Department of Energy allocate funds to build the necessary infrastructure and awards loans to Ford, Nissan, and Tesla Motors to support the R&D of fuel-efficient vehicles</p> <p>2009: China became the largest car market</p> <p>2009: China introduces BEV subsidies</p> <p>2010: First mass produced BEV car</p> <p>2015: US EPA: announced Dieselgate scandal</p>	<p>International focus on climate issues</p> <p>Institutions shift from mandates to market incentives and GHG credit systems</p> <p>Regulatory pressure relaxes in some regions</p> <p>Global climate policy takes shape (e.g., Paris Agreement)</p>	<p>2010 - 2015: Consumer environmental awareness increases (e.g., EU air quality protests, diesel bans)</p> <p>Shift in urban mobility preferences (cycling, car-sharing, clean transport)</p> <p>2011: Launch of Norway EV association to strengthen lobbying, public education, and trust</p>	<p>2003 New entrants Tesla Motors founded Roadster (2008), Model S (2012)</p> <p>2008: Tesla Roadster launch</p> <p>Battery: Li-Ion 18,650 cell</p> <p>Firms enter competitive innovation phase</p> <p>2010: Nissan Leaf launched, the first mass-produced BEV</p> <p>2014: More new entrants (e.g. Nikola)</p>	<p>[66], [68], [73], [74], [76], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [92], [93], [94], [100], [102], [103], [107], [108],</p>

Source: Constructed by the authors based on research findings

Table 2
The co-evolutionary phases (4. - 5.) of the EV transition.

Phase	Key characteristics	Key events and policy milestones	Formal Institutional role and actions	Informal institutions (Society attitude)	Firm-level role and innovation dynamics	Related literature
Phase 4.2015–2020 BEV upscaling, Firms Business Model shift	<ul style="list-style-type: none"> - Market upscaling - Regulatory Recalibration - Institutional support to remove user adoption roadblocks - Emerging markets transform global sector structure - Aligning innovation with environmental and societal goals 	2015: Paris Agreement 2017: Norwegian Parliament announced target: all new car sales should be ZEV by 2025 2020: Norway BEV new car sales mix >20% EU introduced tightened CO ₂ targets and diesel bans began surfacing Norway Parliament announces ICE ban from 2025 2017: China launched its New Energy Vehicle (NEV) policy including NEV mandate	Regulatory recalibration based on Paris Agreement EVs integrated into national climate and industrial strategies Expansion of infrastructure and supply chains	Fridays for Future begins Global youth-led climate protests to influence policymakers to tighten emissions targets	Transition from early adopters to the beginning of market scaling Major OEMs announced dedicated EV platforms (e. g., VW's MEB in 2018) 2015 - 2017: Battery R&D, production upscale drives cost reduction - improving EV feasibility (LG, Panasonic, Samsung) 2016 - 2018: standardization to better interoperability for OEMs and users Upscaling Charging infrastructure and battery supply chain investments 2018 - 2020: Battery upscaling - Tesla Gigafactories (vertical integration, reducing cost and leadtime), Rise of CATL 2018 - 2020: Ultra fast chargers 2019: CATL largest battery supplier	[63], [64], [82], [85], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101], [102], [106], [107], [108],
Phase 5.2020 - Sector transformation drives Institutional policy change	<ul style="list-style-type: none"> - Global Industrial Footprint Shift - Strategic National Industrial Policy 	China dominates global EV and battery supply chains 2020: Norway BEV new car sales mix above 50% 2020: China BEV mandate in place 2020: China biggest EV market 2022: China becomes world largest EV exporter 2022: U.S. Inflation Reduction Act introduced local content and manufacturing requirements EU Green Deal Industrial Plan aimed to retain competitiveness and react to U.S. policy 2022: Norway BEV new car sales mix above 79%	EVs central to industrial and geopolitical strategies Institutions focus on economic sovereignty reflecting the importance of both climate policy and industrial policy National policy links decarbonization and competitiveness	NGOs & legal advocacy groups: Request to tighten decarbonization targets Youth & consumer climate movements: launch Social-media campaigns against high-emission brands City-level civil-society coalitions: Push for zero-emission zones, space allocation for chargers, Pilot neighbourhood V2G micro-grids	Firms increased pressure and influence on institutions 2021: US NEVI: 7.5bn investment for nationwide EV charging Battery: LFP and NCM811 improved chemistry for safer and cheaper batteries (Tesla, CATL, BYD)	[67], [86], [90], [91], [100], [101], [103], [104], [105], [106], [107], [108], [109], [110]

Source: Constructed by the authors based on research findings

international legislative entities, aimed at reducing emissions and import oil dependency.

This strategic shift led to the definition of emission threshold objectives and roadmaps, reshaping sectoral norms and targets. The resulting regulatory policy changes included mandates for car manufacturers and fleets, as well as support for R&D and incentives for users, significantly impacting the automotive sector's (meso-level) objectives, business model, and performance.

6.2. Meso level: sectoral transformation and business model redesign

The automotive sector responded to macro-level institutional pressures and modified objectives by reorienting its R&D, value chains, and transforming its dominant business models.

The development of dedicated EV platforms signifies the sector's strategic shift in R&D, production, and structural configuration. Tesla's entry demonstrated a business model based on direct-to-consumer sales, over-the-air updates, and vertically integrated battery supply chains, challenging legacy OEM approaches. Energy and mobility sectors began to converge, as utilities, charging infrastructure providers, and smart city planners became integral element to the viability of the EV transition. This reshaping of the sectoral business model also facilitated the emergence of new entrants and cross-sector partnerships (e.g., tech firms entering mobility).

Sector level innovation is therefore not only a reaction to macro-level conditions but also a dynamic input shaping firm strategies and inter-industry dynamics.

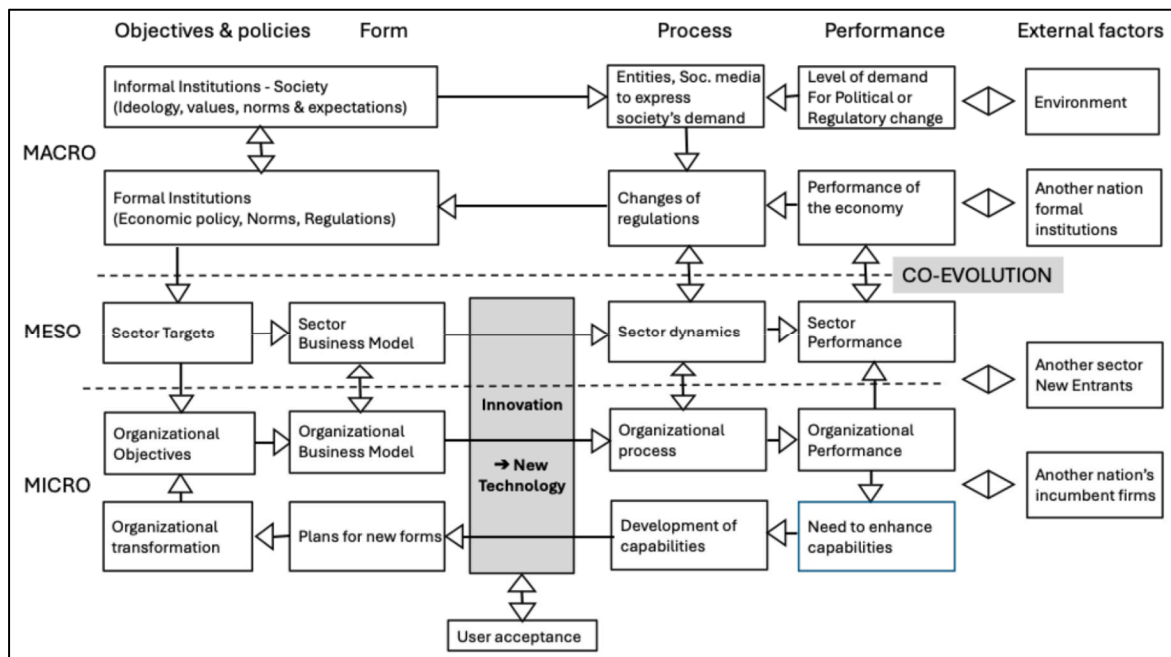


Fig. 3. The Co-evolutionary innovation framework.
Source: Authors' own construction based on research findings, building on Rodrigues and Child [20, p.2139]

6.3. Micro level: organisational capabilities and user engagement

At the firm level, compliance with new regulations (imposed by institutional pressure) and adaptation to sectoral shifts required strategic realignment. Firms reacted by modifying their objectives, identifying the required organization changes, developing new capabilities, reorienting their R&D activities, and preparing the shift of their business models.

Traditional OEMs faced pressure to transition from ICE-based engineering to EV platforms, and to redefine competitiveness based on emissions, digitalisation, and lifecycle sustainability. This reshaping of the sectoral business model also facilitated the emergence of new entrants (e.g., tech firms entering mobility) and cross-sector partnerships (e.g. in battery technology, software integration, and energy management), often requiring alliances with tech firms and startups.

The progress achieved in the innovation process allowed firms to further adjust their objectives, and the main pillars of their business model.

The process described by the Co-evolutionary Innovation Framework (Fig. 3), allows to understand how the macro→meso→micro dynamic is complemented by the micro→meso→macro influence. Organisational performance feeds back into meso-level sectoral dynamics, setting benchmarks and shaping industrial expectations. Firm-level performance can inform or challenge regulatory trajectories. Similarly, poor sector performance can prompt macro-level institutional recalibration.

In this way, innovation is not a linear outcome but an emergent result of continuous reciprocal interaction between firms, institutions, and societal expectations across levels. The performance of other sectors (e.g., technology, energy sourcing, and urban planning) can also influence the transition through complementary innovations or by creating bottlenecks that require additional resources and adjustments.

The sequence of this process including the key dynamics is presented in Appendix C.

7. Conclusions

This study has examined the electric vehicle (EV) transition through the lens of co-evolutionary theory, focusing on how formal institutions

(e.g., government regulation), informal institutions (e.g., societal expectations), and firms' innovation strategies interact over time to shape systemic technological transformation. Using an Integrative Literature Review (ILR), five distinct phases of the EV transition were identified, each illustrating evolving patterns of influence, mutual adaptation, and alignment among institutions, firms, and society.

The progress of BEV and PHEV sales in the different phases is presented in Appendix C.

This study makes a significant contribution to both co-evolutionary theory and the field of innovation management, particularly in the context of sustainability transitions. It builds on the work of Rodrigues and Child [20] by adopting a mission-oriented perspective, positioning innovation not as a by-product but as a central outcome of the reciprocal relationship between institutions and firms. The new Co-evolutionary Innovation Framework incorporates formal and informal institution, as defined by the Institution based view theory [31] and separates them at macro level in a more structured way. The proposed new framework moves beyond its original interpretive function by offering a structured basis for developing testable propositions about the interaction between institutions and firms in sustainability transitions. Combined with the multi-phase model, the framework enables to better structure the levers and actions that drive sustainable innovation.

The proposed multi-phase model provides a useful analytical framework for understanding how institutional pressure evolves into market-based competition as innovation diffuses, offering valuable insight into the dynamic nature of technology adoption and industrial transformation.

This analysis underscores the collaborative influence of government policy, societal pressures, and strategic firm actions on technological innovation. By specifying the regulatory actions of formal institutions, the form of pressure from the society and consumers, and firm-level innovation strategies in each phase, the framework enables researchers to formulate empirical hypotheses about when and how institutional pressures should dominate, when firm-led innovation becomes the primary driver, and under what conditions societal expectations accelerate or constrain diffusion.

Finally, it offers a cross-regional perspective by examining how innovation driven by firms and institutions evolves across markets with

different political structures, levels of institutional development, and societal values, such as those of the EU, the US, Japan, and China, while analysing the impact on firms' strategies and the global industrial footprint, and showing how global feedback loops propagate policy learnings and competitive pressure.

The different policies across regions led to different innovation pathways:

In the first "Strategic Shift and Agenda-setting" phase, institutional actors play a dominant role in defining long-term transition directions and establishing legitimacy for emerging technologies. California, Norway, and China imposed a clear zero-emission vehicle (ZEV) mandates, while Europe announced a CO₂ reduction pathway [77,102,106]. The former provides a clear signal to the industry to develop new technologies and align with upcoming targets, whereas the latter allows firms to consider a short-term reliance on existing technology [85].

During the technology-forcing "Institutional Push for Firm's Innovation" phase, regulatory instruments and targeted incentives become critical in overcoming path dependence and incumbent inertia. The US, Japan, and later China provided significant support (funding, loans, and partnership) to the automotive industry to accelerate the development of new technologies and the required industrial footprint, enabling the production of EVs at prices accessible to mainstream customers. These actions led to significant progress on EV and battery innovation in all three countries [64,89,104].

When governmental support (financial resources, project management, and cross-sectoral partnerships) was combined with regulatory mandates in Japan and China, the impact on firms' innovation processes was decisive, leading to substantial technological breakthroughs (Japan - Toyota Prius, Nissan Leaf; China - EV product launches, battery technology, and production upscaling) [68,81,106]. As new technologies gained legitimacy, market competition emerged and regulatory frameworks evolved toward more flexible, market-supportive mechanisms.

In contrast, "stop-and-go" governmental policies or the absence of a clear and decisive long-term strategy do not provide a strong signal to firms regarding the need to reallocate R&D resources and redesign business model. Regulation based on a gradual CO₂ reduction pathway allowed firms to consider short-term compromise to incremental innovation instead of radical innovation, while simultaneously challenging more severe future regulations. This approach enables firms to prioritize short-term financial performance and delay the reallocation of R&D resources toward new technologies. However, in a context of global industrial footprint and evolving global market structures, such delays in innovation may disadvantage incumbent firms and lead to a loss of their competitive advantage against newcomers from other regions or industries [66,75,85,108].

The study made evident that, beyond the defining ZEV targets and supporting the industry, it is important to consider this transition as a multi-sectorial project, ensuring that not only EV technology (vehicles and battery), but also charging infrastructure (energy production, transmission, and charging points) is available during the "BEV upscaling" phase, enabling easy and seamless usage and payment for mainstream customers [108].

The EV transition represents a complex, multi-sector, multi-country phenomenon that is rarely addressed in such an integrative way in co-evolution literature. By synthesising this case, the research contributes to broadening the empirical base of co-evolutionary studies and enriching the theory's applicability to large-scale, cross-national innovation systems. It reinforces that the EV transition is not simply a technological shift, but a co-evolutionary process through which firms and institutions jointly respond to urgent societal imperatives. Beyond theoretical contributions, the research findings provide practical implications for business practitioners and policymakers. The phase-based framework clarifies the structure of the EV transition, enabling stakeholders to anticipate strategic inflection points and align responses accordingly.

7.1. Limitations

Despite its contributions, several limitations of this study must be acknowledged.

First, the analysis relies exclusively on secondary literature, as the study was designed as an Integrative Literature Review (ILR) aimed at conceptual synthesis rather than primary empirical investigation. Through this process, the analysis systematically integrated documented firm-level and policy-level cases as empirical grounding for the proposed framework. Nevertheless, the absence of primary data collection, such as interviews, in-depth case studies, or longitudinal fieldwork, limits the ability to capture nuanced firm-level decision-making, organizational dynamics, and informal institutional processes that may only emerge through direct qualitative or quantitative data. The lack of empirical validation through case studies, interviews, or longitudinal fieldwork also limits the depth of causal inference regarding how institutional pressures and firm strategies co-evolve in practice.

Second, although the Integrative Literature Review (ILR) method enables conceptual synthesis across diverse fields, it remains dependent on the availability, accessibility, and quality of published research. This introduces the risk of publication bias, as academic literature tends to overrepresent successful transitions, policy "best practices," or technologically optimistic perspectives while underreporting failures, stalled initiatives, or contradictory evidence. Expert and policy documents help mitigate this bias but cannot fully eliminate it.

Third, the review is temporally bounded: only publications available before the second quarter of 2025 were included. Given the pace of innovation in battery technologies, industrial policy, and global EV markets, particularly in China, the United States, and Europe, important developments may have emerged after this period. These could alter the trajectory or interpretation of the later phases of the EV transition.

Finally, the study synthesizes findings from a limited number of key national contexts. While this supports broader theoretical generalization, it may miss valuable region-specific dynamics, institutional design concepts, or industrial strategies.

Future research should therefore incorporate primary data through interviews, comparative case studies or mixed method designs to empirically test, validate and refine the proposed co-evolutionary model.

7.2. Future research

Building upon the findings of this study, several important topics emerge for future research. First, the area of institutional adaptation requires deeper investigation and should be extended to more recent periods not covered by this research. In particular, further analysis is needed on how experimental governance mechanisms and adaptive policy frameworks can enable national innovation in response to rapidly changing technological landscapes. Understanding how governmental policies evolve in reaction to disruptive technologies and firm-level innovations will contribute to a more dynamic conceptualization of institutional responsiveness.

Second, the interplay between different sectors represents an important yet unexplored dimension. Future research should examine how co-evolutionary processes unfolded across interconnected sectors, including energy sourcing, grid integration, urban planning, technology-driven new entrants, and emerging digital mobility services. This cross-sectoral perspective is vital for capturing the full complexity of systemic innovation and transition dynamics. The role of NGOs and labour unions would further enhance understanding of the role and impact of informal institutions.

Third, attention should be directed towards the role of emerging markets in reshaping global innovation structures. Comparative studies could illuminate how differing national institutional configurations generate distinct transition pathways. Additionally, the influence of technology transfer, local content requirements, and the rise of national

champions on global competitive dynamics and institutional responses offers fertile ground for investigation.

Finally, business model innovation emerges as a key mechanism through which firms engage with, and potentially transform, institutional frameworks. Future research could explore how firms use innovative business models to negotiate or reshape regulatory boundaries, as well as the extent to which niche strategies and disruptive new entrants contribute to sectoral structure shifts. Investigating these dynamics will deepen our understanding of how innovation not only responds to, but actively reshapes, institutional environments.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.rser.2026.117010>.

Data availability

No data was used for the research described in the article.

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