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The rise of China's new energy vehicle lithium-ion battery industry: The coevolution of battery technological innovation systems and policies

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ABSTRACT

In recent decades, the technological innovation systems (TIS) framework has been applied to the study of technology development and diffusion. While policy is considered a key element of TIS analysis, less attention has been paid to the influence of TIS dynamics on policymaking. To better understand the coevolution between TIS and policies, this paper develop an analytical framework to highlight the coevolution between TIS dynamics and policymaking. The framework underlines not only the influence of policies on TIS functionality, but also that changes in TIS functionality may in turn feed back into policymaking: policymakers may observe changes in TIS functionality and adjust policies to account for this, but changes in TIS functionality may also have implications for the ability of TIS actors to influence policymaking. Empirically, we study the new energy vehicle battery (NEVB) industry in China since the early 2000s. In the case of China's NEVB industry, an increasingly strong and complicated coevolutionary relationship between the focal TIS and relevant policies at different levels of abstraction can be observed. Overall, we argue that more research is needed to better understand the agency side of how TIS development leads to changes in policymaking.

1. Introduction

A fundamental shift from conventional GDP-oriented development to greener and more sustainable development is currently underway in various parts of the world. As an important means to achieve such fundamental and large-scale sustainability transitions, developments of energy-saving or green technologies are crucial (Bergek et al., 2008; Markard and Truffer, 2008). However, as correctly pointed out by van der Loos et al. (2021), the successful development of green technologies, is neither automatic nor easy. Rather, the rise of a new technology depends not only on the formation of the technological innovation system (TIS) in itself, but also on the interplay with unique context conditions that evolve over time (Bergek et al., 2015).

In particular, TIS development is interlinked with policies (Bergek et al., 2015; Van der Loos et al., 2021). As noted by Bergek et al.

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(2015), interactions between TIS and policies are at the heart of large-scale transformation processes, and therefore deserve greater attention. In the current paper, we address this topic by analysing the coevolution between policymaking processes and TIS development. While TIS studies (e.g. McDowall et al., 2013, Reichardt et al., 2017, van Alphen et al., 2010) have analysed the influence of policies on TIS development, the question of how TIS development in turn influences policymaking processes has received scarce attention. Such a one-sided emphasis on the influence of one element (policy) on another (TIS) within a coevolutionary system is problematic, as it may lead to distorted policy suggestions and thus reduces the explanatory power of the corresponding models when it comes to explaining how green technologies develop.

Consequently, we aim to better understand the reciprocal relationships between TIS and policymaking. Drawing on insights from the policy studies literature (Cashore and Howlett, 2007; Haelg et al., 2020), we contribute with an analytical framework to highlight the coevolution between TIS dynamics and policymaking. In addition to consideration for the influence of policies on TIS functionality, the framework highlights that changes in TIS functionality can influence policymaking in two ways. First, policymakers may observe changes in TIS functionality and adjust policies to account for this. Second, changes in TIS functionality may have implications for the ability of other TIS proponents to influence policymaking.

Empirically, we investigate the developmental process of the new energy vehicle battery (NEVB) industry in China. China has the highest production volume of NEVB worldwide since 2015, and currently dominates the global production capacity, accounting for 77% in 2020 (SandP Global Market Intelligence, 2021). Thus, NEVB follows other green technologies (solar photovoltaic, wind turbine, biomass power plants, etc.) where China is taking a leading global role (Binz et al., 2012; Hansen and Hansen, 2020; Lema et al., 2020; Quitzow et al., 2017; Xu and Su, 2016).

While policy support is generally found to be important to China's rise, its role, however, differs between industries. As argued by Binz et al., 2012, Chinese progress in many green industries is also the outcome of private sector initiatives, international interdependencies, and the flexibility of policymakers in adapting the policy mixes to each industry's technological characteristics. This highlights the importance of coevolutionary perspective on TIS development and policies.

2. Coevolution of technological innovation systems and policies

2.1. TIS and policies

Over the last decades, the technological innovation systems (TIS) literature has emerged as a prominent framework to study the development and diffusion of technologies (Bergek et al., 2008; Hekkert et al., 2007, for a review, see Bergek, 2019). Rooted in innovation systems thinking (Carlsson and Stankiewicz, 1991; Freeman, 1987), a TIS is conceptualized as consisting of actors engaged in innovation efforts related to a technology, the networks between them, and the institutions that guide their actions. A core contribution of the TIS literature is its conceptualization of innovation system processes, which describe the ability of innovation systems to deliver a number of key functions. TIS functions are defined empirically based on readings of existing literatures (e.g. innovation systems, large technical systems and clusters) that describe key systemic processes (Bergek et al., 2008). While variations are found in the list of functions, most studies consider entrepreneurial experimentation, knowledge development and exchange, guidance of the search, market formation, legitimation, and resource mobilization as core functions. Focusing on TIS functions allows for a dynamic analysis that not only examines how the structure of the innovation system develops over time, but also how the ability to deliver these functions changes.

Policy plays a central role in TIS analysis. First, an important motivation for developing and applying the TIS framework has been to provide sound policy advice (Jacobsson and Bergek, 2006; Jacobsson et al., 2017). Specifying key policy recommendations based on structural and functional analysis of TIS is described as an individual step in a generic TIS analysis (Bergek et al., 2008). Second, policies constitute an important category of institutions, and policies with specific implications for a technology are thereby part of the structural components that comprise the TIS. Policies may influence other structural components by changing actor interests and capabilities, shaping networks, or modifying other institutions including informal habits, e.g. risk-taking behavior (Grillitsch et al., 2019). In turn, such changes in the structural components may modify the ability of the TIS to deliver innovation system functions.

Previous TIS work has analysed how individual policy instruments, broader policy mixes or different policymaking styles influence TIS development (e.g. McDowall et al., 2013, Reichardt et al., 2017, van Alphen et al., 2010). In other words, emphasis is here on the implications of specific characteristics of policies on the broader TIS development over time. While it is beyond the scope of this paper to fully review the empirical TIS literature from this perspective, we here provide a summary of how functions may be influenced by different types of policies, based on insights from selected empirical studies and the work of Kivimaa and Kern (2016).

Entrepreneurial experimentation highlights how experimentation with different concepts can reduce technological uncertainty. Examples of policies with an influence on this function include the establishment of pilot and demonstration activities that allow for upscaling and testing of technical and financial viability, as well as incubation schemes that assistant in scaling and development of business models (Reichardt et al., 2016; Kivimaa and Kern, 2016).

Knowledge development refers to technological learning, including both technical aspects of a technology and the ways that the technology is used in practice. Obviously, publicly initiated R&D programmes targeted at specific technologies play a central role here (e.g. Stephan et al., 2017). However, as argued by Randelli and Rocchi (2017), policy may also intervene on the user side, focusing e.g. on creating knowledge on user needs and preferences.

Knowledge exchange signifies the extent to which knowledge is exchanged between actors in the innovation system. Policy may play a role through collecting information and making it broadly available, for example in relation to availability of resources or location of demand (Hawkey, 2012, Gil Perez and Hansen, 2020). Further, policies may influence knowledge exchange through funding and organizing networking organisations with a focus on diffusion of knowledge (Ko et al., 2021; Tziva et al., 2020).

Guidance of the search describes the strength of incentives for actors to join a TIS, as well as mechanisms for directing technology development. Policy is a central factor in shaping guidance of search. Examples include regulations in the form of e.g. emission standards, public procurement practices, and targets for diffusion of technologies (Bach et al., 2021). Beyond concrete targets, broader visions of societal development such as 'a net zero GHG emissions society' can also constrain or promote the future potential of technologies (Kushnir et al., 2020).

Market formation refers to the degree of demand for the technology. Demand pull policies are central to market formation for green technologies, given the double externality challenge where investments in green technologies not only provide benefits for non-payers in the R&D phase through knowledge spillovers, but also in the application phase through e.g. limited emissions (Rennings, 2000). Feed-in tariffs, auctioning schemes and green certificate schemes are all examples of demand pull policies that stimulate market formation (Bergek and Jacobsson, 2010, Jacobsson and Karltorp, 2013, Furtado et al., 2020). Public procurement can also play an important role in creating niche markets for emerging technologies (Bach et al., 2020).

Resource mobilization highlights the degree of access to financial and human capital. Public funding is a central source for multiple activities, such as R&D and technology deployment, and may also allow for the construction of infrastructures supporting the use of the technology (Furtado et al., 2020; Bach et al., 2020). Consequently, industries and technologies considered old or low-tech by policymakers suffer from limited access to financial resources (Dewald and Achternbosch, 2016). On the human capital side, investments in educational programmes are essential for avoiding skills shortages for an emerging TIS (Jacobsson and Karltorp, 2013).

Legitimation describes the extent to which the technology is considered in line with rules and regulations, societal norms and cognitive frames. Legitimation is often strengthened indirectly through policy action that directly target other functions, e.g. policies that mobilise a significant amount of resources will thereby also indirectly create increased legitimacy for a technology. However, in addition, some policies may also directly focus on increasing legitimacy, e.g. in the form of public awards or competitions focused on a specific technology as well as the introduction of labels and certifications (Binz et al., 2016; Kivimaa and Kern, 2016).

Thus, the TIS literature has provided extensive insights to the influence of policy on TIS functionality, however, it is suggested that *"a more thorough understanding of the actual interlinkages between policies and the TIS they are embedded in, as well as a more differentiated treatment of policies are still largely lacking"* (Reichardt et al., 2016). The paper by Reichardt et al. (2016) provides a first analysis of interdependencies between policies and TIS by stressing not only how policies influence TIS functionality, but also how policies in turn need to be continuously adjusted and revised to respond to challenges in a TIS over time. Thus, there is a need for unpacking how different types of policies may influence different TIS functions and vice versa.

In the current paper, we contribute to the understanding of this interdependency between policies and TIS. Doing so, we respond to the critique of Kern (2015) who criticised the TIS literature for lack of attention to politics and the acknowledgement of Markard et al. (2015) of the need for greater attention to the role of agency in driving change. In short, most TIS studies tend to see policies as part of the given structural components, without analysing why they are in place or have a given shape. Ko et al. (2021) offers a clear exception here by taking a political economy approach to understanding how TIS development is influenced by power asymmetries and the interests of key actors. Against this backdrop, we suggest that changes in TIS functionality can influence policymaking in two ways. First, along the lines of Reichardt et al. (2016), policymakers may observe changes in TIS functionality and adjust policies to account for this. Second, changes in TIS functionality may have implications for the ability of TIS actors to influence policymaking. Arguably, it is somewhat simplistic to assume that policymakers automatically respond to challenges in need of intervention as a TIS develops. Rather, TIS proponents may strategically seek to influence policy processes (Musiolik and Markard, 2011), and their ability to do so likely depends on the performance of the TIS (Markard, 2020). In this paper, we do not dive into the specific strategies employed to influence policy processes, which can be conceptualised as different forms of institutional work (Lawrence and Suddaby, 2006). However, we do note that such institutional work is conditioned by actors' access to resources of different types (e.g. economic and intellectual) as well as the storylines and narratives they can promote (Duygan et al., 2019; Madsen et al., 2022). Thus, a strengthened TIS will provide TIS proponents with improved possibilities for influencing policy processes. Below, we introduce insights from the policy design literature to unpack the interdependency between policies and TIS.

2.2. Coevolution of TIS and policies: an analytical framework

In order to analyze the coevolutionary relationship between a TIS and policies, a new analytical framework is proposed in this section (Fig. 1). For the TIS part, we draw on classic TIS functional analysis to understand how key policy changes influence the functional performance of the TIS. For the policy analysis, drawing upon insights from Haelg et al. (2020) and Cashore and Howlett (2007), we highlight two key aspects, namely, level of abstraction of the focal policies, and policy focus including policy aims and means. The distinction between levels of abstraction is useful because it helps to disentangle the complex relationships between policies at different levels. At the high abstraction level, policy changes are *"paradigmatic"* (Cashore and Howlett 2007, 535) and involve modifications to fundamental aims of policy and core assumptions about how policies (should) work. At the low-level of abstraction, policy changes involve revising policy objectives and associated instruments, as well as changes in targets and the specific ways that policy instruments are working.[1] This distinction allows for understanding whether and how changes in TIS functionality have implications for the level of policymaking that TIS actors are able to influence.

[1] Haelg et al. (2020) includes a distinction between mid- and low-level of abstraction, but this level of granularity is not relevant to our analysis.

The need to distinguish between policy means and ends was justified by Hall (1993), because all policy is in fact a complex system of ends and means-related to goals, objectives, and settings (Cashore and Howlett, 2007), and thus only by making a clear distinction between ends and means can we examine whether TIS actors are able to influence both the objectives and goals of policy, as well as the forms of policy interventions and instruments that are put into place. Further, within each level of abstraction, one may distinguish between policy aims and policy means. In short, *"[p]olicy aims represent what the policy intends to achieve. Conversely, policy means define how to achieve these aims."* (Haelg et al., 2020, 312). Changes to policy aims may vary from revising the fundamental goals (e.g. environmental sustainability) that policies should strive for, to setting new policy objectives (e.g. reducing greenhouse gas emissions), or formulating new targets (e.g. net zero emissions by 2045). Similarly, changes to policy means span from changing the fundamental principles of how and where policy intervention is suitable (e.g. a preference for market-based instruments), to introducing new policy instruments (e.g. electricity certificate systems), or calibrating policy instruments (e.g. expanding the sectoral or geographical scope).

Summarizing, in analysing the coevolution relationship between policy and TIS development, we argue that policies instigate changes in the structural components of a TIS, which influence the ability of the TIS to deliver innovation system functions. In turn, policymakers may observe developments of TIS functions and adjust policies accordingly. Further, developments in functional performance will also change the resources available to TIS proponents, and thereby influence their ability to strategically influence policymaking.

3. Research design and methods

3.1. NEVB TIS and its development in China

A battery is a pack of one or more cells, each of which has a positive electrode (the cathode), a negative electrode (the anode), a separator and an electrolyte (Beuse et al., 2018; Malhotra et al., 2021). Different chemicals and materials used in a battery affect the energy density and cycling capacity of the battery – how much power it can provide and the number of times it can be discharged and recharged. Battery technology is a multipurpose technology (Malhotra et al., 2019), and its development is becoming increasingly important for decarbonisation of multiple sectors, including transport (Malhotra et al., 2021).

A lithium-ion battery (LIB) is an advanced battery technology that uses lithium-ions as a key component of its electrochemistry. In the early 1990s, LIBs were mainly produced for consumer electronic devices such as mobile phones, laptops, and digital cameras. After 2011, LIBs began to be increasingly deployed in electric vehicles (EVs) and by 2015, EVs constituted the largest market share (Malhotra et al., 2021). In terms of knowledge development, the US and Japan dominated the first-time patent application in the LIB industry between 1970s and 1990s. Since early 2000s, the proportion of knowledge contributed by new applicants has increased steadily. These new applicants come not only from the US and Japan, but also from China, particularly since 2006 (Malhotra et al., 2021). In terms of production, Japan used to lead the world in mass production of LIBs, but was later overtaken by South Korea. Currently, China is the world's largest producer of LIBs, largely due to the surge in the country's EV market (Beuse et al., 2018).

China also represents an interesting case study from a policymaking perspective (Lieberthal and Oksenberg, 1988), as the state plays a very active role (Wang and Li, 2021). Strongly influenced by the Soviet Union, policymaking in China is featured by centralized, top-down approaches with comprehensive systems of administration and regulation (Wang, 2017). In comparison to many other countries, state interventions are more visible in every field of life. There are considerably more policies in China, and they are often issued and amended at high frequencies (Wang and Li, 2021). As far as science, technology and innovation (STI) policy is concerned, policymakers in China have realized the importance of the role of STI policy in their overall development policy since the 1980s

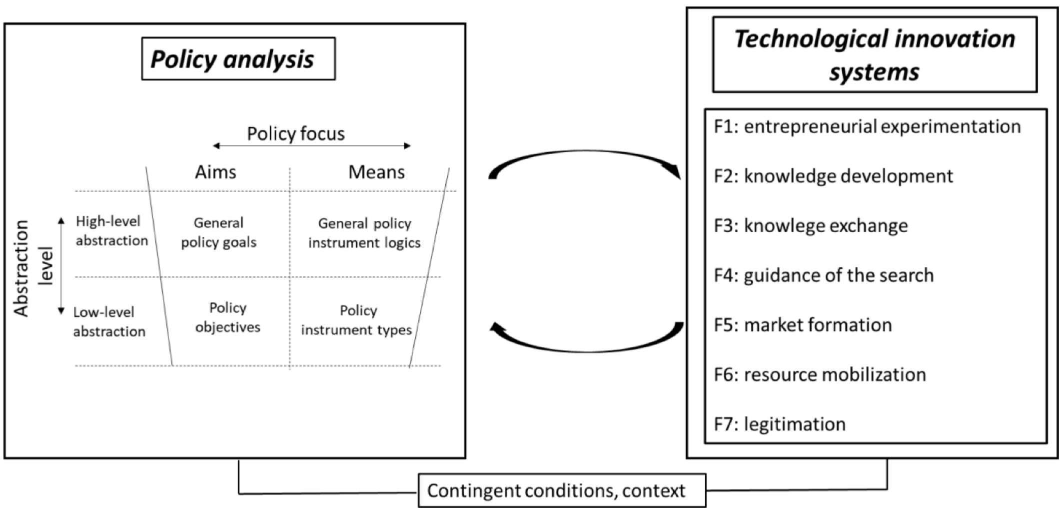

Fig. 1. Coevolution of TIS development and policies: an analytical framework.
Source: own design based on Haelg et al., (2020); Cashore and Howlett (2007).

(Ratchford and Blanpied, 2008). China began the implementation of STI policy with the establishment of the Ministry of Science & Technology (MOST), and since then, R&D output has grown very rapidly. In 2005, China became the world's second largest spender on R&D, and it has overtaken the EU in high-impact publications in 2016 (European Commission, 2019). Despite all these achievements, China's national innovation system is neither fully developed nor sufficiently integrated, and weaknesses such as fragmented funding systems, lack of monitoring mechanisms, and poor regulatory systems persist in the country (European Commission, 2016).

Fig. 2 shows the impressive growth of NEVB production volume in China since 2010, with the industry growing more than 200-fold over the past decade. In particular, since 2015, the market has grown rapidly, exceeding 80 GWh in 2020. Today, China has the highest NEVB production volume in the world, with seven Chinese companies among the global top ten battery manufacturers (Evergrande Research Institute, 2019).

Based on the results of the interviews, as well as the production volume of NEVB showed in Fig. 2, the development of the industry in China can be categorized into three phases. The first period (before 2009) was characterized by the development of domestic technological capabilities and collective efforts in developing demonstration projects for global events. The second phase (2009 to 2014) featured systemic promotion of the NEVs and the emergence of a domestic EV battery industry facilitated by subsidies. During this period, the significance of batteries for the NEV sector has been further stressed, and battery technology has increasing been seen as an important strategic part of the government's ambition to steer and develop a domestic NEV market. The third phase (2015-), is characterized by rapid expansion of the NEV market, increased innovation in domestic battery technology and a full value chain maturity.

3.2. Research methods

To explore the coevolutionary relationship between China's NEVB TIS and policies, the approach of key event analysis is applied. As pointed out by Suurs and Hekkert (2009), within the context of a TIS analysis, an event can be defined as an instance of change with respect to actors, institutions, or technology, which carriers some public importance with respect to the TIS under investigation, and follow from the work of one or more actors. Similarly, in analysing key events in policies, we first consulted experts and secondary materials and identified key policy documents that have had pervasive influence on the battery TIS. We then analysed further how such policy documents came into being and which TIS actors or organizations influenced them. All key events identified are verified either by the primary or the secondary data that we have collected.

A database was constructed containing key events in both the TIS and policies in chronological order. The paper draws upon three main data sources. First of all, 32 in-depth interviews or roundtable discussions with industry representatives along the value chain, policymakers, industry associations, third-party think tanks, scholars in China's major cities and regions, were carried out from October 2020 to January 2021 (for details of the interviewees, see Appendix 1). Some of them have been approached by the first author in conferences, others have been introduced to the author by gatekeepers in the field. Issues addressed in the interviews include 1) the history of the NEVB industry in China; 2) the key policy documents that have significantly influenced the industry; 3) the policymaking processes underlying these key documents; and 4) the role of TIS stakeholders (policymakers, companies, research institutions, users) in influencing policymaking. On average, each interview lasted around one hour, and all interviews were recorded and transcribed. Moreover, in July 2022, we again approached experts, intermediary organizations and officials previously interviewed for follow-up questions. We showed them our preliminary findings, and asked for feedback on key issues. In the end, four of them (intermediary 3, official 3, expert 2 & 5) accepted the invitations and provided additional insights and elaborations on the core topic of this paper. In addition, secondary data was collected and compiled chronologically from various sources including internal materials of intermediary organizations/think tanks, mainstream media reports, professional magazines, industry reports, public speeches of key policymakers, experts and important organizations.

Finally, thanks to the introduction by key persons in the field, the first author was able to participate in three policy discussion events and three conferences organized between December 2020 and January 2021 in China. Participatory observations in these

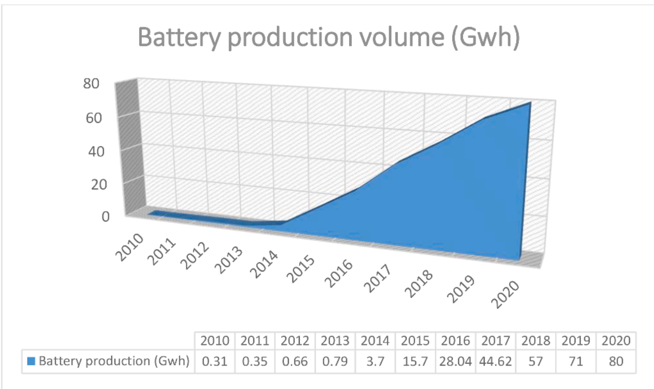

Fig. 2. Annual EV battery production volume.
Source: China Industrial Association of Power Sources.

events were important for understanding the politics behind NEV-battery-related policymaking process in China.

In terms of data analysis, we combine interpretation-focused coding with presumption-focused coding (Adu, 2019). The purpose of the former is to describe what interviewees said and interpret why they did so, and the latter is to develop a theory or model to explain the phenomenon that we are interested in. We coded the interview transcripts and grouped together relevant themes into three phases of development as described above. For each phase, we first analysed the TIS functional dynamics in the NEVB industry. We then identified key policies (both high- and low-level of abstraction) that had strong influence on the NEVB TIS dynamics in China over different periods of time. Finally, we disentangled the coevolution of battery TIS and policies. For the TIS side, we examined how TIS functions were influenced by both low- and high-level policies. For the policy side, we investigated how changes in TIS functionality over time were acted upon by both policymakers and other TIS actors to influence low- and high-level policies. To distill and systematize the coevolutionary relationships, we coded our data abductively by going back and forth between the insights derived from the literature and the insights generated from our data. In total approximately 450 data blocks were coded, and for an illustration of our data structure, see Appendix 2.

In the next sections, the battery TIS functional dynamics, the key policies, as well as the coevolutionary relationships between TIS development and policies in the three developmental phases will be introduced.

4. Before 2009: development of domestic technological capabilities and collective efforts in developing demonstration projects

4.1. *TIS functions*

China's interest in NEVB technology can be traced back to the mid-1990s. However, potential for mass commercialization only began to show in the second part of the first decade of the millennium. In the early 2000s, the development of the NEVB industry was still in a nascent explorative phase. Through the investment of national research funds during the 10th Five-Year-Plan (FYP, 2001–2005), a stable R&D team consisting of more than 200 enterprises, universities and research institutes and more than 2000 key technical personnel was formed, and a number of young and middle-aged engineers was trained to industry's development (the Ministry of Science and Technology, MoST, 2006) (F2 and F3). This intensive R&D support continued in the 11th FYP (2006–2010), leading to a significant increase in patenting activity. Moreover, 59 national standards were promoted and introduced, and 15 national key laboratories working on NEV related technologies were established (State Council, 2012). Due to the attention paid by the national state to this emerging field, significant amounts of resources started to flow into the industry (F6).

In terms of the guidance of the search (F4), the first half of the 2000s featured the development of relatively low energy density, and technologically less demanding battery technologies such as the Lithium Cobalt Oxide (LCO) and Lithium Manganese Oxide (LMO) batteries. However, around 2005, battery manufacturing and research increasingly moved on to the development of higher energy density technologies such as Lithium-iron Phosphate (LFP) batteries (Ouyang, 2015).

Regarding entrepreneurial experimentation (F1), thanks to the occurrence of several global events in China, batteries have been adopted in demonstration buses for example in the 2008 Beijing Olympic Games. Chery, Changan, FAW, Dongfeng, SAIC, Jinhua Bus, Foton and other domestic automotive makers, jointly with Tsinghua University, Tongji University, and Beijing Institute of Technology, provided nearly 600 NEVs to serve the Beijing Olympics (Beijing Institute of Technology, 2009).

4.2. *Key policies*

4.2.1. *Policy at high-level of abstraction: technological capability development and domestic catching-up*

High-level policy aims during the first period were focused on technology development, domestic catching-up and increasing returns to R&D. The high-level document that provided general guidance to the development of important industries in this period was the *Outline of the National Medium- and Long-term Scientific and Technological Development Plan (2006)* or the **MLP program** (Chen and Naughton, 2016; Liu et al., 2011). The MLP was a series of efforts to re-conceptualize China's approach to technology policy within a broader 'innovation policy' framework. In implementing the MLP, in addition to conventional incentive-based policy means such as preferential tax treatment and policies for high-tech zones, attention was also given to strengthening and diversifying the funding for science and technology (S&T), and developing human resources in S&T, including the cultivation of world-class expertise. Moreover, the theme of "indigenous innovation" was emphasised both through support to independent enterprises and large government sponsored projects (***high-level policy means***). In this MLP, 68 priority sectors, 27 frontier fields and 18 basic research areas were identified. Furthermore, 16 state-funded Megaprojects were expected to break bottlenecks and contribute to the development of an innovation-based economy. Development of new energy vehicles was listed as one of the priority sectors. In Article 36, it stipulated that high priority should be placed on R&D of power system integration and control technology, high-efficiency low-emission internal combustion engine, power battery, drive motor and other key components technology (Gov.cn, 2006). Guided by this programmatic document, more concrete policy actions were fleshed out in the NEV(B) industry.

4.2.2. *Policies at low-level of abstraction: industry-specific policy specification and implementation*

The goal of technological capability development and domestic catching-up at the higher level was reflected in the low-level policy documents. The most important industry-specific policy documents during this period were two 863 national high-tech projects announced by the MoST during the 10th and 11th FYP period, respectively, focusing on domestic technological development.

In 2001, the "Major Science and Technology Special Project for Electric Vehicles" under the 863 Plan was launched by the MoST, and the R&D layout of "three verticals and three horizontals" (three verticals: hybrid vehicles, pure EVs and fuel cell vehicles; three horizontals: battery technologies, electric motors and electric control systems) was established as the goal of the 863 project in the 10th FYP period (***low-level policy aims***). After the success of Beijing's Olympic bid in the same year, China's MoST decided to achieve "zero emission" for transportation in the Olympic venues in 2008. Beijing Municipal government further proposed to put in electric buses to serve the Olympic Games and Paralympic Games in order to achieve the specific "zero emission" goal set by the MoST (Beijing Institute of Technology, 2009). In 2006, the MoST released another 863 project on Energy-saving and New Energy Vehicles for the 11th FYP, aiming to accelerate the development of powertrain technology platforms and key components such as lithium-ion batteries in NEVs (Gov.cn, 2012). The main ***low-level policy means*** to achieve such domestic technological development policy aims were public R&D funds, state strategic high-tech projects, as well as incentives to boost early entrepreneurial experimentations.

4.3. Coevolution of NEVB TIS and policies

In the first phase, initial coevolutionary relationships between the battery TIS and relevant policies started to form. In terms of the impact of key policies on NEVB TIS, the two national 863 projects have substantially improved the R&D capabilities of the Chinese firms and research organizations (F2, F3), thus enabling the development of demonstrative NEVs that were used in global events (F1, F5, F7) (Expert 2). Moreover, these projects have also led to the exploration and development of various technologies such as LCO, LMO, and LFP (F4) (Expert 2). Finally, the generous support from the government at different levels also led to the increase of TIS actors both in terms of number and diversity (Official 2).

Regarding the influence of TIS functionality on policies, we investigate how changes in TIS functionality over time were acted upon by both policymakers and other TIS actors to influence low- and high-level policies. In terms of policymakers, they quickly responded to the initial success of the NEVB industry by directing the flow of resources to the nascent industry through policy tools. As one representative recalled,

> "…*the demonstrated feasibility of developing electric-powered vehicles led central government to become aware of the potential of batteries for transport electrification, and so it became an important part of the MLP program*" (Industry Representative 8)

In addition to policymakers, experts and scientists also leveraged the momentum to influence relevant policymaking processes. Although in general the influence of industrial actors on China's high-level policies is often limited (Expert 5), NEVB is an exception, as the industry showed high possibilities of success both in terms of technology superiority and market potential (Expert 5). This was confirmed by another interviewee, who claims that

> "..*knowledge development and technological breakthroughs achieved by privately-owned firms and universities in the electrochemical field … had either direct or indirect impact on all-level of policy design. …Especially key experts and scientists such as academicians, they were not only able to influence industry-specific policymaking process [low-level policy], some of them also had influence [albeit indirect] on the MLP program [high-level policy]*" (Intermediary 3)

The most clear example of this was the first NEV-related 863 project announced in 2001. A key figure pushing this high-tech project forward was Wan Gang, an automotive engineer who had been working for Audi in Germany for 10 years. In 1999, he wrote a letter to the State Council complaining about the shortcomings of China's auto industry. In the letter, Mr. Wan suggested that Chinese automakers should not continue on the current path of relying on conventional internal combustion engine (ICE) technology from abroad. Instead, they should focus on achieving autonomy by developing future automotive technologies. Among other things, he suggested that the development of NEVs could be a possible way to overtake the pre-existing leaders in the ICE sector, as all global players were at a similar starting point for developing radical new technologies (Expert 1). Wan Gang's proposal was adopted by the Party's top leaders (F7), and in 2001 the Chinese government set up the "Electric Vehicle Special Expert Group" and decided to launch a special 863 Program to support the development of NEVs. In the same year, Wan Gang returned to China and settled in Tongji University and was appointed as the Chief scientist and head of the Special Expert Group (Expert 5).

The central government and relevant ministries' openness towards key scientists and technological elites was further strengthened during its preparation for the Olympic Games. An expert from Tshinghua University who was strongly involved in the e-bus demonstration project in the Games mentioned:

> "*At that time, the Olympic Games were considered a big event by the Chinese people, and it was the first time that China hosted such an international event. … Therefore, the main leaders [politicians] took the preparations for the Games very seriously… We were invited to meetings and workshops organized by several ministries. … we reported on the progress made, but also the obstacles encountered, and they [the politicians] would try their best to help us solve the problems*." (Expert 1)

Overall, thanks to the various support by the central government mentioned above, the 2008 Beijing Olympic Games indeed boosted the development of the NEVB industry in China. Moreover, the policymaking process in this period (both at high- and low-level of abstraction) also featured voices from elites and experts with strong expertise. However, similar to Chen and Naugton's (2016) observation, there was no formal process in which the policy objectives were articulated and through which diverse opinions could be systematically (re)aggregated. The assignment of tasks and objectives of policy among ministries had not been specified, and professional consultation was wide-ranging, but not systematic.

5. 2009–2014: systemic NEV promotion and industry-specific policy experimentation

5.1. TIS functions

In stark contrast to TIS development in the first period, which focused on catching up with global forerunners in technological capabilities, TIS dynamics in the second period was characterized by a strong focus on market exploration (F5). Following the two 863 projects supported by the MoST and the implementation of demonstration projects at events such as the 2008 Beijing Olympics and the 2010 Shanghai Expo, China made significant progress in key battery component technologies (anodes, cathodes, separators, electrolytes), vehicle integration and testing technologies (Expert 2) (F2 and F3). As for entrepreneurial experimentation (F1), enterprises were focusing on exploring higher energy density battery technologies that can be mass produced and installed in NEVs. Regarding R&D directionality (F4) during the 12th FYP period, firms and research organizations continued to adhere to the basic R&D layout of "three verticals and three horizontals" specified in the first 863 project, but additional attention was paid to the "three horizontal" common key technologies (i.e. battery technologies, electric motors and electric control systems) targeting the development of the "pure electric drive" technologies. Technology-wide, due to BYD and other domestic enterprises' technological accumulation in LFP batteries in the 1990s and early 2000s, LFP was the mainstream technology adopted in NEVs in this period (Expert 2) (F4).

In terms of resource mobilization (F6) and legitimation (F7), development of NEV in China was deemed feasible and promising, consequently by the end of the period, the number of NEV(B)-related universities and research institutes has increased to 177, and altogether, more than 1000 scientific papers had been published, and 1000 patent applications submitted (Ouyang, 2015). Regarding market formation (F5), encouraged by the successful application of NEVs in the global events mentioned early on, policymakers began to consider promoting large scale NEV applications (Official 3). Although policymakers actively promoted the adoption of NEVs, the market only experienced modest growth during this period (Industry representative 3), driven primarily by growth in the commercial vehicle subsector, while private car purchases remained very limited (Industry representative 6).

5.2. Key policies

5.2.1. Policy at high-level of abstraction: cultivating markets for emerging and high-tech industries

The key policy document at high-level abstraction in this period was the *Decision of the State Council on Accelerating the Cultivation and Development of Strategic Emerging Industries*, or the **Strategic Emerging Industries (SEI) program** in 2009. It was specified in this document that starting from 2010, the state would launch a number of major projects and programs with the aim to promote strategic emerging industries with good market potential. The ***high-level policy aims***, thus, shifted from the earlier emphasis on state-funded S&T activities to the cultivation of strategic industries such as energy conservation and environmental protection, renewable energy, new materials, new energy vehicles, etc., that have mass-production potentials. Unlike the MLP program in the first phase, where the state was one of the major players in supporting S&T development, in this period, government was supposed to create favourable market conditions for enterprises to commercialize and test commercializable technologies (Chen and Naughton, 2016). In contrast to the MLP, which was initially led by MoST and started as a science policy and only subsequently spilled over into industrial policy, the governing body for the SEI program was from the start the National Development and Reform Commission (NDRC), the main economic planning agency (Chen and Naughton, 2016). The SEI program stipulated that policy effort should be made to support market expansion and business model innovation (***high-level policy aims***). It was argued that NEVs provided a good opportunity for industrial upgrading and transformation. Therefore, if China wanted to build a globally competitive automotive industry in the future, it had to strive to become one of the pioneers in research, technology development and commercialization of NEVs (Gov.cn, 2010)

5.2.2. Policies at low-level of abstraction: industry-specific policy specification and implementation

Following the guidance of the SEI document, ministries and State Council jointly took crucial policy actions to realize the overall objectives specified for the NEV(B) industry. Encouraged by the successful demonstration of NEVs in the Beijing Olympic Games, industry-specific policy actions in this period featured systemic market exploration and NEV promotions.

In 2009, an important policy on "*Notice on the Pilot Demonstration and Promotion of Energy-saving and New Energy Vehicles*" was announced jointly by the MoST and the Ministry of Finance (MoF). In the same year, another project called "*Ten cities and a thousand energy-saving and new energy vehicles demonstration and application project*" ("Ten Cities, Thousand Vehicles Project" in short) was jointly established by the MoST, MoF, NDRC, Ministry of Industry and Information Technology (MoIIT), to carry out the first experimentations with NEV adoption in public sectors in major Chinese cities. The plan was that over the next 3 years, through the provision of financial subsidies, about 10 new cities would be added annually to the list of pilot cities each with at least 1000 NEVs adopted in public transport (including taxis, buses, city and postal use, etc.). The overall goal was to make national NEV sales reach 10% of the total car sales in 2012 with major Chinese auto makers as the central contributors (State Council, 2009) (***low-level policy aims***). This project was successfully carried out between 2009 and 2011, and by the end of the period, the pilot cities had been expanded to include major city clusters (e.g., Yangtze River Delta, Pearl River Delta, Beijing-Tianjin-Hebei Region).

In order to promote NEV adoption, corresponding subsidy schemes (***low-level policy means***) were designed jointly by the abovementioned four ministries. The initial explorative subsidy scheme was only targeting the public sectors (e.g., buses, taxi, municipal and postal usage, etc.), but was expanded to cover private purchase in 2010. The major subsidy rules specified in the respective documents during this period are showed in Appendix 3.

After the three-year policy experimentation, in 2012, the "*Energy-saving and New Energy Vehicle Industry Development Plan (2012–2020)*" was issued by the State Council. According to this key document, by 2020, the energy density of battery modules was required to reach 300 Wh/kg, and the cost drop to less than 1.5 yuan/Wh. Moreover, this policy called for the creation of regional clusters for the NEVB industry, and the cultivation of 2–3 highly competitive (both in terms of production and R&D capabilities) domestic battery firms; 2–3 key Chinese enterprises in battery components including anodes, cathodes, electrolytes, and separators (State Council, 2012) (***low-level policy aims***). This document provided a clear direction for the industry towards 2020 and guided the actions of the bureaucracy, industrial players and other relevant stakeholders.

5.3. Coevolution of NEVB TIS and policies

In the second phase, the reciprocal relationships between NEVB TIS and policies was strengthened. The incorporation of NEV(B) in the SEI program, as well as the promulgation of a series of key policy actions by multiple ministries, strengthened relevant stakeholders' confidence in the emerging market, and thus led to high level of legitimacy (F7) to the industry, as well as market expansion of power batteries in commercial vehicles (F5), increased entrepreneurial exploration by companies (F1), knowledge development and exchange (F2, F3), and the inflow of all sorts of resources (capital, human resources, technology, attention, etc.) to the booming battery TIS (F6) (Intermediary 3, Expert 5).

> "…*Overall, you can think of policies in this period as a catalyst or an accelerator for the battery industry, … and this emerging field has been greatly expanded in terms of both staffing and resources due to strong policy incentives*." (Expert 5)

On the other hand, TIS functional developments (e.g., F1, F2, F3, F5) in the first and second periods strengthened policymakers' confidence in overtaking their western rivals in the NEV field, and thus influenced their policy actions both at the high- and industry-level (Intermediary 1). Among others, the MoST, and Mr. Wan Gang, as a key expert who became the minister of MoST in 2007, seemed to play a significant role. Due to Mr. Wan's experience in the German automotive industry, the central government gave significant responsibility and power to him to guide the development of Chinese NEV industry (Expert 4). Mr. Wan was also the key person behind the "Ten Cities, One Thousand Vehicles" pilot project. An official from the MoST commented,

> "…*after nearly 10 years of government support, enterprise exploration and university research, we [MoST] believed that China's technological gaps with the world leaders had narrowed tremendously. Therefore, our next task was to create the conditions for mass industrialization of power batteries for electric cars, … or to create a first-mover advantage, …because no other country was promoting e-cars on a large scale at that time. … This was also the original motivation of our former Minister Wan Gang to promote the 'Ten Cities, Thousand Vehicles' program*" (Official 3).

Furthermore, due to the positive expectation of the market potential of the NEVB industry, a series of industry-specific market-exploration policies, announced jointly by several ministries, was implemented during this period. Moreover, policymakers incorporated the NEV(B) industry into the high-level SEI program, due to its high market potentials (Intermediary 3).

> "…*The SEI program focused on emerging industries with good market opportunities. …Importantly, the industries selected in such a program were usually the activities in which China could expand its comparative advantages. …The inclusion of power batteries in this program also showed that policymakers believed in China's potential for talent training, capital mobilization, and market formation, etc., in this new field*." (Intermediary 3)

As for the role of other TIS proponents, knowledge inputs from third-party think tanks, public and private research institutes, and key scientists were important inputs for deciding on concrete policy aims and means. One official gave detailed information on how policy goals were decided:

> "*When a policy program such as the 'Energy-saving and New Energy Vehicle Industry Development Plan (2012–2020)' was to be launched, we [the responsible ministries] had to draw concrete conclusions on feasible policy targets and means to achieve them, … we defined research topics in our internal research institute or commissioned external think tanks, intermediary organizations, universities or consulting agencies to conduct research on specific topics. With input from various organizations, the people in charge [*e.g.*, the minister] discussed the findings with key experts and finally decided on specific targets.*" (Official 3)

Thus, unlike the ad hoc consultation process articulated in the first phase, consultation and opinion soliciting was done in an increasingly formalized, systemic manner.

6. 2015-: intensified policy actions and domestic full battery value-chain construction

6.1. TIS functions

Chinese NEV market experienced rapid growth in the third phase, and China became the world's largest NEV market in 2015 (Ouyang, 2015). Driven by the high sales of NEV in the domestic market, China's NEVB industry has entered a phase of rapid growth (F5). During this period, CATL grew to become the world's top NEVB producer in 2017 and has maintained its leading position in production to date (Benchmark Mineral Intelligence, 2020). Meanwhile in battery subfields such as component manufacturing, Chinese players have achieved competitive advantages as well, and a highly robust domestic battery value chain, from raw materials, to component manufacturing, to cell and pack production, to EV application, has been formed (Industry representative 12). This development momentum also conferred greater legitimacy for further development of the industry, as past support was perceived as successful (F7). Due to an increasingly foreseeable bright future of the NEV market, numerous resources have been attracted to the emerging industry, and the number of enterprises that entered the industry reached a peak of 150 in 2016 (GG-LB.com) (F6).

Regarding knowledge development and exchange (F2 and F3), Chinese battery enterprises have increased their R&D expenditure, leading to several technological breakthroughs as well as increasing domesticalization of the key technologies in the four core battery components (anodes, cathodes, electrolytes, and separators)(Gov.cn, 2020). As a result, several key enterprises have emerged in each of the battery component fields including Easpring and Ronbay in anodes, Shanshan and BTR in cathodes, Capchem, and Tinci in electrolytes, and Shenzhen Senior and Yunnan Energy New in separators (Industry representative 12).

In terms of the guidance of the search (F4), due to the biased subsidy scheme largely in favor of higher energy density battery technologies, Lithium-manganese-cobalt-oxide (NMC) batteries have become increasingly important due to their high energy density (150–220 Wh/kg compared to around 90–160 Wh/kg for LFP). As a result, the installation of NMC batteries in cars increased steadily, eating into the market share of LFP batteries, and overtook the installed volume of LFP in 2018. In 2019, the share of NMC and LFP reached 65% and 32%, respectively (see Appendix 4).

6.2. Key policies

6.2.1. Policy at high-level of abstraction: achieving breakthroughs and gaining technological independency

In the third period, the most important high-level policy document was the **"Made in China 2025″ (MIC 25) program**, which was announced in 2015 by Premier Li Keqiang. This blueprint was developed jointly by NDRC (economic goals) and MOST (science development), with additional inputs from MIIT (industrial development) and other constituencies (Li, 2018), showing the comprehensiveness of this central policy. The document's aims to propel China through the middle-income trap and transform the country into a globally competitive manufacturing superpower largely independent of foreign technologies (***high-level policy aims***). Zenglein and Holzmann (2019) interpret this as China's attempt to localize high-tech value chains, with its government increasingly acknowledging the importance of markets, private enterprises and favourable institutional conditions as determinants of a well-functioning innovation system (Liu et al., 2017). Moreover, various ***high-level policy means*** including cultivation of national champions, and mediation of market access for domestic and foreign firms, are promoted as pathways to technological independence and superiority. At its core, the MIC25 strategy defined ten key industries in which China wants to achieve major breakthroughs over the next decades (Gov.cn, 2015a). NEV(B) were featured prominently in the MIC25 program. It stipulated that by 2020, development of the NEVB, drive motor and other key components should reach an internationally advanced level, and account for 80% of the share in the domestic market. Furthermore, by 2025, these component sectors should develop large-scale export capabilities (Gov.cn, 2015b). More importantly, in 2016, China's first Manufacturing Innovation Center – the National Power Battery Innovation Center – was established in Beijing under the direct approval of Vice Premier Ma Kai. Minister of MIIT, Miao Wei, told in a public speech that the establishment of this center was one of the five major projects under the MIC 25 program, shouldering the major mission of gathering innovation power, and supporting the strong manufacturing profile of China (gov.cn, 2016). Therefore, it became clear that NEVB has increasingly entered the core discourse at the top-level policy document.

6.2.2. Policies at low-level of abstraction: industry-specific policy specification and implementation

Following the rules and principles specified in MIC25, industry-specific policy actions have intensified. In contrast to previous phases, where policy instruments on batteries were incorporated under the generic automotive or EV industry, in this third phase, several NEBV-specific policy documents have been announced. Critical policy documents in this period include the "*Automotive Power Battery Industry Specification Conditions*" (or the "Battery Whitelist") by MoIIT in 2015 and its termination in 2019; and the annually-adjusted subsidy schemes released jointly by MoF, MoST, NDRC and MoIIT. Unlike previous phases, where the main responsible bodies of the industry were MoST and MoF, in the third phase, the MoIIT – the ministry in charge of industrial development – took a central position in various policymaking process.

> "… *This change reflects the shift in focus from pure scientific and technological development to overall industrial development and the pursuit of global leadership in the domestic and global markets…*" (Expert 2).

These policy actions have fundamentally shaped the development of the NEVB industry in China in the last phase.

The "Battery Whitelist" policy has been mentioned by nearly all of the interviewees as the most crucial policy for the industry.

> *"…The overarching goal of this key policy was to create a protective space for the development and growth of the then still weak Chinese battery manufacturers…and to cultivate a domestic battery industrial ecosystem with strong Chinese players along the whole value chain…* " (Expert 2) (***low-level policy aims***)

The policy stipulated that only NEVs that were equipped with batteries that met the conditions specified in the document were eligible to be listed in the "*Recommended Model Catalog for the Promotion and Application of New Energy Vehicles*" (MoIIT, 2015) and thus receive subsidies (***low-level policy means***). Several interviewees (Industry representative 3, 8, 11; Intermediary 3; Expert 2, 3) interpreted this measure as a protective instrument in favor of domestic players as no single foreign battery producers have ever been included in the list.

This protective Whitelist has been welcomed by the industry and has indeed played a crucial role in boosting the domestic battery value chain cultivation. Due to the steering of the policy in favor of domestic battery manufacturers, many of the Chinese automakers, which had previously contracted with Korean and Japanese suppliers, shifted battery orders to domestic manufacturers in order to receive generous subsidies. This preserved market has thus led to more R&D and technology expenditures by domestic battery producers and was therefore seen as helpful in narrowing the technological gaps with global incumbents. It was also praised as it contributed to the emergence of competitive domestic battery component manufacturers in nearly all subfields (Industry representative 5, 8, 12, 14; Expert 4).

Following the introduction of the battery whitelist, subsidies were reserved for domestic battery producers, but at the same time, other policy actions sought to reduce the subsidy level, i.e. the phase-down subsidy schemes (see Appendix 5), to prevent a subsidy culture that would harm the future competitiveness of Chinese producers on export markets (***policy means at low-levels***). In addition to annually reducing the amount of subsidy for public and private purchases, these policy adjustments also imposed more stringent technical requirements (e.g., energy density, driving range, etc.) for receiving subsidies in order to promote the development of core battery technologies by the domestic firms (***policy aims at low-levels***). Finally, in the last few years, increasingly a number of policies have been targeting the hurdles that hinder the uptake of mass market in China. These includes subsidies for charging stations, battery swapping systems, strengthening the regulation on battery safety, etc.

6.3. Coevolution of NEVB TIS and policies

In the third phase, as the industry developed further, the reciprocal influence between the battery TIS and its policies became more complicated. First of all, the success of the early pilot projects guaranteed a strong position of the NEV(B) industry in the MIC25 strategy. Battery technology was mentioned in the MIC25 document, and the establishment of the National Power Battery Innovation Center as one of the five major projects under the MIC 25 program also showed the significance of the battery technology (a general purpose technology) in China’s top-level innovation policy.

Specific to the industry-level, the coevolution of battery TIS and policies also became intensified in this period. In terms of the influence of policies on TIS dynamics, the Battery Whitelist, in combination with the generous subsidy schemes, had boosted enormous market growth and technological advancement of the domestic battery industry (Intermediary 3): the number of firms increased rapidly in this period (F1); CATL became the global top 1 battery supplier in 2017, and strong market leaderships in several battery component subfields were formed (F2, F5). And because of the protection, as well as the efforts to domesticalise the battery value chain, the huge Chinese market was effectively restricted to domestic firms, and hence they could invest more in R&D and technology development and capture more added value (F2, F3). Moreover, adaptations of subsidies in this period influenced the choice of technology trajectories by automakers (F4).

Concerning the influence of TIS functionality on policies, despite all the technological progress achieved, in the beginning of the third phase, Chinese actors were still relatively lagging behind their competitors from South Korea and Japan both in innovation capabilities and in market development (relatively weak F1, F5 compare to global leading players). Consequently, policymakers identified the need for temporarily shielding of the domestic players from global competition to build an independent, domestic battery value chain on par with foreign competitors. As explained by a senior manager:

> “ … *Within the industry, we often say that we have been able to catch up to 90% or even 95% of the technological capabilities of the pioneers in each of the technological subfield [anode, cathode, separator, electrolyte], but added up, we still lagged behind foreign forerunners in overall battery quality. …the launching of the Whitelist can be interpreted as the central state’s [*i.e. *policymakers] intension to protect the domestic emerging industry, at least for a limited time”. (Industry representative 8).*

While the Battery Whitelist has in general been praised by our interviewees for supporting the development of the battery TIS in China, it was also criticized for leading to innovation inertia (Expert 1). Due to the very generous subsidy scheme, many of the Chinese car and battery manufacturers increasingly shifted their focus to meeting the subsidy criteria required by the policy, instead of concentrating on product and process innovations that would guarantee their market success in the long run (Intermediary 3, Expert 4). Moreover, reports on subsidy frauds have also caused strong criticisms of the industry by the public (Industry representative 5). Such potential negative influence on TIS development has also been taken into account in policy amendments. Therefore, after hosting several roundtable discussions with experts, industry representatives, and intermediary organizations, the MoIIT decided to terminate this policy in 2019.

In terms of other TIS actors' influence on policies, an interviewee from one of the major intermediary organizations mentioned:

> "…*as the industry becomes increasingly complex, the policy-making process also needs to involve more different stakeholder groups to reach consensus on critical issues*…. *Intermediary organizations, therefore, are important players in policymaking*" (Intermediary 3).

Policy formation and discussion in this period were thus subject to the influence of increasingly diverse groups of actors coordinated by intermediary organizations. Among others, we spoke to representatives from three key intermediary organizations, including the China Electric Vehicle Association (China EV 100), the China Automotive Technology & Research Center (CATARC), and China Society of Automotive Engineers (China SAE). China EV 100 is particularly worth mentioning here, as it is seen by many industry representatives as the most important intermediary organization that has a major influence on policymaking. Founded in 2014 with special permission from the State Council, China EV 100 is expected to better coordinate interests between different ministries as well as between government, industry and society. It received a great deal of attention from various ministries from its establishment, and each year several ministers participated in policy discussions at its annual meeting. Due to the positive reception by the top-level ministers, it is also seen as an important platform by industrial representatives, experts and the public where critical voices can be passed on to policymakers (industry representative 3, 12, intermediary 2).

The engagement of various interests groups in policymaking was nicely shown in the following example. In a recent press conference on *Energy-saving and NEV Technology Roadmap (2021–2035)*, Li Jun, Member of the Chinese Academy of Engineering and professor from Tsinghua University, provided information on the increasingly complicated policymaking process behind this policy. According to him, relevant policy design started in early 2019, and took in total one and a half year to finalize. Specifically, 93 seminars, brainstorming meetings, expert review and validation sessions, result acceptance meetings, etc., were organized by the Expert Special Group and relevant ministries. Participants were coming from industry associations, universities and research institutes, enterprises from the whole value chain, and third-party think tanks. More than 1000 experts were either consulted or invited to participate in policy discussions (China SAE, 2020). China SAE, as an intermediary organization, was the body coordinating vested interests during the whole process.

In addition to the above-mentioned groups and actors that frequently participate in and influence battery policymaking, key entrepreneurs have also in recent years sought to influence policy through various channels. In addition to the conventional informal ways of building personal relationships with key decision makers, these entrepreneurs, elected as Chinese People's Political Consultative Conference (CPPCC) members or National People's Congress (NPC) representatives, have increasingly used formal channels to influence top-level policymaking by submitting battery-related proposals to China's Two Sessions[2] held annually in March. For example, at least 9 representatives from the battery sector made NEVB-related proposals in the 2021 Two Sessions (China Power Battery Recycling and Secondary Utilization Union, 2021).

7. Discussion and conclusion

7.1. *Policy aims and means at different levels of abstraction*

Table 1 summarizes the policy aims and means at different levels of abstraction during the three phases. Overall, we confirmed previous observation that high-level policies in China often have indeed significant influence on how policy is designed at the lower, more specific levels (Chen and Naughton, 2016; Haelg et al., 2020). Low-level policies, on the other hand, can also become influential in the high-level when the sector is deemed strategically important by the top leaders. During the last two decades, change of policies at high-level of abstraction was observed when there was a fundamental change of mindset (i.e. rationale) of policymakers in Chinese innovation policy. Since the early 2000s, we identify MLP, SEI, and MIC25 as the three most influential innovation and industrial policies at the high-level that had tremendous impact across sectors and industries in China. In many ways, MLP represented the Schumpeterian growth thinking of the Chinese leadership in the early 2000s. Such a thinking, in turn, led to generous state-led S&T investments in general, and the establishment of two national high-tech projects relate to the NEVB industry in particular. SEI, on the other hand, reflected the change of the high-level policy rationale from Schumpeterian growth theory to a developmental approach in the second phase. Guided by such a developmental thinking, emphasis at the high-level has been placed on the commercialization and marketization of strategic industries. Market expansion and business model innovation thus were the key focus of policies at the industry level. Finally, MIC25 reflected a combination of developmental approach and systemic institutional approach. This change of rationale was also observed in the policies (Battery Whitelist, various subsidy schemes) and practices (domestic value chain construction) at the industry-level.

7.2. *The coevolutionary patterns and TIS actors' power in policymaking*

Fig. 3 illustrates the coevolution of the battery TIS and policies across the three phases of development. In this subsection, we elaborate on how dynamics in battery TIS functionality have influenced the actions of policymakers, but also created possibilities for TIS actors to influence policies at different levels of abstraction.

As we showed in our case study, policymakers and other TIS actors have played non-trivial roles in China's EV battery

[2] The "Two Sessions" or *Lianghui (两会)* are the main annual meetings of China's two highest political bodies, namely the National People's Congress (NPC) and the Chinese People's Political Consultative Conference (CPPCC).

Table 1
Policy aims and means at different levels of abstraction in China's NEVB industry.

PHASES	LEVELS	KEY POLICIES	AIMS	MEANS
PHASE 1	High-level	Outline of the National Medium- and Long-term Scientific and Technological Development Plan (MLP)	Technological capability development, domestic catching-up, creating conditions for increasing returns to R&D	Preference for R&D support to high-tech sectors; Criteria of concentration for increasing returns; Emphasis on individual organizations; Science push with large projects
	Low-level	Two 863 projects	Support accumulation of endogenous R&D in NEVB technologies	Public R&D funds, state strategic high-tech projects, as well as incentives to boost early entrepreneurial experimentations
PHASE 2	High-level	Strategic Emerging Industries (SEI) program	Cultivating markets for emerging and high-tech industries	Government to create favorable market conditions for enterprise to develop and grow, i.e., supporting market expansion and business model innovation
	Low-level	"Ten Cities, Thousand Vehicles" program	NEV sales reaching 10% of the total car sales; Creation of regional clusters, and the cultivation of highly competitive firms within the value chain	Subsidy schemes; direct investment in skills and human capital development; Subsidize firms in strategic industries to reduce risk
PHASE 3	High-level	Made in China 2025 (MIC 25) program	Achieving breakthroughs and gaining global leadership; Cultivating a domestic innovation system that is technological autonomous	Combination of market-leveraging approaches (protected market for domestic firms, market access in return for foreign technology), public funding for R&D, and fiscal stimulation
	Low-level	Battery whitelist; Phase-down subsidy schemes	Creating a protective space for the development and independence of the Chinese NEVB industry; Cultivate a domestic battery industrial ecosystem with strong Chinese players along the whole value chain	Biased (gradually phased-out) subsidies to Chinese firms; Domesticalize the value chain, strengthen innovation capabilities; Cleansing hurdles for market upscaling

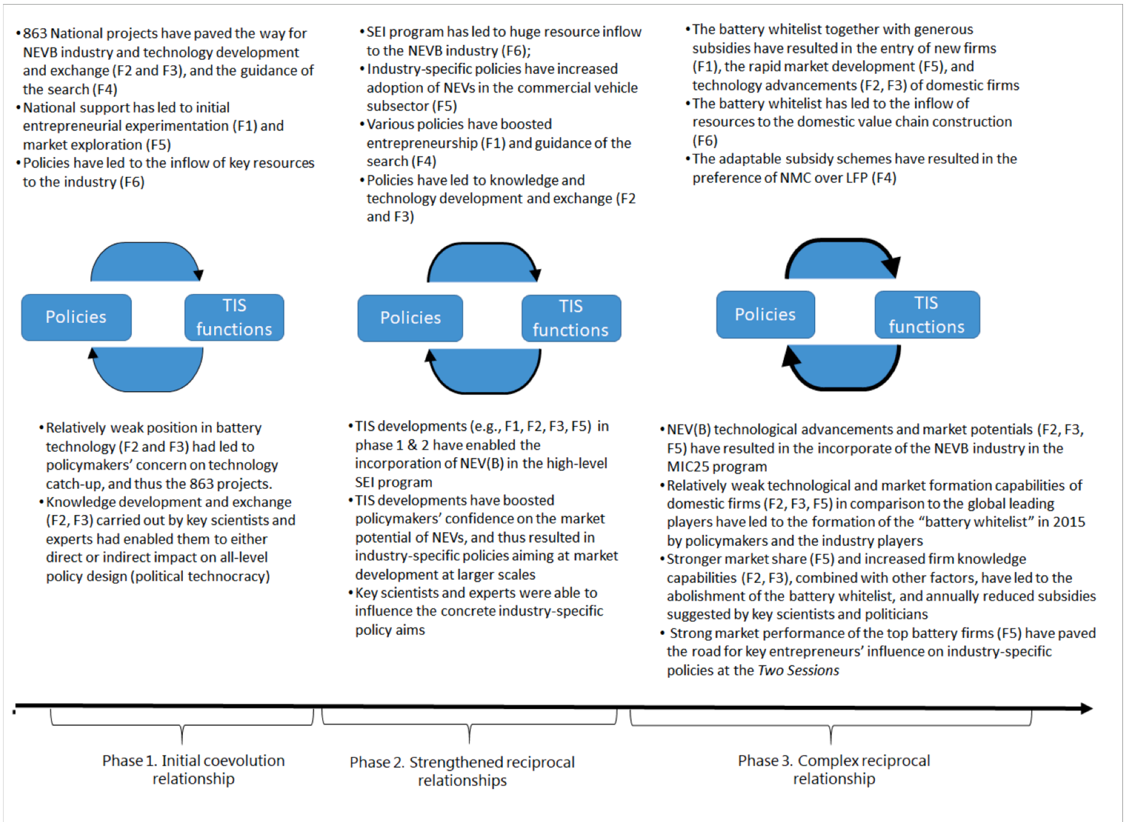

Fig. 3. Coevolution of battery TIS and policies.

policymaking. On the one hand, based on assessments of TIS functional developments in different phases (both positive and negative assessments), policymakers have quickly adjusted policy initiatives to give more momentum to the emerging technology sector. On the other hand, TIS advocates also strategically sought to influence policy processes (Musiolik and Markard, 2011) by leveraging the dynamics in TIS functionality. Their approaches included a combination of formal and informal channels, and their ability to influence policymaking depended on the performance of TIS functions (Duygan et al., 2019; Markard, 2020). A central facilitating factor is the overall positive expectation in China for EV battery technology in terms of both technological superiority and market opportunity. This positive expectation has led to very concentrated efforts by both policymakers and other TIS proponents, and thus a rather positive mutual reinforcement of activities on both the TIS and policy sides.

On the one hand, these findings confirm the suggestion of Markard (2020), by highlighting how TIS-policymaking relations become increasingly interdependent as the TIS matures. On the other hand, our analysis also underlines that TIS actors may influence policymaking already in the emergence phase, as technology experts and scientists had significant influence on policymaking early on. Thus, the relationship between TIS and policymaking was never unidirectional in our case.

Although everything seemed to be moving relatively smoothly at all stages of development (i.e., functional development of the TIS, policymaking and implementation), there were also moments when tensions and vested interests surfaced. The abolishment of the battery whitelist was one such example. Although this policy was much needed at the beginning of the third period, the potential negative impacts (e.g., subsidy fraud, innovation inertia) of overly generous subsidies ultimately led to its termination by MIIT. We believe that such tensions and conflicts of interest are inevitable in experimental policymaking. However, an important lesson that can be drawn from this study is that policymakers need to develop dynamic policy evaluation capabilities and mechanisms to increase the effectiveness of the key policies. Despite such conflicts, EV battery policymaking is generally perceived to be successful by all interviewees. Moreover, as showed in Fig. 3, the actor and networks that were relevant for policymaking became denser over time. Drawing upon the work by Musiolik et al. (2020), we can see that the collaboration modes that actors adopted to influence policymaking experienced a shift from single mode (i.e., single actor/ organization), to partner mode (collaboration among actors without the establishment of an intermediary) and intermediary mode (the establishment of intermediary organizations) as the industry matures. Single mode, based on the power of individual actors or organizations, remains to be an important mode in influencing policymaking at all levels, highlighting the significance of policy consultation and epistemic learning in China (Li and Dunlop, 2021). Moreover, as the industry develops, the increasing complexity has led to greater emphasis on the partner and intermediary modes. Another important observation was that the actor coalitions and their strategies differed from one stage to another. The intellectual pool in influencing policy process was enlarged over time, and the policy process became increasingly formalized and institutionalized (Chen and Naughton, 2016). Overall, we argue that more research is needed to better understand the agency-side of how TIS development leads to changes in policymaking.

7.3. Conclusion

In summary, the contribution of this paper was to develop an analytical framework to highlight the coevolution between TIS dynamics and policymaking. The framework underlines not only the influence of policies on TIS functionality, but also that changes in TIS functionality may in turn feed back into policymaking: policymakers may observe changes in TIS functionality and adjust policies to account for this, but changes in TIS functionality may also have implications for the ability of TIS actors to influence policymaking. We analyze this in one of the fastest growing green technologies in China, examining the mutually reinforcing and amplifying dynamics between the focal TIS and policy over the past two decades. While China is often referred to as a special case characterised by a very active government approach to technology and industry development, a renewed emphasis in developed economies on industrial policies (Aiginger and Rodrik, 2020) reduces some of the differences across contexts. Still, future research could benefit from a better understanding of how different political contexts influence the coevolution between policies and TIS development. Examples of relevant factors that would be expected to vary geographically include the structure of policy networks and their influence on policy processes, the degree of stability of policymaking across political cycles, as well as centralised versus decentralised political systems (see e.g., Flanagan and Uyarra, 2016; Normann, 2017).

Our research has primarily focused on the coevolution of the EV battery TIS and policy, we have thus largely excluded the influence of other TIS(s) and their dynamics from our analysis. Future research should take a full value chain perspective (Maholtra et al., 2019) to highlight the cross-sector dynamics along the battery technology value chain (upstream mining and materials processing, midstream battery and component production, downstream EV application and end-of-life management, etc.) and the relevance of policy decisions along the value chain. In general, a closer examination of the relationship between a TIS and its embedding context (Bergek et al., 2015) is an interesting topic that requires further research. Also, the analysis of Chinese policymaking in this paper was primarily based on a "rationality model" (Lieberthal and Oksenberg, 1988), which focused on the evolution of policy and the response of policymakers and TIS actors to the changing EV battery situations in order to advance industrial and national interests. In the future, an in-depth study of the "power model" (Lieberthal and Oksenberg, 1988), which shows the struggle for power between ministries (e.g., MoST, MIIT), individuals and especially between top politicians, would be of great value.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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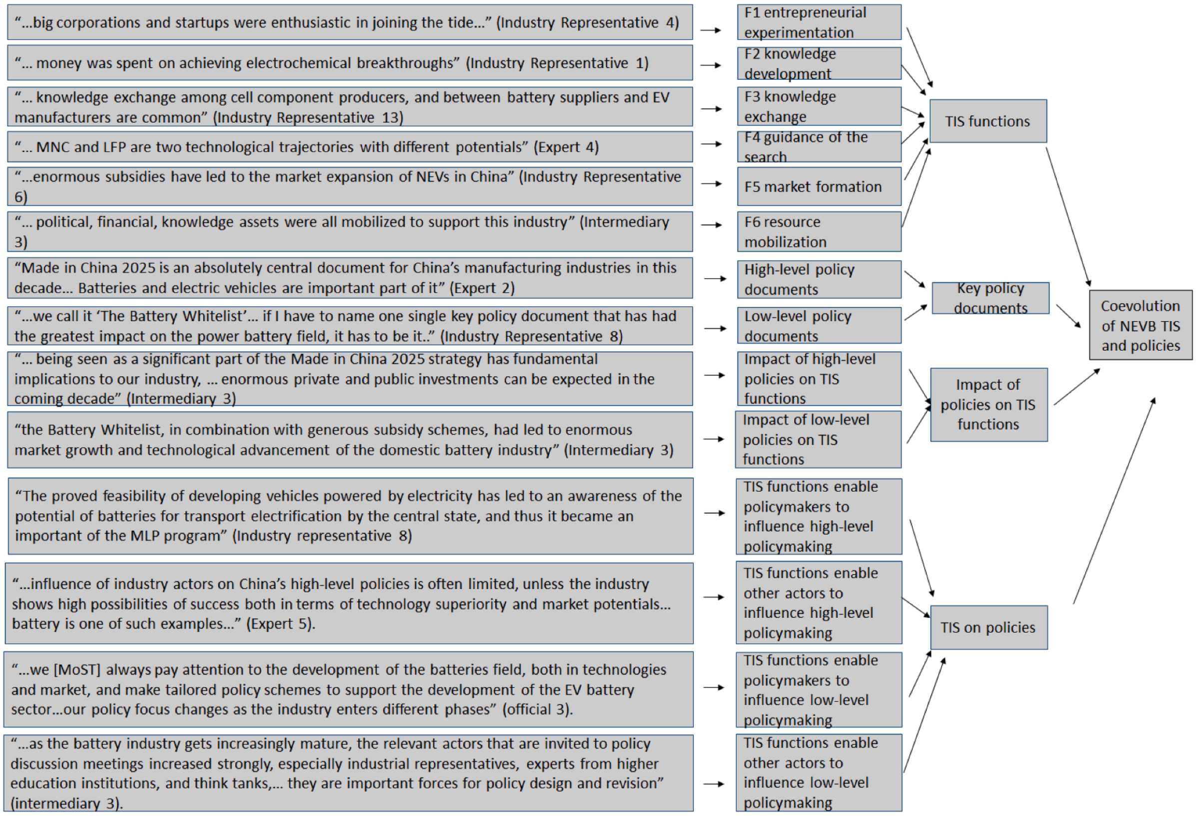
Data availability

Data will be made available on request.

Appendix 1

Interviewees	Functions and positions
Industry representatives	
CATL	RP manager
CATL	Senior engineer
BYD	Engineer
Guoxuan High-Tech	Investment Director
Chiwee	Assistant Director of Industrial Development Department
Tianneng	RP manager, CTO, Engineer (roundtable)
Sunwoda	Investment Director
Eve Energy	Engineer
CALB	Director of Market department
Shenzhen Senior Tech	Board Secretary, CTO, Investment Director(roundtable)
BTR New Material Group	Director, vice Director of Strategic Investment Department (roundtable)
Beijing Easpring Material Technology	Engineer, market manager
Xiamen Tungsten	RP manager
Zhejiang Huayou Cobalt	Investment Director, manager, postdoctoral researcher (roundtable)
GEM	Group Vice President, Director of strategy department, Director of international Department, researcher (roundtable)
Guangzhou Tinci Materials	Engineer
Shenzhen Capchem	Senior Engineer
Volkswagen China	Manager, Investment Department
FAW Group	Vice Director, Investment Department
Industry associations and intermediary organizations	
China EV 100	Secretary General
China EV 100	Director of the International center
China EV 100	Head of Research Department
CATARC	Researcher
Battery Industry Association Guangdong	Secretary General
Experts, research institutions	
School of Automotive Vehicles and Transport, Tsinghua University	Professor
Institute of Process Engineering, Chinese Academy of Science	Senior Researcher
Development Research center of the State Council	Postdoctoral researcher
School of Mechanical Engineering, Beijing Institute of Technology	Professor
New Energy Vehicle Engineering center, Tongji University	Postdoctoral researcher
Officials	
Equipment center, Ministry of Industry and Information	Officer
Beijing Bureau of Industry and Information Technology	Head of Industry Section
Department of High and New Technology, Ministry of Science and Technology	Officer

Appendix 2. Illustration of data analysis process

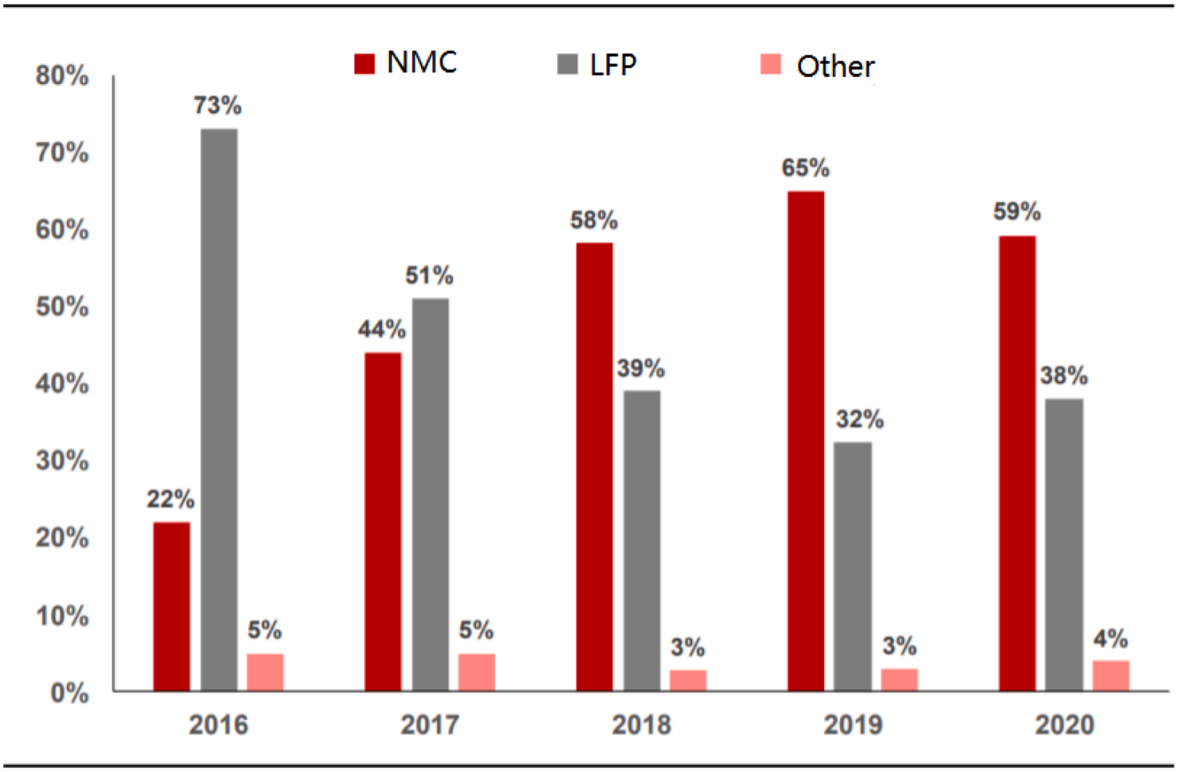


Appendix 3. Subsidy schemes in 2010 and 2013

Subsidy scheme	2010	2013
Geographical scope	26 cities	Yangtze River Delta, Pearl River Delta, Beijing-Tianjin-Hebei Region
Subsidy scheme		
BEV	Power to weight ratio based Max. subsidy 60,000 yuan	R-based, $80 \leq R < 150$ km 350,000 yuan; $150 \leq R < 250$ km, 50,000 yuan; $R \geq 250$ km, 60,000 yuan Min battery energy density 80 Wh/kg
PHEV	Fuel saving rate based Max. subsidy 50,000 yuan	35,000 yuan
FCEV	/	200,000 yuan

R: driving range; BEV: battery electric vehicles; PHEV: plug-in hybrid electric vehicles; FCEV: fuel cell electric vehicles
Source: complied by authors from www.gov.cn

Appendix 4. Battery installation volume in cars: NMC and LFP compared



Source: Zhejiang Securities 2021

Appendix 5. Annually adjusted subsidy schemes from 2014 to 2020

Subsidy scheme	2014–2015	2016	2017	2018	2019	2020
BEV	R-based 5% and 10% reduction compare to 2013 for 2014 and 2015; $80 \leq R < 150$km 35,000 yuan; $150 \leq R < 250$ km, 50,000YUAN; $R \geq 250$ km, 600,000 yuan	R-based, 20% reduction compared to 2016 for 2017–2018, 40% reduction for 2019–2020; complete end after 2020 $100 \leq R < 150$km 25,000yuan; $150 \leq R < 250$ km, 45,000yuan; $R \geq 250$ km, 550,000 yuan	R-based, + system energy density + energy consumption, 20% reduction compared to 2017 for 2019–2020; local subsidy shouldn't exceed 50% of the central subsidy $100 \leq R < 250$km 20,000 yuan; $150 \leq R < 250$ km, 36,000 yuan; $R \geq 250$ km, 44,000 yuan Min. energy density: 90 Wh/kg;	R-based, + system energy density + energy consumption, local subsidy shouldn't exceed 50% of the central subsidy $150 \leq R < 200$km 15,000 yuan; $200 \leq R < 250$ km, 24,000 yuan; $250 \leq R < 300$ km, 34,000 yuan; $300 \leq R < 400$km $R \geq 250$ km, 45,000 yuan Min. energy density: 115 Wh/kg	R-based, + system energy density + energy consumption, 50% reduction compared to 2018 for 2019; $250 \leq R < 400$ km, 18,000 yuan $R \geq 400$, 25,000 yuan Min. energy density 125 Wh/kg;	R-based, + energy consumption, 10%, 20%, 30% reduction compared to previous year for 2020–2022; Pre-subsidy price≤ 300,000 yuan; $300 \leq R < 400$ km 16,000 yuan $R \geq 400$ km, 25,000 yuan
PHEV	/	30,000 yuan	24,000 yuan	22,000 yuan	10,000 yuan	8500 yuan
FCEV	200,000 yuan	200,000 yuan	200,000 yuan	200,000 yuan	200,000 yuan	200,000 yuan

R: driving range; BEV: battery electric vehicles; PHEV: plug-in hybrid electric vehicles; FCEV: fuel cell electric vehicles
Source: Complied by authors from www.gov.cn

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