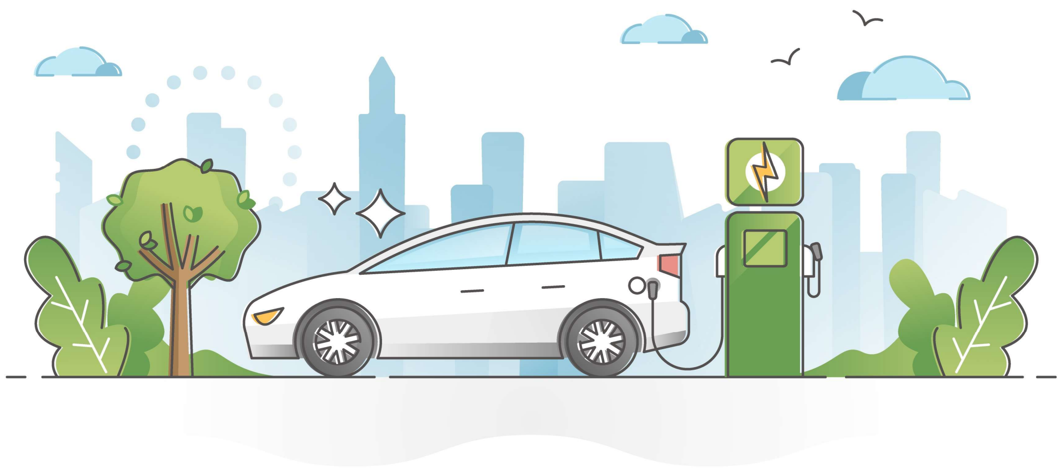
The Socio-Technical Transition for EVs in China



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MSc Program Sustainable Energy Technology

Author Zelin Wang (5298490)

Master Thesis Supervisors Linda Kamp

Hanieh Khodaei

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TU Delft Delft University of Technology

Abstract

In 2021, China is already the largest electric vehicle (EV) market with more than half of global sales. Compared to the situation ten years ago, EV development in China has experienced a huge growth almost from nothing. This development is a complex socio-technical transition process, which cannot be simplified as technology progress or business success. Therefore, based on the framework of multi-level perspective (MLP), this thesis aims to study how the socio-technical transition for EVs in China take place from the perspective of interactions and dynamics. The literature, reports, news and policy documents related to EV development and vehicle industry in China are collected, and the collected data and information are sorted and categorized into different elements for analyzing and proposing the interrelationships of these elements and how they change. The typical and significant findings and insights of the analysis are validated by semi-structured interviews with experts. A set of interaction mechanisms based on the MLP framework is proposed to explain how dynamics emerge and affect the socio-technical transition, and the effect of interactions on the transition is also conceptualized. The main findings of this thesis show how the socio-technical transition take place: Energy security and oil price are secondary landscape factors to drive the transition, and the smog issue and climate change emerge in succession as dominant landscape factors. The former opens a window of opportunity for early commercialization of EVs in China, the latter directly initiates the boom in EVs. The pressure from landscape developments makes the government, car manufacturers, consumers and the public have to make responses, which are or lead to element dynamics, such as the transformation of public perception and opinion on carbon emissions. Due to that there are interactions among these elements, more element dynamics are generated, such as intelligent and networking development of EVs. These element dynamics participate in the process of industry environment reshaping, industry layout adjustments and industry resource reallocation to further

prompt the transition process, which helps EVs gradually gain socio-technical advantages and quickly penetrate the vehicle market.

Contents

1 Introduction

As of 2021, more than one out of every two EVs worldwide is owned in China (CDM Fund, 2021), which shows a quite considerable EV consumer market. Meanwhile, when focusing on the growth rate of the EV ownership in China, it is similarly compelling, and the EV ownership increased more than 540 times over ten years (IEA, 2021). However, if some news about EVs in 2015 and 2016 is reviewed (Cui, 2016; Wang, 2015), it is difficult to ignore the generally negative public opinion of EVs, including “manufacturing cars in Powerpoint” and subsidy fraud, which means using a model car and fake performance data in Powerpoint to deceive for subsidies. Thus, whatever for the sales or public opinion, it can be observed that the EVs in China experienced huge and quick changes in these years, which means the EV development consists of several different stages.

The development of EVs in China can be divided into three stages. The first stage starts in 2001, in which EVs was treated as a research project of the national "863" science and technology plan, marking the beginning of EVs at the national R&D level. In 2007, the regulation of EV production access was released, which contained the technical standards and requirements of granting EV production licenses for companies (CAOAM, 2007). The pilot projects and initial commercialization of EVs emerged in the first stage, but EV use in this stage was mainly tried with the government taking the lead. The typical policy in this stage was the ‘Ten Cities Thousand Vehicles’ plan starting from 2009, which was implemented in ten cities every year, applying 1000 EVs as pilot projects in each city every year through financial subsidies, and these EVs were mainly used in the municipal bus system or postal system (Central Government Portal, 2009). The first stage provides the initial technology basis for the subsequent stages. The second stage starts in 2012, in which the smog issue became serious and was a wide concern by the public and government. In this stage, the landmark policy was Energy-saving and New Energy Vehicle Industry Development Plan (2012-2020), and in which EVs were mainly treated as an auxiliary measure to reduce the use of gasoline and diesel vehicles to alleviate the smog issue (Central Government Portal, 2012b). Meanwhile, EVs started to be purchased by common consumers to cope with travel and license restrictions for gasoline and diesel vehicles implemented for alleviating the smog issue. The third stage starts in 2018 with the landmark policy of the vehicle credit regulation, and it was partially adjusted in 2020, which makes gasoline and diesel vehicle manufacturers have to pay for the credit trading and allows EV manufacturers to gain additional revenue through the credit trading (Central Government Portal, 2020b). In this stage, the government pressure forces the traditional vehicle industry to begin electrification transformation, and the target served by EV promotion is changed as coping with climate change and reducing carbon emissions. This thesis mainly focuses on EV development in China in a period from 2012 to the present, namely the above second and third stages, because the two stages witness EV commercialization and the most rapid growth of the EV number. A lot of changes related to the EV industry emerge in the two stages, which leads to the current situation of EVs.

The above changes actually involve the effect from several different aspects, such as market, technology and policy, etc, which means the development of EVs in China is a process of socio-technical transition. Analyzing and understanding how the transition process takes place can help recognize the drivers and barriers for the subsequent development of EVs and take necessary measures to prompt the widespread use of EVs in the future. Therefore, this thesis aims to make research on how the socio-technical transition of EVs in China take places.

According to the framework of multi-level perspective (MLP) (Geels, 2002), there are three levels of a socio-technical transition, namely landscape, regime and niche. The landscape developments are the macro background of the socio-technical transition, and it can affect the regime and niche. The socio-technical regime refers to the dominant technology and the relevant elements supporting it, which include technology, markets

& user practices, culture & symbolic meaning, infrastructure, industry structure, policy and techno-scientific knowledge. The changes of regime elements and actions of regime actors cannot have a huge and decisive impact at the landscape level. The technological niche is the sources of the socio-technical transition, and the new technology can be protected in a narrow market where the new technology can gain basic profit, cultivate initial users and receive feedback to improve technical performance. Once the innovative technology gradually becomes mature, it may capture the dominant status of the original technology. The interactions of elements at and across the different levels and the dynamics of the regime and niche systems are two significant characteristics of the socio-technical transition. The interactions are the interrelationships of different elements, and they represent how an element affect or act on another one. There are two types of interactions, which are element interactions and cross-level interactions. The former refers to the interactions of various elements at the same level, and the latter refers to the interactions of elements at two different levels (i.e. landscape, regime and niche level). Dynamics of regime elements can be new policies, technology progress, public opinion changes, infrastructure improvement and enterprise business adjustments, etc., and these related items are categorized into different elements. Because there are interrelationships of elements, and when one element changes it is possible for another one interacting with it or affected by it to change with it. Therefore, the socio-technical transition is a complex process, and only taking research from the perspectives of interactions and dynamics can comprehensively answer how the transition of EV in China take places. That is why the interactions and dynamics are basic and significant standpoints for next analysis.

This thesis analyzes the whole socio-technical transition for EVs in China. In Chapter 2, The MLP framework is introduced, and the knowledge gap based on literature review, main research question and sub-questions are also included. In Chapter 3, the research approaches for each sub-questions are proposed. In Chapter 4, the effect of landscape developments on the dominant regime and niche cluster is analyzed. In Chapter 5, the interrelationship of regime elements is discussed for understanding how these elements interact with each other and sustain the dominant status of gasoline and diesel vehicles. Chapter 6 focuses on how niche elements interact with each other, which can explain how EVs are supported by the niche cluster and the market opportunity is created for EVs. In Chapter 7, the interactions of niche elements with regime elements are analyzed, which shows why the niche cluster and regime can affect each other. In Chapter 8, the dynamics of regime and niche elements are described and their effects on the socio-technical transition are also analyzed. In Chapter 9, the discussion of the MLP framework and the findings about the case of EV development in China are proposed, and recommendations for stakeholders and the possible directions of further research are also proposed. In Chapter 10, the main research question and sub-questions are answered to provide research conclusions.

2 Theory and Literature Review

For the research on the socio-technical transition, the commonly used analysis framework is the multi-level perspective (MLP) as shown in Fig.1, which is presented by Geels (2002), and it can be used to analyze the transition from the perspective of landscape factors, socio-technical regime elements and technological niche elements. The landscape developments are the macro background for the socio-technical transition for a certain innovative technology, and some possible landscape factors can be the macroeconomic situation, energy price and climate change, etc. The stakeholders in the related field have to actively or passively take measures to cope with the pressure or influence from the landscape developments, but their efforts cannot have a huge and decisive impact on the tendency at the landscape level, at least in the short term, such as that climate change cannot be stopped only by the government actions. The socio-technical regime refers to the dominant technology and the relevant elements around it, which include technology, markets & user practices, culture & symbolic meaning, infrastructure, industry structure, policy and techno-scientific knowledge. These elements interact with each other and together shape an environment that is usually beneficial to the dominant technology, ensuring the dominant status of one certain technology. However, the interactions and combination are possible to become inefficient due to the pressure or influence from the landscape developments, changes in one or several regime elements or shock from the technological niche. Furthermore, the inefficiency will offer an opportunity for the new technology to replace the original technology and reach the dominant position. The technological niche is the source of the socio-technical transition, and the new technology can be protected in a narrow market where the new technology can gain basic profit, cultivate initial users and receive feedback to improve technical performance. The market usually forms due to new policies aiming to hatch innovation or certain users not satisfied by the dominant technology. Once the innovative technology gradually becomes mature, it will challenge the dominant status of the original technology.

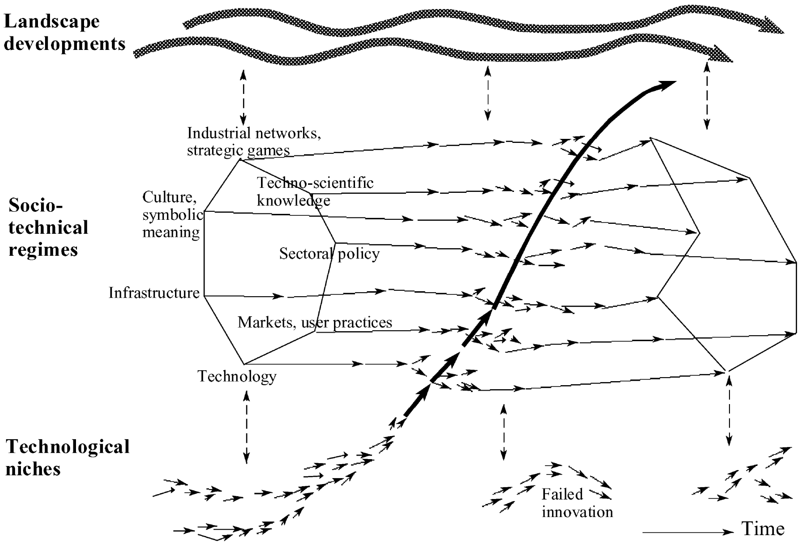

Figure 1 The multi-level perspective framework (Geels, 2002)

In the field of transportation, the typical application of MLP is the research on low-carbon transport by Geels himself (2012), which involves some discussion about EVs but pays more attention to the whole transportation system. If the research scope is only limited to EVs, another typical application of MLP is the research by Van Bree (2010), and the literature mainly analyzes the interactions between car manufacturers and consumers and presents that fuel price increase and emission standard tighten can cause different technical paths for EVs. The research by Van Bree (2010) is not restricted to geographic scopes, such as one certain country or region, therefore it cannot deeply analyze the local situation.

If the geographic scope of MLP-based research on EVs is selected in one certain country or region, a large amount of literature with different focuses can be found, such as the research by Krätzig, Franzkowiak and Sick (2019) on the sustainable transition of EVs in Germany, the research by Malinen, Haahtela, Kosonen and Alku (2013) on the demonstration pathways of EVs in Finland, the research by Cinar (2021) on consumers' willingness to adopt electric vehicles in Sweden and the research by Berkeley, Bailey, Jones and Jarvis (2017) on the drivers and barriers of EV development in Europe. However, this type of research on EVs in China is limited. The research on the innovation pathway of EVs in China by Xue, You and Bi (2012) is the relatively early application of MLP for EVs in China. The research by Xue et al. (2012) shows that the transition for EVs is long-term and there is no one innovative technology with obvious and overwhelming advantages, therefore they think the related policymakers should not be partial to a certain technology. But the situation and data on which the research based are a little outdated.

Therefore, a search for literature from 2014 on Google Scholar is taken with the combination of key terms, which are multi-level perspective, EVs and China. The principle of literature selection is that literature applying the MLP framework to analyze EV development in China is selected. All selected literature's analysis frameworks and research focuses are reviewed with emphasis to classify the literature. Overall, the selected literature is classified into two categories: **(1)** literature that analyzes elements, interactions or dynamics only within the MLP framework; **(2)** literature that extends the research to other aspects based on the analysis within the MLP framework or the framework itself.

(1) The research by Tyfield (2014) and Tyfield and Zuev (2018) are both focused on political and power elements, and they think the current driver for the development of EVs in China is government and policies. Meanwhile, they also think that only relying on policies is insufficient. The research by Rao (2020) is taken to discuss the effect of policy, technology, market and user and infrastructure elements on EV development, and these elements are divided as resistance and motivation factors. Rao (2020) holds that the government should implement purchase subsidies and government procurement, improve the market competitiveness of EVs by policies, and enlarge R&D input and improve industrial standards. The research by Wu, Shao, Su and Zhang (2021) only describes the development state of EVs in China from the landscape, regime and niche level, but for each level only limited elements are mentioned and how different levels and elements interact with each other is not analyzed.

(2) The research by Xue, You and Shao (2014) aims to apply MLP for the analysis of the barrier for the socio-technical transition for EVs in China, and they list barriers of six aspects, namely auto production & industry structure, government policy & regulatory framework, refueling infrastructure, technology, consumers and culture & symbolic meanings, but the research does not analyze the interrelationship of these aspects. The research by Bohnsack (2018) analyzes four different niche modes and respective firm responses to distill the relationship between niche modes and firm responses, which can help government choose proper niche policies. The research by Huang (2020) applies the MLP framework to build a quantitative model and analyzes the effect of the business model on consumer preference, and the data is collected by taking the stated preference (SP) experiment and surveys for selected households in China.

It can be observed that the above literature about EVs in China usually focuses on only several elements of MLP, and a complete discussion involving all elements and their interactions and dynamics is not found.

Dynamics are one of the significant characteristics of the MLP framework, and thus it is necessary to review the related literature to understand how to analyze the dynamics. The literature focusing the MLP framework and regime and niche dynamics is selected, and how the selected literature identifies, analyzes and explains dynamics is reviewed with emphasis. Overall, the selected literature is classified into two categories: **(1)** literature that refines the concepts and mechanisms of dynamics within the MLP framework; **(2)** literature that applies the MLP framework to analyze the dynamics for specific cases.

(1) When the MLP framework is proposed, the dynamics of regime elements are also discussed by Geels (2002). Geels (2002) argue that the regime elements linked and co-evolving can change when they are confronted with pressure, and these changes may cause tensions, which is likely to create opportunities for niche technologies. Subsequently, Geels (2005) makes an analysis of transition dynamics based on the case of horse-drawn carriages and automobiles, which shows that there are interactions of landscape developments with regime and niche dynamics. Based on the case of the power system in the Netherlands, Verbong and Geels (2007) propose three aspects of niche dynamic processes, namely social networks building, learning processes and articulation of expectations to guide learning processes. Geels and Kemp (2007) further explain niche dynamics based on the cases of sewer systems and waste management in the Netherlands. They argue that learning processes with niche technologies on multi-element dimensions first emerge, subsequently elements supporting niche technologies gradually link together and interact with each other, and finally niche technologies take windows of opportunity to breakthrough and change the regime. Schot and Geels (2008) mention a niche internal processes, namely technological niches - market niches - regime shift, which is a conceptual summary of niche dynamics.

(2) When applying socio-technical scenarios to analyze innovations in the power system, Hofman and Elzen (2010) treat the learning process as significant niche dynamics and focus on how the learning process takes place. Nilsson and Nykvist (2016) apply scenarios and the MLP framework to analyze how to govern the development of battery electric vehicles (BEV), and they find that besides the technology itself the niche dynamics also involve business model developments, supporting behavior changes and networking expansions. Based on the case of the socio-technical transition of the heat energy system in Sweden, Dzebo and Nykvist (2017) analyze the regime dynamics and hold that landscape pressure drives the regime dynamics to emerge. Moradi and Vagnoni (2018) study the dynamics of the urban mobility system based on the MLP framework, and landscape dynamics are proposed in the form of political, economic, social and technological factors and regime and niche dynamics are analyzed with different technical paths. When studying the case of plant-based milk in the UK, Mylan, Morris, Beech and Geels (2019) divide regime and niche dynamics into more specific element dynamics to analyze, including market, business, cultural and policy dynamics.

Based on the above literature, regime dynamics can be understood as the regime actors' responses to landscape pressure and resulting regime element change changes, and niche dynamics are the process of niche formation (learning process), niche growth (supporting element formation) and niche breakthrough. Meanwhile, as for how to analyze niche dynamics, focusing on the whole process or element changes of a part of the process are both feasible, which depends on specific cases.

Apart from the interactions of elements at the same level, the interactions of different levels are also worth analyzing to gain a complete understanding of EV development in China, especially the interactions of regime level with niche level. When the new technology develops in the niche environment, a new set of supporting elements for the new technology is also growing as a niche cluster. As for the regime of the dominant technology (i.e. gasoline and diesel cars), they usually consist of socio-technical elements that sustain the dominant status, such as existing refueling station system and oil pipe network (infrastructure element), mature and reliable internal combustion engine (ICE) technologies (technology element), complete fuel supply and sale chains (market element), etc. As for the niche cluster of the new technology (i.e. EVs), they similarly consist of socio-technical elements, but these elements are protecting and promoting the application of EVs. For example, the purchase tax reduction policy for EVs (policy element) can incentive citizens to choose EVs instead of gasoline and diesel cars, and the public recognition of EVs' emission reduction value (culture element) can keep citizens more inclined to EVs in the dimension of the personal responsibility for climate change. The interactions between the niche cluster and regime usually appear in several forms, such as reconfiguration, competition or cooperation, etc. The niche-regime interactions can directly affect the socio-technical transition of EVs in China.

Therefore, it is also significant to analyze the niche-regime interactions to understand the socio-technical transition for EVs in China. With two key terms, multi-level perspective and niche-regime interactions, a search for the typical research of the niche-regime interactions on Google Scholar is taken. The principle of literature selection is that literature based on the MLP framework analyzing niche-regime interactions is selected. All selected literature's conceptual and descriptive results about the types, definitions and explanations of niche-regime interactions are reviewed with emphasis. Overall, the selected literature is classified into three categories: **(1)** literature that provides the descriptive analysis of niche-regime interactions applicable for specific cases; **(2)** literature that conceptualizes the types of niche-regime interactions or proposes and validates related concepts; **(3)** literature that focuses on the characteristics of niche-regime interactions.

(1) Smith (2007) proposes a concept of translation to analyze the niche-regime interactions based on the case of eco-housing and organic food in the UK, and the concept of translation means niche elements being selectively integrated into the regime. Rode and Crassard (2007) propose three types of niche-regime interactions, legitimation, market formation and political interactions, when exploring the evolution of building integrated photovoltaics within the German and French technological systems, and the aim of proposing the niche-regime interactions is to explain the niche formation. Schot and Geels (2008) mention niche-regime interactions when discussing empirical findings and conceptual elaborations in strategic niche management research (SNM), and they think the niche-regime interactions do not only contain technological substitution, but also contains regime's incorporation, translation, reconfiguration and transformation. Based on the case of reducing energy consumption in the Dutch glasshouse horticulture sector, Elzen, Leeuwis and Van Mierlo (2008) propose the concept of anchoring, and they define anchoring as the link or interactions between niche and regime elements, namely how niche and regime developments influence each other. They conclude that anchoring contains three forms, institutional, network and technological anchoring. Based on the case of biomethane injection in the Dutch natural gas grid, Negro and Hekkert (2014) point out that there is the confrontation between niche actors and regime actors because they usually have divergent institutional logics, and they propose the concept of boundary bridgers who are activating in both niche and regime fields and helping to match logics. The emergent of boundary bridgers can be seen as a niche-regime interaction, and it is similar to the concept of network anchoring proposed by Elzen et al (2008). Warneryd and Karltorp (2020) propose four types of niche-regime interactions when analyzing the case of building solar photovoltaics in Sweden, which are role changes of regime and niche actors, network expansion, inclusion of regime actors in niche fields and niche empowerment (stretch-and-transform patterns and fit-and-conform patterns).

(2) Witkamp, Raven and Royakkers (2006) describe the interactions between regime and niche elements as conflicting and shared values when studying the case of social entrepreneurship in the Netherlands, and these values refer to something at the public perception or socio-cultural level. De Graaf and Van Der Brugge (2010) discuss a process of niche-regime interactions based on the case of water management and urban planning in Rotterdam, and the process is described as a policy niche being integrated into the water management and urban planning regime. The integration has some overlap with the concept of institutional anchoring proposed by Elzen et al. (2008) or reconfiguration proposed by Schot and Geels (2008). Kemp, Avelino and Bressers (2011) treat the competition between the existing mobility system and sustainable mobility technologies as a niche-regime interaction process when analyzing the sustainable transition of the mobility system. The research by Diaz, Darnhofer, Darrot and Beuret (2013) on green tides in Brittany describes the niche-regime interactions in the case as an extensive farming system extends its network, links with the regime and draws in resources, such as regime actors not satisfied with the regime situation proactively participating in the niche-related field and expanding niche markets. These actors link regime elements with niche elements, and the actor behavior is described as a niche-regime interaction. The research by Walz and Köhler (2014) on how the lead market concept can contribute to the analysis of sustainability transition involves the discussion of niche-regime interactions, and they describe policy diffusion and learning as a niche-regime interaction. An EV-related research on the niche-regime interactions is taken by Dijk (2014), who analyzes the interactions of ICE vehicles with EVs, hybrid electric vehicle (HEVs) and hydrogen fuel cell vehicles (FCVs) from the aspects of market and user, policy and technology elements and conclude that the interactions are both competitive and symbiotic. Opazo (2014) focuses on the policy-making aspect of the niche-regime interactions when studying the case of off-grid renewable electricity in rural Chile, and he holds that due to niche technologies having to compete with dominant technologies under the regime regulations providing stability and protection for these dominant technologies the government implements protection measures for niche alternatives. The policy adjustments by the government between niche and regime aspects are described as an interaction. Berggren, Magnusson and Sushandoyo (2015) find established firms active at both regime and niche levels and develop several technology alternatives simultaneously when studying the case of the heavy vehicle industry, and they call the firm behavior as bridging strategies, which is a beneficial niche-regime interaction to support niche development. Based on four cases about French agri-food system, Bui, Cardona, Lamine and Cerf (2016) analyze the anchoring effect and how the regime reconfiguration is caused by network, institutional and technological anchoring, which validates the concept proposed by Elzen et al (2008). Based on the case of green buildings in Norway, Nykamp (2017) thinks niche-regime interactions occur through intermediary projects, which allows some regime actors to explore niche technologies, and the view of intermediary projects somehow supports the concept of boundary bridgers proposed by Negro and Hekkert (2014) or bridging strategies proposed by Berggren et al (2015). Based on the cases of LED lighting and biofuels in the Netherlands, Smink, Hekkert and Negro (2015) analyze incumbent companies' behaviors and find that incumbent companies as a part of regime elements try to apply a series of strategies to cope with niche technologies that threaten their interests, and their strategies may initially aim to slow down or obstruct the new technologies, but the incumbents could also actively support after a tipping point. The strategy changes are also a little similar to the concept of network anchoring proposed by Elzen et al (2008). De Laurentis (2015) think niche elements can interact with regime elements in conflict and alignment ways based on the case of bioenergy in the UK. Pant (2016) mentions two types of niche-regime interactions, cooperative and competitive interactions when discussing agroecology in developing countries. When studying the agroecology transition in Uganda, Maye and Duncan (2017) hold that the sources of resources that niche and regime actors compete for determine if they can coexist and cooperate, and thus the resource competition here is described as a niche-regime interaction. Schäfer and König (2018) describe two types of niche-regime interactions when studying two cases in Germany, sustainable supply chain of ethical poultry production and innovations of cultural landscape conservation, and the two niche-regime interactions are only described as the oppositional and divergent interaction and emergent interaction. The former refers to contrasting paradigms and recognitions, and the latter refers to cooperation between niche and regime aspects. Bui (2018) analyzes two niche-regime interactions reconfiguring the regime in the process of agroecology transition in a French region, including partial integration of niche proposals within the regime and cooperation of network actors of niche and regime fields. Based on four cases about the transition of Finnish elderly care services, Pekkarinen and Melkas (2019) discuss the interactions between niche and regime elements by analyzing their practices (values, institutions, service models and user practices) and technologies confrontation and conclude that the confrontation interaction is related to barriers of the transition. Geddes and Schmid (2020) treat finance as a part of regime elements, and they argue that the financial element can interact with niche elements, which occurs in the form of mutual adaptation and responsive adjustment. Based on interview materials of State Investment Bank (SIB) in Germany, the UK and Australia, they point that risk level, transaction magnitude, industry knowledge and industry networks are significant factors of interactions. Schiller, Godek, Klerkx and Poortvliet (2020) analyze Nicaragua's agroecological transition but find that a reconfiguration of the food system seems not complete but rather that agroecology is added to the regime without deeper regime changes. Based on three business model innovations (phoenix rise, business model expansion and incumbent catch-up) of the Finnish demand response industry, Ruggiero, Kangas, Annala and Ohrling (2020) study niche-regime interactions, and they conclude that the disruptive niche innovations are usually resisted by incumbent energy companies with the strong lobbying power and large resources but the less disruptive innovations can receive the technical support from incumbent companies. For this case, the resistance and support from incumbent companies are described as niche-regime interactions.

(3) Klerkx, Aarts and Leeuwis (2009) describe the niche-regime interactions as a reformism process, such as framing novelties within existing rules, when analyzing how actors of niche projects interact with the regime to change the institutional environment and make it more beneficial for niche projects, and their views are a deeper explanation for the concept of reconfiguration proposed by Schot and Geels (2008). Mylan et al. (2019) think the niche-regime interactions are bidirectional and have different effects on different aspects (policy, business, user and culture) when analyzing the case of plant-based milk in the UK. When they study the collaborative business model for the neighborhood battery in the Netherlands, Proka, Hisschemöller and Loorbach (2020) point out that the exploration of niche-regime interactions can be taken by identifying different dimensions of interactions, which means niche-regime interactions can be multi-dimensional.

The above literature mainly contributes to the conceptualization of niche-regime interactions, such as incorporation, translation, reconfiguration and transformation (Smith, 2007; Schot & Geels, 2008), technological, network and institutional anchoring (Elzen et al., 2008) and bridging strategy, boundary bridger and intermediary projects (Berggren et al., 2015; Negro & Hekkert, 2014; Nykamp, 2017), and the descriptive work about how niche elements interact with regime elements focusing on the specific cases, such as conflicts and alignments between niche and regime elements (De Laurentis, 2015) or resistance and supports from regime elements to niche elements (Ruggiero et al., 2020). The conceptualization work partially overlaps with the description work, but a set of unified and integrated theories examined by empirical analysis and cases is still not proposed. Meanwhile, the research on how niche-regime interactions prompt the socio-technical transition still focuses on non-generalizable descriptive analysis based on specific cases, and a conceptual analysis for the effect of niche-regime interactions on the socio-technical transition is not found. Besides that, the MLP-based research on EVs involving niche-regime interactions is quite limited, and only Dijk (2014) analyzes the competitive and symbiotic relationships between niche technologies and dominant technologies.

The above literature about EVs in China focuses on only several elements of MLP and their limited interactions, and all of them do not deeply analyze the dynamics of the whole socio-technical system. Meanwhile, for the niche-regime interactions of EV development in China, the related research is still absent. It can be observed that there is a scientific knowledge gap for the MLP-based research of EVs' development in China, which is analyzing the interactions of all elements and levels and the dynamics of these elements, especially the interactions between the niche cluster and regime. Therefore, the research objective of this paper is to analyze the socio-technical transition for EVs in China from the perspective of interactions and dynamics, and the main research question is: **How is the socio-technical transition for EVs in China taking place?**

For answering the main research question, six sub-questions are presented:

1. *How does the pressure from landscape developments affect the dominant regime and niche cluster?*
2. *How do regime elements interact with each other?*
3. *How do niche elements interact with each other?*
4. *How do niche elements interact with regime elements?*
5. *How does the dominant regime change?*
6. *How does the niche cluster change?*

3 Methodology

In this thesis, a qualitative research approach is applied. Each sub-question is presented in this chapter, followed by the further explanations and how to apply the responding research method. Meanwhile, how the interviews are organized is also described in this chapter. Considering the scientific knowledge gap, for answering the main question **"How is the socio-technical transition for EVs in China taking place?"**, the explanations of six sub-questions and responding research methods are presented in the following.

1. *How does the pressure from landscape developments affect the dominant regime and niche cluster?*

   Sub-question 1 is mainly focused on the source drivers of the socio-technical transition for EVs in China and how they activate the transition. The pressure from the landscape developments usually shows in the policy making and market operation first, subsequently the effect of the pressure will be diffused via the element and cross-level interactions, which finally leads to the socio-technical transition of the whole system. Sub-question 1 will be answered by analyzing the effect of landscape developments on the dominant regime and niche cluster, namely the interactions between the landscape level and the other two levels. A set of qualitative methods is applied for analyzing the landscape interactions: Firstly, possible landscape factors are selected based on experience, and the related literature, reports, news and policy documents are collected to understand these landscape factors; secondly, based on the element categories of the regime and niche cluster, the related materials are also collected, and data and information are categorized into different elements; thirdly, based on the above materials related to landscape factors and regime and niche elements, their interaction relationships are proposed with the prerequisite that there are sufficient materials to explain and support them; Lastly, some main findings are validated by the interviews with industry experts in the discussion chapter.

2. *How do regime elements interact with each other?*

   Sub-question 2 is mainly focused on the interactions of regime elements. The regime elements can interact with each other to make gasoline and diesel cars dominate the market. Therefore, the answer for sub-question 2 will be formed by analyzing elements' interrelationship and how the interactions can sustain the dominant status of gasoline and diesel cars. A similar set of qualitative methods is applied for analyzing the regime element interactions and their effects: Firstly, based on the above information and data categorized by elements, the interaction relationships of regime elements are proposed (with materials explaining and supporting them); secondly, materials both related to regime elements and ICE-vehicle industry development are further collected to help analyze how regime element interactions act on ICE vehicles' dominant status; Lastly, some main findings are validated by the interviews with industry experts in the discussion chapter.

3. *How do niche elements interact with each other?*

   Sub-question 3 is mainly focused on the interactions of niche elements. The niche cluster has a similar structure to the dominant regime, and there are also niche elements interacting with each other, which can support the development of EVs. Therefore, the answer for sub-question 3 is formed by the qualitative analysis of the element interrelationship at the niche level and the effects of these interactions on EV development. The analysis process is in the following: Firstly, based on the above information and data categorized by elements, the interaction relationships of niche elements are proposed (with materials explaining and supporting them); secondly, materials both related to niche elements and EV industry development are further collected to help analyze how niche element interactions act on EV diffusion; Lastly, some main findings are validated by the interviews with industry experts in the discussion chapter.

4. *How do niche elements interact with regime elements?*

   Sub-question 4 is mainly focused on the interactions of niche elements with regime elements, namely niche-regime interactions, which act as the interactive bridge of niche and regime element dynamics. The literature on the MLP framework and niche-regime interactions is collected. For the literature, the conceptual research results of niche-regime interaction types provide the definitions and categories of some niche-regime interactions, which are examined with the case of EV development in China to see if these interaction concepts are applicable; the descriptive research results of niche-regime interrelationships for specific cases are categorized according to the similarity of the described interrelationships so that the conceptualization of similar interrelationships can be taken, and the conceptualization is also examined with the case of EV development in China to see if they are applicable. Lastly, for the case of EV development in China, the conceptualized and applicable niche-regime interactions are proposed (with materials explaining and supporting them), and some main findings are validated by the interviews with industry experts in the discussion chapter.

5. *How does the dominant regime change?*

   Sub-question 5 is mainly focused on the dynamics of regime elements. Dynamics of regime elements can be new policies, technology progress, public opinion changes, infrastructure improvement and enterprise business adjustments, etc., and these items are categorized as certain elements, which can affect other elements via the element interactions. Due to these element dynamics, the dominant regime is actually changing. The analysis process of answering sub-question 5 is in the following: Firstly, based on the information and data categorized by elements, the dynamics of each element (emerging time of new policies, technology progress, public opinion changes, infrastructure improvement and enterprise business adjustments, etc.) are sorted out by timeline; Secondly, all element dynamics are analyzed to see if there are relationships between the dynamics and interactions at the logic level, and the relationships are explained with the support of practical information and data; Lastly, some main findings are validated by the interviews with industry experts in the discussion chapter.

6. *How does the niche cluster change?*

   Sub-question 6 is mainly focused on the dynamics of niche elements. The method for answering sub-question 6 is same as that used in sub-question 5: Firstly, based on the information and data categorized by elements, the dynamics of each element are sorted out by timeline (emerging time of new policies, technology progress, public opinion changes, infrastructure improvement and enterprise business adjustments, etc.); Secondly, all element dynamics are analyzed to see if there are relationships between the dynamics and interactions at the logic level, and the relationships are explained with the support of practical information and data; Lastly, some main findings are validated by the interviews with industry experts in the discussion chapter.

For validating some main findings in this thesis, two semi-structured interviews are taken with two experts. The two interviewees are respectively a professor studying EV-related technologies and policies (interviewee Y) and a business manager of an EV manufacturing and sales enterprise (interviewee F). Attempts is also made to contact policy makers to conduct interviews, but there is no access. Interviewee Y mainly studies EV-related technologies and ever acted as an advisor for policy makers, and thus the connections between the professor and the government can help validate the policy-related aspects of findings. Meanwhile, the professor's technical background can also help validate the technology research and progress aspects of findings. Interviewee F as a business manager of an EV manufacturing and sales enterprise has a lot of insights about products, consumers and the EV market, and thus the interview with the business manager can help validate the findings of product performance and functions, consumer behavior and market operation. The two interviews are organized in a semi-structured way and consist of four topics and related questions, namely the smog issue and related policies, the 3060 target and related policies, the transformation of public environmental perception and EV intelligent and networking development. These topics and related questions are given to the interviewees prior to the interviews so that they can prepare for them. The four topics are detailed in Chapter 9.2 and corresponding to four findings proposed in that sub-chapter, which are first proposed to interviewees and subsequently interviewees are asked related questions to see how they reflect on these findings. These topics, related questions and interview transcripts can be found in the appendix.

4 Effect of Landscape Developments on the Dominant Regime and Niche Cluster

This chapter aims to answer sub-question 1 *How does the pressure from landscape developments affect the dominant regime and niche cluster?* The pressure from landscape developments is driving sources of the whole socio-technical transition of EVs in China, and government, car manufacturers, consumers and the public are the actors facing the pressure, whose response can cause dynamics of the dominant regime and niche cluster. The process of the landscape pressure changing the dominant regime and niche cluster is the cross-level interactions of landscape factors with these two levels. Therefore, this chapter proposes crucial landscape developments and indicates their interactions with the ICE-vehicle regime and EV niche cluster, which is shown in the form of the interaction map in Fig.1. Meanwhile, how the cross-level interactions cause regime and niche cluster dynamics is also detailed in this chapter.

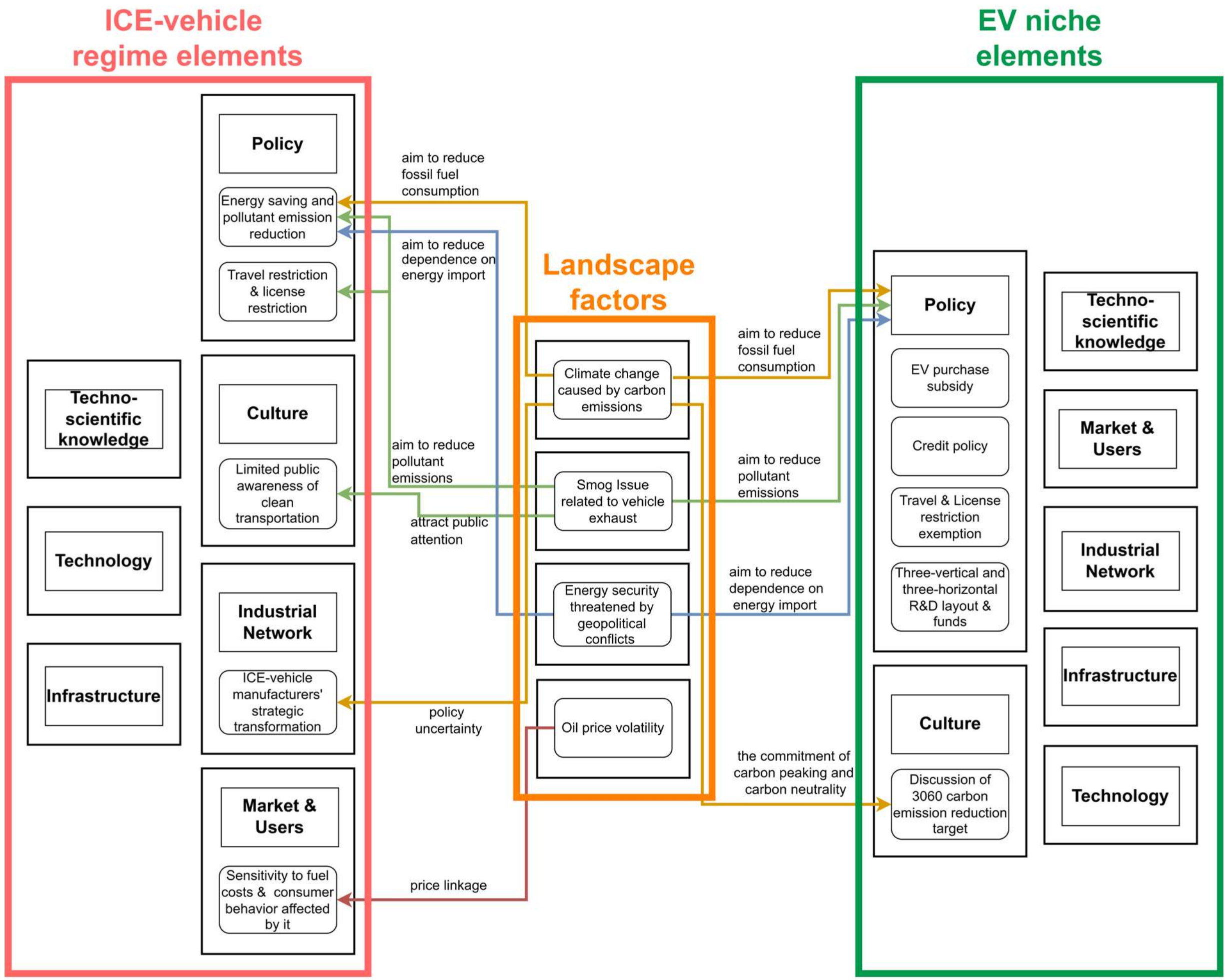

Figure 1 The interaction map of landscape factors with the regime and niche cluster

4.1 Climate Change

Climate change and global warming caused by carbon emissions have become an unavoidable issue of all mankind. Facing this issue, in 2020 the Chinese government made a commitment that China will peak carbon emissions by 2030 and strive to achieve carbon neutrality by 2060. To fulfill the “3060” commitment, a direct measure is reducing fossil fuel consumption, and thus ICE vehicles using fossil fuels as a significant source of carbon emissions becomes one of the focus points. The government’s policies for vehicles mainly involve two aspects, namely reducing existing ICE vehicles’ fuel consumption and promoting EVs to reduce the number of ICE vehicles. As shown in Table 1 (all subsequent related policy contents can be found in Table 1), the policy portfolio of energy saving and pollutant emission reduction is adjusted in 2021, and the 2021-version portfolio contains stricter vehicle fuel consumption limitations and vehicle pollutant emission regulations proposes a target that by 2025 the sales of new energy vehicles (NEVs) will reach roughly 20% of total new vehicle sales (Central Government Portal, 2021b). Meanwhile, a series of EV encouragement and promotion policies is proposed. Also in 2021, Energy-saving and New Energy Vehicle Industry Development Plan (2021-2035) is implemented, and it contains requirements for local governments to provide EV purchase subsidies, improve credit trading mechanisms and deepen the R&D layout (Central Government Portal, 2020a). Besides that, travel restriction exemption and license restriction exemption are also treated as encouragement policies to promote EVs. Take Shanghai as an example, in 2021 Shanghai municipal government issued a regulation, Measures to Encourage NEV Purchase and Use in Shanghai, and it allows EV users to gain travel priority and get free car licenses (Shanghai Municipal Government, 2021). The pressure from climate change, global warming and “3060” commitment causes new policies being proposed in the ICE-vehicle regime and EV niche cluster, and this process can be seen as cross-level interactions of landscape factors with the regime and niche cluster. In other words, the policy element dynamics are also the result of the interactions. After the “3060” commitment, a lot of discussion about carbon emissions occurs and the public focuses on carbon emissions more than before. The increasing public attention (culture elements) can be confirmed by the data from Sina Weibo (the most popular social media in China), and the post hotness of low-carbon and green consumption on the platform has rapidly raised from less than 10,000 before 2018 to more than 60,000 in 2020 (Huang, Long, Chen, Sun, & Li, 2022). Therefore, the culture element dynamics like public attention increase can be seen as the result of interactions between landscape developments (climate change) and the niche elements. The climate change and global warming also make ICE-vehicle manufacturers face more policy uncertainties, because it is possible for the government to implement ICE-vehicle ban in the further, which can cause huge loss for these manufacturers. To cope with the policy uncertainties, they usually choose to take strategic transformation and start EV business or participate in the EV supply chain. For example, in 2021 Chang'an Automobile, a traditional ICE-vehicle manufacturer and an ICE-vehicle regime actor, announced that they have started to cooperate with Contemporary Amperex Technology Co. Limited (CATL) and Huawei for hedging the potential ICE-vehicle industry risks in the future and seizing the EV business opportunity (Xinhua Net, 2021b); CATL’s business is power battery manufacturing, and one of the businesses for Huawei is EV smart driving system development. Similarly, the industrial network element dynamics like the business adjustments are the result of interactions between landscape factors and the regime.

Table 1 Policy summary

Policy	Related Content	Proposal Year	Core Policy Goal
Three-vertical and Three-horizontal R&D Layout	Three verticals: PHEVs + EVs + FCVs Three horizontals: power batter technology + drive motor and power electronics technology + intelligent and networking technology	Proposed in 2001 Adjusted in 2021	1.Indicate technology development directions
Energy Saving and Pollutant Emission Reduction Policy Portfolio (2006 Version)	1.Fuel consumption regulation (GB 19578-2004): 8L/100km 2.Pollutant emission regulation: National Stage II Motor Vehicle Pollutant Emission Standards 3.Research funds for ICE energy-saving and exhaust treatment technologies	2006	1.Increase fuel economy of ICE vehicles to improve energy security 2.Reduce ICE-vehicle pollutant emissions
The Regulation of EV Production Access	1.Technical standards and requirements of granting EV production licenses for companies	2007	1.Serve the initial application of EVs
'Ten Cities Thousand Vehicles' Plan	1.EV procurement for public transport systems through government finance	2009	1.Serve the initial application of EVs
Ambient Air Quality Standards (GB3095-2012)	1.PM2.5 is listed in the standards 2.CO_2 is not treated as a pollutant subject to be mandatorily regulated	2012	1.Regulate the smog-related pollutants and serve the smog alleviation
Energy Saving and Pollutant Emission Reduction Policy Portfolio (2012 Version)	1.Fuel consumption regulation (GB 19578-2014): 6.9L/100km 2.Pollutant emission regulation: National Stage IV Motor Vehicle Pollutant Emission Standards 3. More research funds for ICE energy-saving and exhaust treatment technologies, and list them as the key funded project of the National Science and Technology Major Project and National Science and Technology Plan 4.Raise the market access threshold of exhaust pollutant emissions for ICE vehicles	2012	1.Reduce ICE-vehicle pollutant emissions to quickly resolve the smog issue in the short term 2.Increase fuel economy of ICE vehicles to improve energy security
Travel Restriction and License Restriction Regulations	1.Travel and license restrictions for ICE vehicles	Depends on specific cities	1.Restrict ICE-vehicle use to alleviate the smog issue
Energy-saving and New Energy Vehicle Industry Development Plan (2012-2020)	1.EV purchase subsidies 2.Emphasize the guiding position of three-vertical and three-horizontal R&D layout 3.Research funds for EV-related technologies	2012	1.Let EVs gradually replace ICE vehicles to alleviate the smog issue (only as an auxiliary measure) and improve energy security

Travel Restriction and License Restriction Exemption	1.Travel and license restrictions for ICE vehicles	Depends on specific cities	1.Incentive EV use
The guidance of State Council on Accelerating the Promotion and Application of New Energy Vehicles	1.EV procurement by the government is replaced by purchase subsidies for EV consumers	2014	1.Serve the commercial application of EVs
Measures for the Parallel Administration of the Average Fuel Consumption and New Energy Vehicle Credits of Passenger Vehicle Enterprises	1.Car manufacturers obtain negative CAFC credits if they manufacture ICE vehicles and positive NEV credits if they manufacture NEVs 2.Car manufacturers with net negative credits have to pay fines and even stop production 3.The NEV credits can be used for offsetting CAFC credits or cross-enterprise trading	2018	1.Use market mechanisms rather than mere subsidies to drive EV promotion 2.The government pressure forces the traditional vehicle industry to begin electrification transformation
Energy Saving and Pollutant Emission Reduction Policy Portfolio (2021 Version)	1.Fuel consumption regulation (GB 19578-2021): 4L/100km 2.Pollutant emission regulation: National Stage VI Motor Vehicle Pollutant Emission Standards 3.Raise the market access threshold of exhaust pollutant emissions for ICE vehicles 4.Target: by 2025 NEV sales will reach roughly 20% of total new vehicle sales	2021	1.Increase fuel consumption and pollutant emission requirements to gradually phase out ICE vehicles and leave market share for NEVs to achieve the goals of carbon peaking and carbon neutrality and improve energy security
Energy-saving and New Energy Vehicle Industry Development Plan (2021-2035)	1.EV purchase subsidies 2.Deepen and adjust the guiding position of three-vertical and three-horizontal R&D layout 3.Research funds for EV-related technologies 4.Require the local government to introduce supporting regulations to improve the NEV credit trading mechanism	2021	1.Promote EVs to achieve the goals of carbon peaking and carbon neutrality and improve energy security
Proposals of the Executive Meeting of the State Council (November 18, 2020)	1.Encourage rural vehicle consumption by purchase subsidies	2020	1.Encourage vehicle consumption to stimulate economy
Measures to Encourage NEV Purchase and Use in Shanghai	1.EV travel priority 2.EV can get free car licenses	2021	1.Incentive EV use

4.2 Smog Issue

ICE vehicles' exhaust emissions are one of the sources of smog. In 2012, Ambient Air Quality Standards (GB3095-2012) was promulgated and fine particulate matter (PM2.5) was first listed in the standards, indicating the smog issue was widely concerned by the government and the public in China. Therefore, the policy portfolio of energy saving and pollutant emission reduction (2012 version) contains a lot of pollutant emission regulations for ICE-vehicle exhaust, such as stricter National Stage IV Motor Vehicle Pollutant Emission Standards, and it also raises the market access threshold of exhaust pollutant emissions for ICE-vehicle manufacturers; the research funds are also offered for ICE-vehicle exhaust treatment technology (Central Government Portal, 2012c). Meanwhile, administrative measures, such as travel restrictions and license restrictions, are also taken to reduce ICE-vehicle use to alleviate the smog issue. Actually, after the smog issue became more serious and caused widespread public concern (around 2013), a number of cities, including super tier-1 cities such as Beijing, Shanghai, Guangzhou and Shenzhen, implemented travel restriction and license restriction regulations to reduce ICE-vehicle use and pollutant emissions (iCET, 2019; Yi, Kang, Yang, Musa, & Wang, 2021). Travel restrictions mean citizens can drive only in odd or even dates, and license restrictions mean the license availability for new ICE vehicles is limited. These restrictions can directly reduce ICE-vehicle exhaust in total. Besides the policies involving ICE vehicles, the application of EVs is also seen as an effective way to reduce ICE-vehicle exhaust in total and alleviate the smog issue. Energy-saving and New Energy Vehicle Industry Development Plan (2012-2020) was implemented in 2012, which offered purchase subsidies to EV consumers and research funds for EV-related researchers (Central Government Portal, 2012b). The purpose of these EV encouragement and promotion policies is to reduce vehicle exhaust pollutant emissions by replacing ICE vehicles with EVs. The smog issue, as one of landscape factors, makes the government have to implement new policies and administrative measures to cope with it, and these new policies and administrative measures become policy elements of the ICE-vehicle regime and EV niche cluster. The process of landscape pressure resulting in element changes shows how landscape factors interact with the regime and niche cluster. When the smog issue became severe, the post hotness of the smog issue on Sina Weibo also increased a lot (Wang, Paul, & Dredze, 2015), which shows the pollutant emissions and the resulting smog issue attract public attention. Similarly, based on the data from Baidu Index (similar to Google Trends), the hotness value of public concern about the smog issue increased from 2012 and peaked in 2015, and subsequently went down as the smog issue was gradually alleviated (CEEP-BIT, 2019). The increase in public attention about the smog issue started in 2012, but the rapid growth in public attention about the carbon emission and climate change started in 2020 (Huang et al., 2022). Therefore, the smog issue became a concern in China earlier than climate change and global warming caused by carbon emissions, and that is because smog is relatively closer at hand for the public compared to climate change and global warming. The smog issue attracts public attention and makes the public ignore the carbon emission issue before the “3060” commitment, which can be confirmed by the above data analysis, and this ignoration means the public awareness of emissions and clean transportation is limited and one-sided. The process of the smog issue affecting public awareness can also be seen as the cross-level interactions of landscape factors.

4.3 Energy Security

Energy security is the problem that countries depending on imported energy have to face, and the access to external energy sources can be affected by geopolitical conflicts. The latest example of energy security affected by geopolitical conflicts is the conflicts between Russia and Ukraine making the price of natural gas fluctuate in Europe. As shown Fig.2, as the largest oil importer today, the share of crude oil imported in consumption for China continues increasing, and based on the research on Chinese oil imports (Wang, Li, & Li, 2018), China's dependency on imported oil may exceed 80% by 2030. Therefore, the geopolitical situation of oil-exporting countries can influence China’s energy security. Meanwhile, more than half of the oil is consumed in the transportation sector in China (iCET, 2019). Under the pressure of energy security, the government has to reduce gasoline and diesel consumption in transportation to decrease the dependency on oil imports. Therefore, the policy portfolio of energy saving and pollutant emission reduction and EV encouragement and promotion policies also serve this target. For example, the policy portfolio of energy saving and pollutant emission reduction (2012 version) required the average fuel consumption of passenger cars to decrease from 8 liter fuel/100 km to 6.9 (Central Government Portal, 2012c). The process of the pressure of energy security acting on policy making and causing policy dynamics shows how landscape factors interact with the regime and niche cluster.

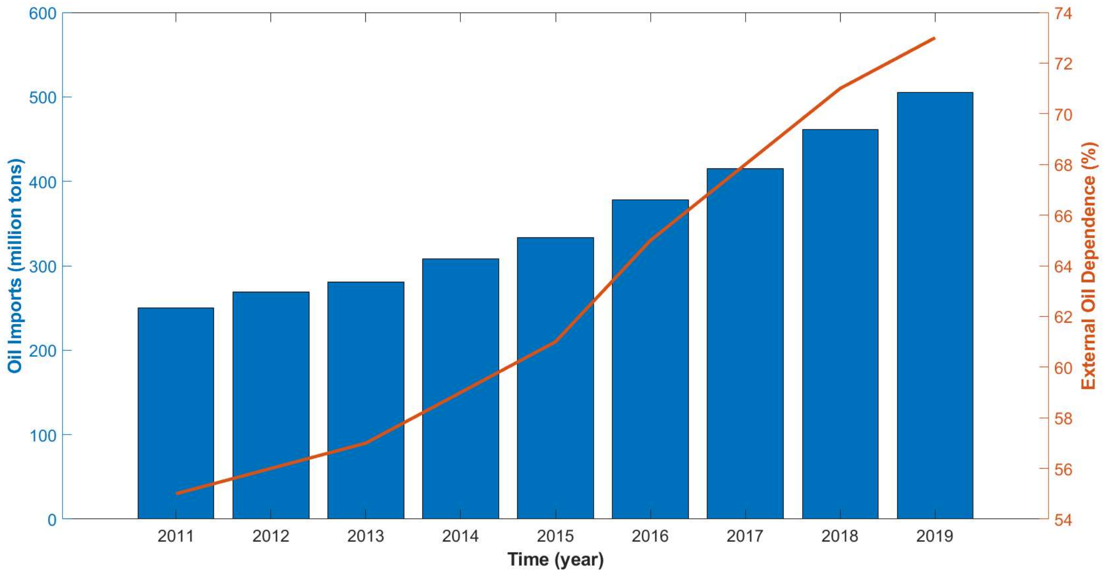

Figure 2 The oil imports and external oil dependency in China (NBS, 2022)

4.4 Oil Price

Based on the research on consumer behavior (Sun, Xu, & Yin, 2016; Soltani-Sobh, Heaslip, Stevanovic, Bosworth, & Radivojevic, 2017), the vehicle consumers are sensitive to vehicle fuel costs, and when gasoline and diesel prices are too high the consumers will tend to choose ICE vehicles with better fuel economy or EVs to reduce their fuel costs. As shown in Fig.3, the gasoline and diesel prices in China are fluctuating upwards overall from 2000 to the present, especially more than 60% increase in the gasoline and diesel prices in China from March 2020 to March 2022, and the oil price rise increases fuel cost burden for ICE-vehicle users and affects potential vehicle consumers' choices. Therefore, oil price volatility and rise, as one of landscape factors, is interacting with the ICE-vehicle regime by affecting consumer behaviors, and the process of oil price volatility and rise affecting consumer behaviors can be seen as one type of cross-level interactions of landscape factors.

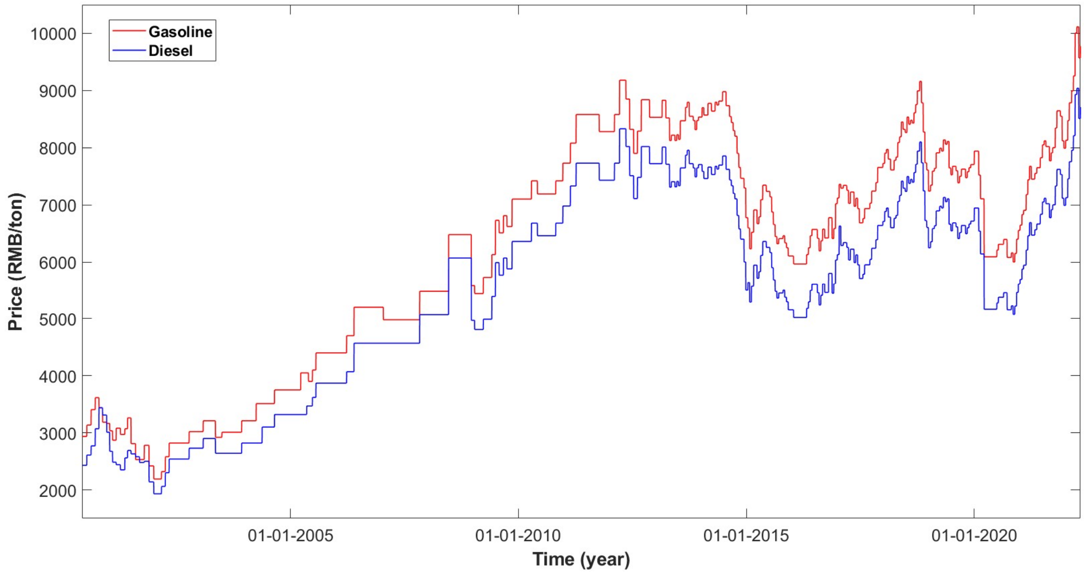

Figure 3 The gasoline and diesel prices in China (Central Government Portal, 2022)

This chapter proposes a dynamic generation mechanism via landscape interactions and analyzes their effects to answer sub-question 1 *How does the pressure from landscape developments affect the dominant regime and niche cluster?* The pressure from landscape developments directly acts on crucial actors, namely government, car manufacturers, consumers and the public, and these actors have to make some responses. The government's responses can be the introduction of new policies, car manufacturers' responses can be business adjustments, consumers' responses can be choosing more cost-effective alternatives, and the public's responses can be changes in perception of emission issues. These responses all mean some element dynamics of the ICE-vehicle regime and EV niche cluster. Under the pressure from landscape developments, actors react and element dynamics emerge, and the dynamic generation mechanism via landscape interactions explains how landscape factors interact with and affect the regime and niche cluster. These dynamics can also cause more element dynamics via further element interactions, which is detailed in Chapters 5 and 6.

There are four landscape factors proposed in this chapter, namely climate change, smog issue, energy security and oil price, and their emerging times are different. Energy security and oil price act on the entire transition process, but they do not play a significant role. The international energy supply is not tight for the vast majority of the time, and the pressure of oil price rise can be alleviated by high economic growth, therefore they are less urgent than other landscape factors. The smog issue emerged as a landscape factor in 2012, and it directly affected the public health, which can be observed in a short period. Therefore, the ensuing widespread public concern led to great public opinion pressure, forcing the government to take the lead and start reacting. EVs were treated as an auxiliary measure to alleviate the smog issue and thus gained a window of opportunity to develop. After the smog issue is mostly alleviated, climate change acts as the last and most significant landscape factor for EV development to emerge in China, especially the "3060" target proposed in 2020, which directly causes a wide range of public concern. Corresponding to the landscape factor, EV sales and market shares in China start to experience a huge growth, which is also detailed in Chapters 5 and 6.

5 Interactions of Regime Elements

This chapter aims to answer sub-question 2 *How do regime elements interact with each other?* Different elements interacting with each other can form a regime that sustains the dominant status of gasoline and diesel cars in the vehicle industry. This chapter analyzes typical policies, situations and technologies, etc. related to different regime elements to further indicate their interaction relationships, which is shown in the form of the interaction map in Fig.4. Meanwhile, the discussion about how the interactions are fulfilled to sustain the dominant status of gasoline and diesel cars is detailed in the following sub-chapters.

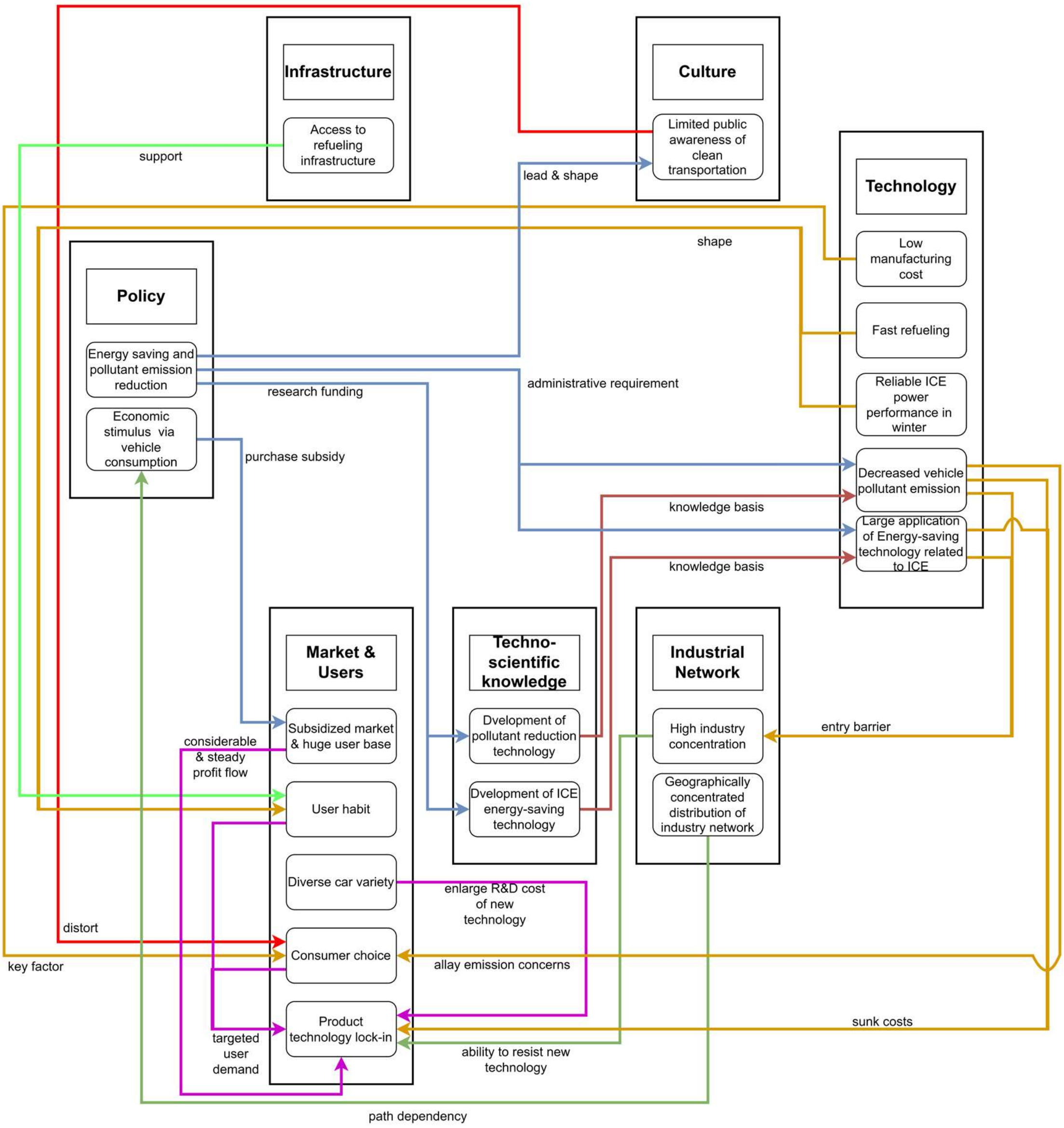

Figure 4 The interaction map of regime elements

5.1 Policy Elements and Related Interactions

The policy portfolio of energy saving and pollutant emission reduction was first proposed in 2006, and it directly improved fuel economy and reduced pollutant emissions for gasoline and diesel cars. The 2006-version policy portfolio contains vehicle fuel consumption limitations (GB 19578-2004, 8 liter fuel/100 km) and vehicle pollutant emission regulations (National Stage II Motor Vehicle Pollutant Emission Standards). When the policy portfolio is updated, the vehicle fuel consumption limitations and vehicle pollutant emission regulations usually become stricter, such as 2012-version policy portfolio (GB 19578-2014, 6.9 liter fuel/100 km & National Stage IV Motor Vehicle Pollutant Emission Standards) and 2021-version policy portfolio (GB 19578-2021, 4 liter fuel/100 km & National Stage VI Motor Vehicle Pollutant Emission Standards) (Central Government Portal, 2012c, 2021a). However, in these vehicle pollutant emission regulations, the definition of pollutants is limited, namely CO_2 is not treated as a pollutant subject to be mandatorily regulated (Fuzhou Government Portal, 2020). The limited definition of pollutants can lead and shape the public opinion about pollutant types and clean transportation, which causes the public mainly focuses on NOx, SO_2, particulate matter (PM10) and PM2.5, etc. but ignores CO_2. The ignoration continued until the "3060" commitment, which can be confirmed by the fact that the post hotness about low-carbon and green consumption on Sina Weibo was low until 2020 (Huang et al., 2022). Therefore, the process of policies leading and shaping the public opinion and further making the public ignore the carbon emission issue of gasoline and diesel cars when people purchase them is the interaction of policy elements with culture elements. The regulation of fuel consumption and pollutant emissions is administrative measures imposed directly on car manufacturers and fuel suppliers, which can be seen as the interaction of policy elements with technology elements, because the administrative requirements make the manufacturers and suppliers have to apply energy-saving technologies and pollutant-reducing technologies and supply the fuel containing less pollutant-related composition. The fact also confirms this: As shown in Fig.5, total vehicle pollutant emissions per year in China continued decreasing and vehicle fuel consumption per year only increases by 95% from 2009 to 2019 even the number of vehicles increased by more than three times in these years. Therefore, with gasoline and diesel cars' energy-saving and pollutant-reducing performances improved, ICE vehicles become more appealing to consumers than before. The policy portfolio of energy saving and pollutant emission reduction (2006 version and 2012 version) also provides research institutes research funds to develop energy-saving technologies and pollutant-reducing technologies, which makes the energy-saving and pollutant-reducing performances of gasoline and diesel cars continuously improved (as shown in Fig.5). Via the research funding, the policy elements can interact with the elements of techno-scientific knowledge.

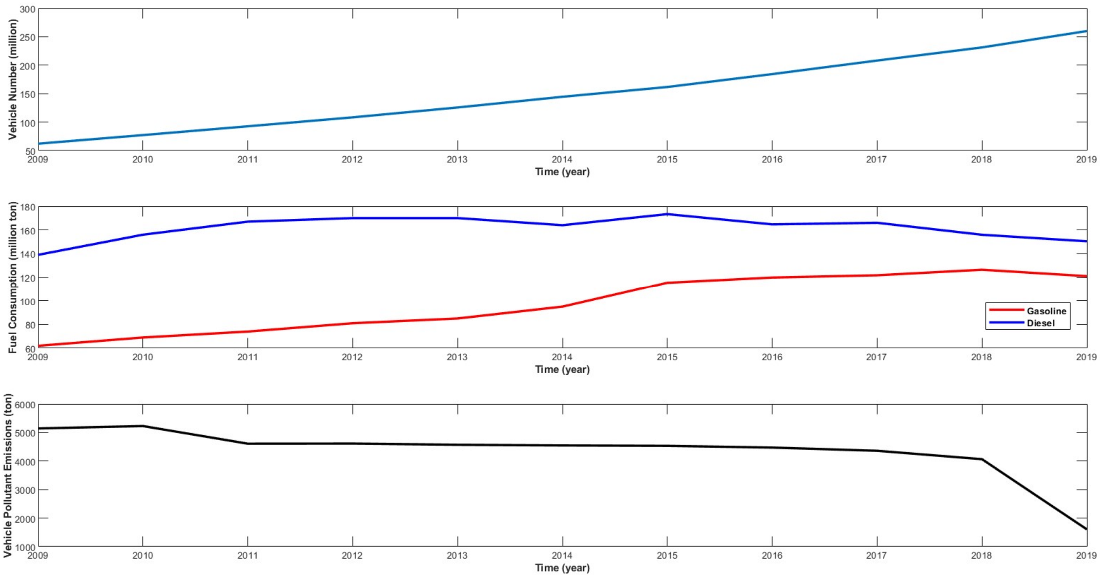

Figure 5 The vehicle number, fuel consumption and pollutant emissions in China (MEE, 2022; MIIT, 2021b)

Vehicle consumption plays a significant role in the economic growth in China, and in 2020 total retail sales of vehicles accounted for more than 10% of total social consumption goods (MIIT, 2021b). Therefore, policies of encouraging vehicle consumption, such as providing purchase subsidies, are usually implemented as economic stimulus measures, especially during the economic downturn. For example, during the executive meeting of the State Council in 2020, providing purchase subsidies is proposed as an effective measure of encouraging rural vehicle consumption and stimulating the economy to cope with the economic downturn during the COVID-19 pandemic period (Daily Economic News, 2020). The economic stimulus measures create a subsidized market environment for gasoline and diesel cars in the period when EVs were not introduced to the market and did not share the subsidies, which can be treated as the interaction of the policy elements with the elements of market and users. As shown in Fig.5, the subsidized market environment cultivates a huge user base of ICE vehicles, and they depend on the ICE maintenance service offered by gasoline and diesel car manufacturers, which means considerable and steady profit flow for manufacturers if they insist on producing ICE components instead of choosing other new power technologies (e.g. electric motors).

5.2 Infrastructure Elements and Related Interactions

In 2020, the distribution density on roads of refueling stations for gasoline and diesel cars in China is 2.03 per 100 kilometers (MOC, 2021), and thus gasoline and diesel car users can reach the refueling service quickly and conveniently when they need it. The interaction of infrastructure elements with the elements of market and users is realized by well-established refueling infrastructure supporting users' habit of convenient refueling. The habit of convenient refueling formed by using gasoline and diesel cars can lead to the poor user experience when they try to use EVs in the period when charging stations for EVs are insufficient, which gives gasoline and diesel cars an edge in the initial competition with EVs.

5.3 Culture Elements and Related Interactions

Based on the above data analysis of Baidu Index and Sina Weibo (CEEP-BIT, 2019, Huang et al., 2022), before the "3060" commitment, the smog issue was more in the spotlight, compared to carbon emissions, and actually CO_2 related to global warming was concerned by rare people in China at that period. The public concern about vehicle emissions usually focuses on NOx, SO_2, PM10 and PM2.5, etc. that can directly lead to environment issues, but CO_2 related to global warming is ignored because environment issues such as acid rain or smog are relatively closer at hand for the public compared with global warming. Therefore, even for consumers who are concerned about environment issues and embrace the clean transportation it is still possible to ignore gasoline and diesel cars' carbon emission issue when they purchase cars, and the limited public awareness of clean transportation can distort consumer choices and make them ignore gasoline and diesel cars' issues, which shows how the culture elements interact with the elements of market and users to form a regime supporting the dominant technology.

5.4 Technology Elements and Related Interactions

Some product characteristics of gasoline and diesel cars are significant to sustain the dominant status, which are mainly low manufacturing cost, fast refueling and reliable ICE power performance in winter. As the power source of vehicles, ICE is more mature than electric motors and power batteries, thus the manufacturing cost of gasoline and diesel cars is still lower than that of EVs (Ouyang, Zhou, & Ou, 2021). The lower manufacturing cost allows gasoline and diesel cars to have cost advantage over EVs when consumers consider purchasing which vehicles, and the cost advantage is also a key factor for consumer choices (Mandys, 2021), which shows the first type of interactions between technology elements and the elements of market and users.

Meanwhile, it usually takes several minutes to refuel gasoline and diesel cars, but for EVs even with the extreme fast charging technology, it still needs at least 15 minutes to take the whole recharge process (Liu, Zhu, & Cui, 2019). As for the power performance in winter, ICE is more reliable than that of power batteries due to the effect of low temperature, which also causes the vehicle range of EVs in winter cannot reach the rated value (Steinstraeter, Heinrich, & Lienkamp, 2021). The two product characteristics can shape user habits requiring EVs to provide equivalent user experience, such as fast charging within several minutes and similar vehicle range in winter, which create more barriers for consumers to choose EVs. The research on factors influencing EV purchase in China confirms this, charging inconvenience and limited driving range, etc. are crucial barriers to EV purchase (Ouyang, Ou, Zhang, & Dong, 2020). The process of shaping user habits is the second type of interactions between technology elements and the elements of market and users.

In addition to some product characteristics, the improvement of some technical performance is also crucial for sustaining the dominant status of gasoline and diesel cars, namely pollutant emission reduction and energy saving. The pollutant emission reduction is mainly driven by stricter vehicle pollutant emission regulation (National Stage II~VI Motor Vehicle Pollutant Emission Standards). The emission concern of consumers who focus NOx, SO_2, PM10 and PM2.5, etc. instead of CO_2 can be allayed by the improved technical performance of pollutant emission reduction, which is beneficial to the sales of gasoline and diesel cars. The improvement of energy-saving performance depends on the large application of crucial energy-saving technologies for ICE, such as turbocharged, cylinder direct-injection and idle start-stop. As shown in Fig.6, the application ratios of these technologies increase a lot from 2016 to 2020. Meanwhile, the two technical performance improvement requires car manufacturers to invest a lot in ICE-related technologies, which also means a large amount of sunk costs. For example, SAIC, as a traditional ICE-vehicle manufacturer, invested more than 14.9 billion RMB in the R&D sector in 2021 (Sina Finance, 2021). These sunk costs cause product technology lock-in and make it hard for ICE-vehicle manufacturers to shift to EVs. Therefore, allaying emission concern and creating sunk costs are another two types of interactions between technology elements and the elements of market and users. The huge investment for ICE-related technologies also indicates that there is a capital barrier to entering the vehicle industry whether the investors choose gasoline and diesel cars or EVs, and the entry barrier is conducive to forming a high industry concentration. The fact confirms this: Considering the annual vehicle production, the industry concentration of the top ten car manufacturers in China is more than 90% (MIIT, 2021b), and it is usually hard for companies in an industry with entry barriers to generate economic incentives to adopt new technologies. The above process shows how the technology elements interact with the elements of industrial network.

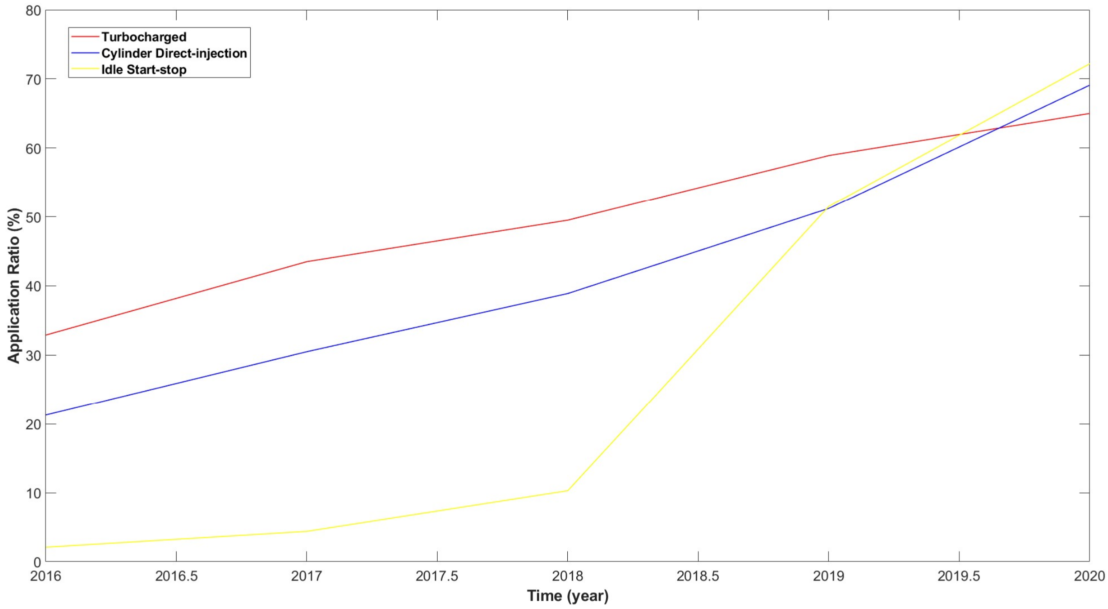

Figure 6 The Application Ratio of Energy-saving technologies for ICE (MIIT, 2021b)

5.5 Industrial Network Elements and Related Interactions

From an economic perspective, the sunk costs caused by investment in ICE-related technologies and the capital barrier for new players to enter the vehicle industry both further provide the ICE-vehicle manufacturers the ability to stick with gasoline and diesel-based ICE technologies and resist the diffusion of new technologies. As shown in Fig.7, no matter the ownership share and the market share, EVs do not dominate the mainstream, and ICE-vehicle manufacturers have captured a large ownership and market shares and formed scale effects, which can generate sufficient profit for them to cope with the shock of EVs when pioneers starting EV entrepreneurship do not capital advantages. In this situation, a high industry concentration also means top ICE-vehicle manufacturers capture the large ownership and market shares, and thus they have huge market power to resist the diffusion of EVs when there are no landscape developments. The ability to resist the diffusion of new technologies can cause product technology lock-in and hinder the emergence of EV products in the market, which is the interaction of industrial network elements with market and user elements.

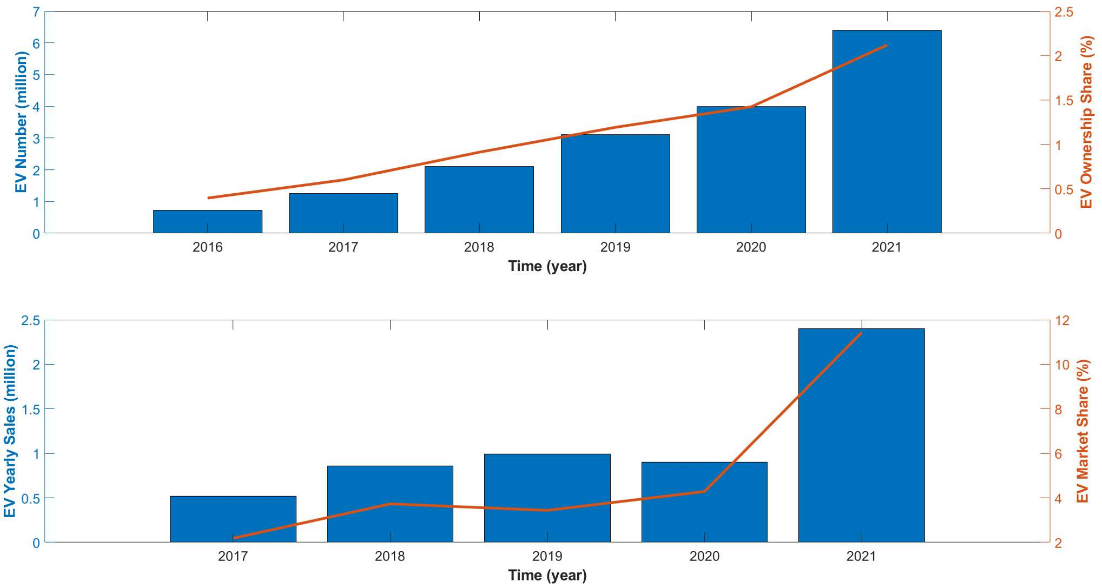

Figure 7 EV ownerships, sales and shares in China (MEE, 2022)

The vehicle industry network is geographically concentrated in specific areas, such as Guangdong province where 12.3% of vehicles are manufactured in 2020 (MIIT, 2021b). Therefore, the local government with the concentrated vehicle industry network tends to encourage the development of advantageous industries during the economic downturn and implement corresponding policies, such as the Guangdong government providing subsidies of 3000~8000 RMB for each eligible car purchaser from 2022 to stimulate vehicle consumption (Sina Finance, 2022). Similar policies in the past ever generated a lot of users who are bound by gasoline and diesel cars before EVs were introduced to the market. The economic stimulus based on advantageous industries is usually direct and easy for government, which can be seen as path dependency in policy formulation. The path dependency is the interaction mode of industrial network elements with policy elements.

5.6 Techno-scientific Knowledge Elements and Related Interactions

Due to the research on vehicle exhaust treatment technology, as shown in Fig.5, the vehicle pollutant emissions in China continued to decrease from 2009 to 2019, and considering the annual growth in vehicle ownership the average pollutant emissions per vehicle actually decreased more, which can also be confirmed by the related research (Wang et al., 2019). Meanwhile, the progress of crucial energy-saving technology, such as turbocharged, direct-injection in the cylinder and idle start-stop, made the average fuel consumption for gasoline and diesel vehicles decrease from 6.87 L/100km in 2016 to 6.46 L/100km in 2019 (MIIT, 2021b). The research of pollutant emission reduction and energy-saving technologies offers the knowledge basis of technical performance improvement to gasoline and diesel vehicles, which is also how techno-scientific knowledge elements interact with technology elements.

5.7 Market and User Elements and Related Interactions

The subsidized market and huge user bases can generate steady profit flow for gasoline and diesel car manufacturers, therefore it is risky and unnecessary to shift their business focus to EVs, which delays the introduction of EV product and makes the product choices for consumers locked in gasoline and diesel cars. Meanwhile, users are used to fast refueling supported by well-established refueling infrastructure and reliable power performance in winter, which makes it hard for EVs to satisfy the demand of users with these habits. Furthermore, the consumer choices are distorted by limited public awareness of clean transportation and vehicle emissions, and thus user demand usually does not include the requirement of carbon emissions, which limits the emergence of potential EV consumers and further sustains product technology lock-in. The varieties of gasoline and diesel cars are large and also increasing, and different varieties are targeted for different consumer aesthetic preference and further make the vehicle market fragmented (Van Bree, Verbong, & Kramer, 2010). Facing the fragmented market, EV manufacturers have to invest more in R&D for offer more varieties of EV products. Actually, they will not choose to offer more varieties due to the risk of new products, and limited varieties make it hard for EVs to penetrate the fragmented market (Ouyang et al., 2020), which causes the market to lock in gasoline and diesel cars. Based on the above analysis, it can be observed that the lock-in phenomenon of product technologies is caused by multiple factors, namely the subsidized market environment, huge user bases bounded with traditional products, existing user habits, diverse product varieties and distorted user choices. These factors are categorized as market and user elements, thus there is the self-interaction for market and user elements.

Based on the above analysis of regime element interactions, sub-question 2 *How do regime elements interact with each other?* can be answered.

(1) The policy elements interact with culture, technology, techno-scientific knowledge and market and user elements. The policy portfolio of energy saving and pollutant emission reduction leads and shapes the public opinion and makes the public usually ignore the issue of carbon emissions. The policy portfolio directly requires car manufacturers and fuel suppliers to apply energy-saving and pollutant-reducing technologies and supply high-quality fuel. The policy portfolio also encourages research on energy-saving and pollutant-reducing via R&D funds. Meanwhile, the economic stimulus policy usually offers purchase subsidies to ICE-vehicle users for driving the economy.

(2) The infrastructure elements interact with market and user elements, which shows in the form of sufficient refueling stations supporting the refueling habits of users.

(3) The culture elements interact with market and user elements, which shows in the form of limited public perception of clean transportation making consumers choose ICE vehicles but ignore their carbon emissions.

(4) The technology elements interact with market and user elements, and also with industrial network elements. The low manufacturing cost and price affect consumer choices. The fast refueling and reliable power performance shape user habits not compatible with EVs. The pollutant emission reduction technologies of ICE allay the emission concern of ICE-vehicle users. Meanwhile, the sunk costs caused by the investment for energy-saving technologies make car manufacturers reluctant to switch to EV products. The huge investment for ICE-related technologies is a huge capital barrier to entering the vehicle industry leading to high industry concentration, which means there are no economic incentives for ICE-vehicle manufacturers to adopt new technologies.

(5) The industrial network elements interact with market and user elements, and also with policy elements. The high industry concentration means a large market share and scale effects, which allows traditional car manufacturers to resist the diffusion of

EV technologies and causes product technology lock-in. The economic stimulus based on ICE-vehicle industries becomes a type of policy path dependency.

(6) The techno-scientific knowledge elements interact with technology elements. The research on vehicle exhaust treatment and energy saving acts as the knowledge basis of technical performance improvement to ICE vehicles.

(7) The market and user elements self-interact with themselves. The subsidized market and huge user bases can generate steady profit flow for ICE-vehicle manufacturers, and there is no incentive for them to shift to EVs. It is challenging for EVs to cater to user habits shaped by fast refueling and reliable power performance. The consumer choices are distorted by limited public perception of clean transportation and EVs' carbon emission reduction benefits are ignored. Meanwhile, the diverse varieties of ICE vehicles make the vehicle market fragmented, and thus there is financial pressure for EV manufacturers to develop more varieties of EV products. All these factors delay EV development and cause product technology lock-in.

The above answers explain how regime elements interact with each other to sustain the dominant status of ICE vehicles in a long period. Because there are interrelationships between regime elements, dynamics of one element can affect other elements and further cause changes in other elements. Therefore, via element interactions in the regime, element dynamics caused by landscape interactions can generate more element dynamics. This chapter shows these interrelationships by analyzing the existing element interactions in the regime, and what dynamics are generated via these interrelationships or regime element interactions are proposed in Chapter 8.

6 Interactions of Niche Elements

This chapter aims to answer sub-question 3 *How do niche elements interact with each other?* The niche cluster of innovative technologies usually has a similar structure to that of the dominant regime, which also consist of different elements interacting with each other. The niche cluster can support the development and diffusion of innovative technologies, and act as a socio-technical system to interact with the socio-technical system of the original technologies and gradually become dominant, which can finally shape the dominant status of innovative technologies. This chapter discusses significant niche elements and analyzes their interaction relationships, which is shown in the form of the interaction map in Fig.8. Meanwhile, how the interactions support EVs in the market is also discussed.

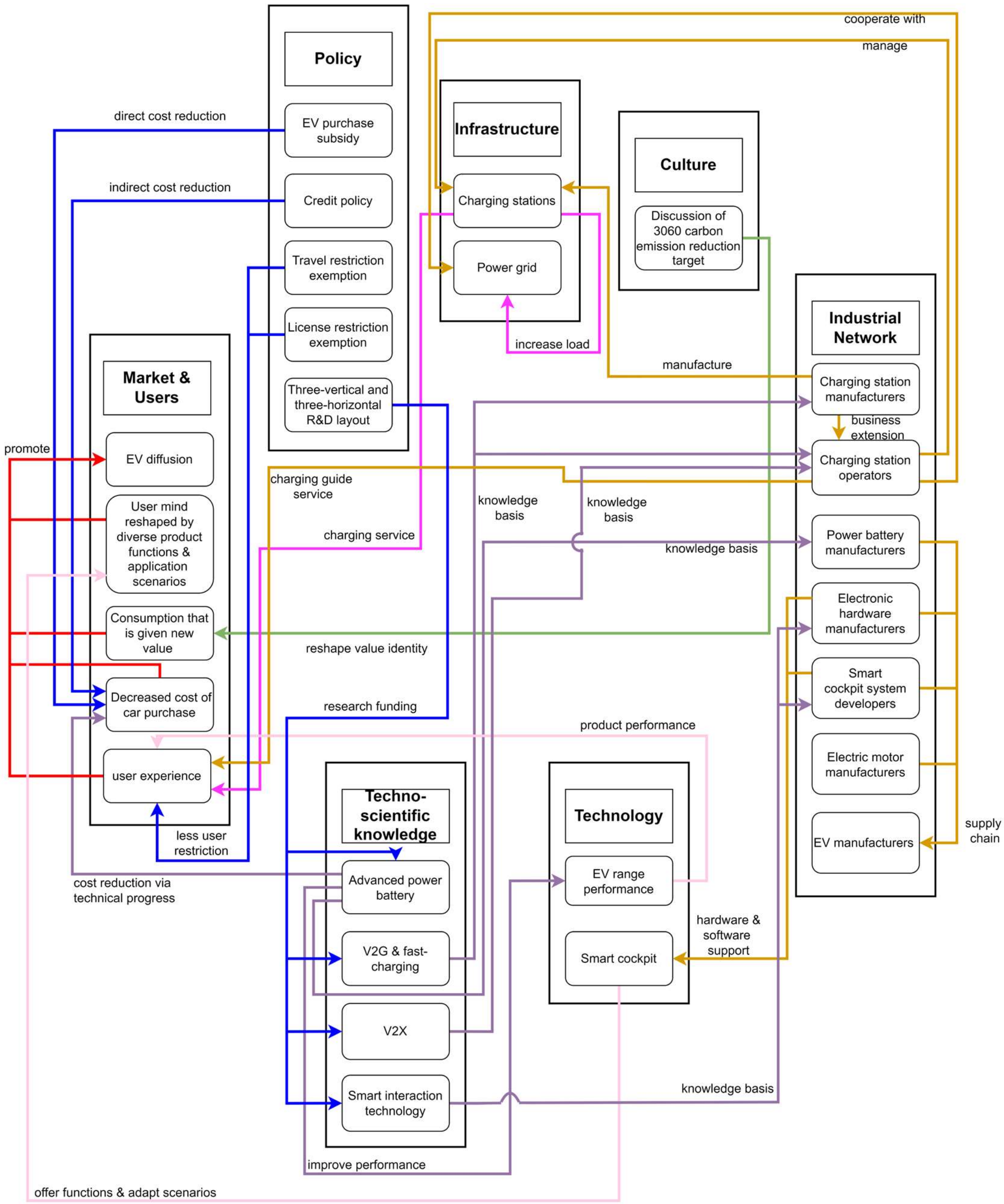

Figure 8 The interaction map of niche elements

6.1 Policy Elements and Related Interactions

The initial EV subsidies were provided to EV manufacturers, appearing in the form of EV procurement for public transport systems through government finance, such as the ‘Ten Cities Thousand Vehicles’ plan starting from 2009 (Central Government Portal, 2009). Due to the lack of consumers in the initial stage, EVs with worse performance than ICE vehicles were purchased by the government at a profitable price, and this purchase can be seen as a disguised subsidy. Subsequently, with the development of EV-related technologies and the growth in the number of EV consumers, the subsidy policy was further adjusted as a direct purchase subsidy for these consumers in 2014 (Central Government Portal, 2014). As the discussion in the above chapter, the vehicle market is a subsidized market, but after 2014 the subsidy started to be assigned to the EV market instead of the ICE market. Energy-saving and New Energy Vehicle Industry Development Plan (2012-2020) and Energy-saving and New Energy Vehicle Industry Development Plan (2021-2035) both mention that the local government should encourage EV use via purchase subsidies (Central Government Portal, 2012b, 2020a). The subsidy can directly reduce purchase costs for EV consumers, and thus can create an economic incentive for potential vehicle consumers to choose EVs, which is the first interaction of policy elements with market and user elements.

In 2018, Measures for the Parallel Administration of the Average Fuel Consumption and New Energy Vehicle Credits of Passenger Vehicle Enterprises were proposed in 2018 and partially adjusted in 2020, and the policy starts to be implemented from 2021, which indicates NEV credit trading is opened (Central Government Portal, 2020a). Energy-saving and New Energy Vehicle Industry Development Plan (2021-2035) also requires the local government to introduce supporting regulations to improve the credit trading mechanism. For car manufacturers in China, they can obtain negative CAFC (corporate average fuel consumption) credits if they manufacture ICE vehicles with insufficient fuel economy and positive NEV credits if they manufacture NEVs. Meanwhile, the fuel economy requirements for ICE vehicles are being increased by related regulations. The car manufacturers with net negative credits will have to pay fines and even stop production. The NEV credits can be used for offsetting CAFC credits or cross-enterprise trading, and the vehicle credit policy offers EV manufacturers the opportunity to gain additional revenue by selling positive NEV credits to ICE-vehicle manufacturers. For example, in 2020 Tesla obtained more than 860000 NEV credits (MIIT, 2021a), which were roughly valued at $270 million based on the credit price 2020 (CATARC, 2021). The cross-enterprise trading allows EV manufacturers to keep EV price at an acceptable level for consumers, even lower than production costs, because the credit revenue can cover the loss caused by lower price, which means the purchase costs for consumers is indirectly reduced and EVs can attract more potential users. Therefore, the vehicle credit policy can be seen as the second interaction of policy elements with market and user elements. Until 2019, in more than 30 major cities including all super tier-1 cities (Beijing, Shanghai, Guangzhou and Shenzhen), EV users are exempted from travel restrictions and license restrictions applied to ICE vehicles to prompt the application of EVs (iCET, 2019). The exemption policy greatly improves the user experience of EV users compared with ICE-vehicle users facing policy restrictions. Based on the analysis of EV purchase incentives, in large cities, EV privileges, namely the exemption of travel restrictions and license restrictions are even a more significant factor to incentive consumers to choose EVs than purchase subsidies (Ma, Xu, & Fan, 2019), and the improvement of user experience led by these EV privileges is the result of policy elements interacting with market and user elements.

The government designed the three-vertical and three-horizontal R&D layout in 2001, which aimed to prompt EV knowledge accumulation by funding research institutes, and the research directions of the layout are also adjusted with the EV development (Central Government Portal, 2020a). Two versions of Energy-saving and New Energy Vehicle Industry Development Plan both clearly emphasize the guiding position of this layout for technology development (Central Government Portal, 2012b, 2021b). Until now, the three-vertical layout means three technical paths, namely plug-in hybrid vehicles (PHEVs), EVs and FCVs, and three-horizontal means three key technologies, namely the power batter technology, drive motor and power electronics technology and networking and intelligent technology. The research funding for EV research shows the interaction of policy elements with techno-scientific knowledge elements.

6.2 Infrastructure Elements and Related Interactions

Charging stations are the crucial infrastructure for EV application, and they can be installed in public charging areas and private residential communities, which depends on whether charging stations are owned by individual consumers or charging station operators. The charging service offered by the charging station system is also a significant factor affecting user experience. The charging speed is one of the most concerning technical performances for charging stations, and a shorter charging time can make it more convenient for EV users though the charging time is still longer than the refueling time of traditional ICE vehicles. Similarly, the research by Coffman, Bernstein and Wee (2017) shows long charging time is a major barrier to EV diffusion. Therefore, charging speed can affect user experience, which shows how the infrastructure elements interact with market and user elements.

No matter the public charging stations or private ones, charging stations must be connected with another significant infrastructure, namely the power grid, and have to directly influence the operation of the power grid. The large application of EVs requires more charging stations and will inevitably increase the peak load of the power grid (Chen, Li, Yang, & Ma, 2020), which can cause grid congestion, grid instability and even local disruption. The issue of peak load increase can be alleviated by charging station operators via V2G and V2X, and the power system can even become smarter and more flexible than before, which are detailed in the following. The physical connection between charging stations and the power grid is the self-interaction for the infrastructure elements.

6.3 Culture Elements and Related Interactions

In 2020, at the 75th session of the UN General Assembly, the Chinese President made a commitment that China will take stronger measures to peak carbon emissions by 2030 and strive to achieve carbon neutrality by 2060. Subsequently, in 2021 the "3060" target (carbon peaking by 2030 and carbon neutrality by 2060) was included in the 14th five-year plan, and promoting the application of EVs was proposed as a crucial measure to reduce carbon emissions in the five-year plan (Central Government Portal, 2021a). The commitment and attention of the government cause a lot of discussion of carbon peaking and carbon neutrality, and the public focuses more on the carbon emission issue than before (Xinhua Net, 2021a). The value identity is being reshaped, and the public agrees on the necessity of resolving carbon emission issue, which means the behavior of purchasing EVs is attached with a new value. EV consumers believe that EV consumption and application can help reduce carbon emissions, therefore they can gain extra moral satisfaction, which attracts potential consumers to choose EVs to a certain extent. The research by Haustein and Jensen (2018) also confirms this, they find ethical responsibility of environmental protection is an important driver for ICE-vehicle users to purchase EVs. The process of reshaping value identity and attaching new value is the interaction of culture elements with market and user elements.

6.4 Techno-scientific Knowledge Elements and Related Interactions

Ternary batteries and lithium iron phosphate batteries are currently the two main power battery technologies used for EVs in China, together accounting for 99.2% of the total installed battery capacity in the market. As shown in Fig.9, the energy density of ternary batteries and lithium iron phosphate batteries have increased from 166Wh/kg and 132Wh/kg in 2016 to 213Wh/kg and 169Wh/kg in 2020, with an improvement of 28%

for both. The growth in the energy density of power batteries means that more powerful power sources can be installed in the limited vehicle space, and thus EVs can have a larger range, which can be also seen in Fig.9. The growth in the energy density of power batteries depends on the accumulation of knowledge and related research, which further enlarges EVs' range. The process of knowledge improving technical performance is the interaction of techno-scientific knowledge elements with technology elements. Meanwhile, the knowledge of advanced power batteries acts as a basis for the production of power battery manufacturers, which shows how the techno-scientific knowledge elements interact with industrial network elements. The accumulation of knowledge and related research has also led to a huge reduction in the price of power batteries from 2015 to 2020 shown in Fig.9, and this progress can reduce the EVs' manufacturing costs for manufacturers and purchase costs for consumers, which is the interaction of techno-scientific knowledge elements with market and user elements.

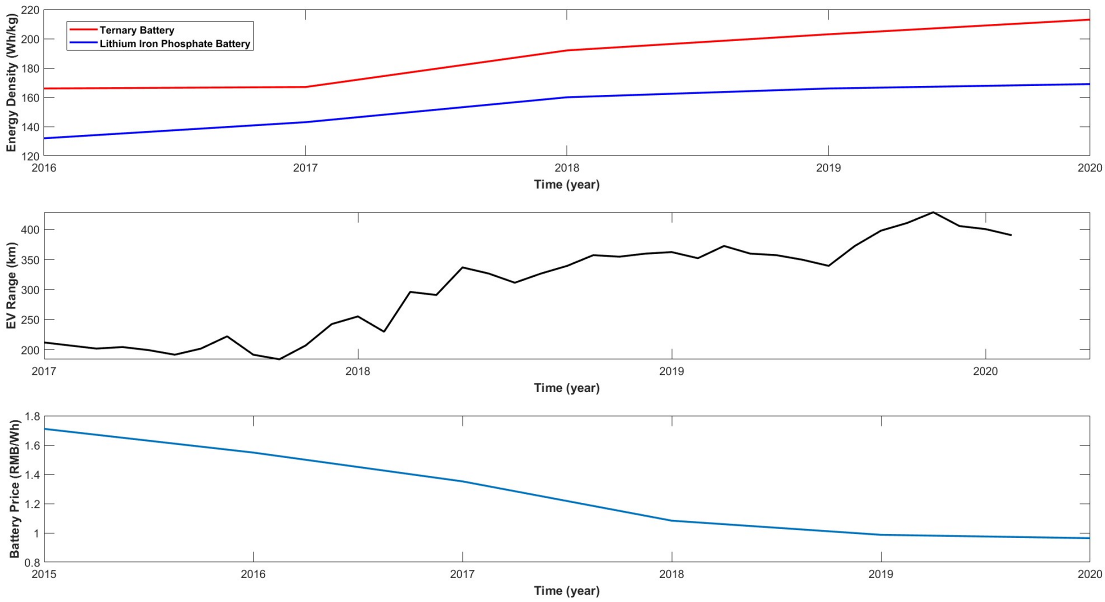

Figure 9 Battery energy density, EV range and battery price
(ERI, 2020; ICCT, 2021; MIIT, 2021b)

In 2020, cooperating with State Grid, Weltmeister successfully passed the vehicle test, charging station test and road test for vehicle-to-grid (V2G), which means Weltmeister becomes the first EV manufacturer to start V2G commercialization (Xinhua Press Net, 2022). V2G is an innovation of charging modes and charging scenarios, and it allows

EVs with bidirectional power interfaces to supply power from batteries to the grid when there is too much power demand. Meanwhile, EV users can gain revenue by taking the quick response for the grid. With V2G and the quick response, peak load increase caused by the growth in the EV number can be alleviated (Li et al., 2020). When taking the quick response, EVs are usually connected with specific charging stations applying the fast-charging technology. The fast-charging technology can not only be applied for V2G to take the quick response, but also be used for common charging scenarios to shorten charging time and improve user experience. V2G is one of the knowledge bases for charging station operators to cooperate with grid operators to optimize power dispatch and make the grid smarter and more flexible, and the fast-charging technology is one of the knowledge bases for charging station manufacturers to improve product performance. The interaction of techno-scientific knowledge elements with industrial network elements is taken in the form of the above knowledge bases.

Until 2020, as one of charging stations operators, State Grid has built the largest EV charging platform applying vehicle-to-everything (V2X), and the platform contains over 1.03 million charging stations (SASAC, 2020). V2X is an innovation allowing vehicles to interface information and data with everything, such as other vehicles and charging station operators. Charging station operators develop platforms for EVs installed with V2X-related communication devices, where EV users can share their locations, battery remaining power and charging demand. Based on the EV user data, grid load and the availability of charging stations, the charging station operators make an optimization to guide EV users where their cars can be charged or supply power to the power grid. Meanwhile, the platform can also offer navigation service to reduce traffic congestion. Therefore, V2X is another knowledge basis for charging station operators to optimize charging resources and grid load, which also shows the interaction of techno-scientific knowledge elements with industrial network elements.

Human-Computer Interaction (HCI) refers to the interaction between a human and a computer for exchanging information and accomplishing defined tasks, and the smart interaction technology applied to vehicles is also in the category of HCI. For example, the smart interaction technology applied in smart car solutions of Huawei allows vehicle functions to be fulfilled based on driver instructions from the touchscreen, gesture sensors and voice sensors, and it mainly depends on commutative electronics and the interaction software system (Huawei, 2021). Therefore, related electronic hardware technologies and software development are cores of smart interaction, and the research on these technologies is the knowledge basis for electronic hardware manufacturers and software system developers to produce smart cockpits, which also shows the interaction of techno-scientific knowledge elements with industrial network elements.

6.5 Technology Elements and Related Interactions

EV range is a significant performance of EVs, and it can directly affect user experience. Based on the research by Ouyang et al. (2020), limited EV range is a significant barrier to EV purchase and use. Without sufficient range, EV users have to charge their cars frequently and range anxiety will be enlarged. The effect of EV range on user experience shows how technology elements interact with market and user elements.

As shown in Fig.10, until 2021 for cars in most price ranges in China, the market penetration rate of smart cockpits has reached over 50%. Take the smart cockpit developed by Huawei as an example, it supports intelligent interactions, and all interactions can be taken on a screen, which allows EV users to directly control almost everything in vehicles even through gesture and voice; the smart cockpit system has diverse functions adapted to new application scenarios, for example, the function of advanced driver-assistance can be applied for real-time navigation, adaptive cruise, lane departure warning, automatic lane change, collision Warning, pedestrian detection and automatic parking (Huawei, 2021). Compared to EV power sources that can be controlled in real-time by electronic devices, real-time control of ICE is difficult due to the response lags, thus ICE vehicles cannot provide the best user experience even applying smart cockpits. The diverse product functions and application scenarios supported by the smart cockpit system can gradually reshape vehicle user mind, and vehicle users will require a new driving experience that cannot be satisfied by ICE vehicles, which is similar to that smartphone user expect cannot be satisfied by Nokia phones only with communication functions. Actually, based on the market demand analysis for vehicle consumers by Equal Ocean (2021), smart user experience is even a more significant factor than prices to incentive purchase in China. Therefore, the process of reshaping the user mind is the interaction of technology elements with market and user elements.

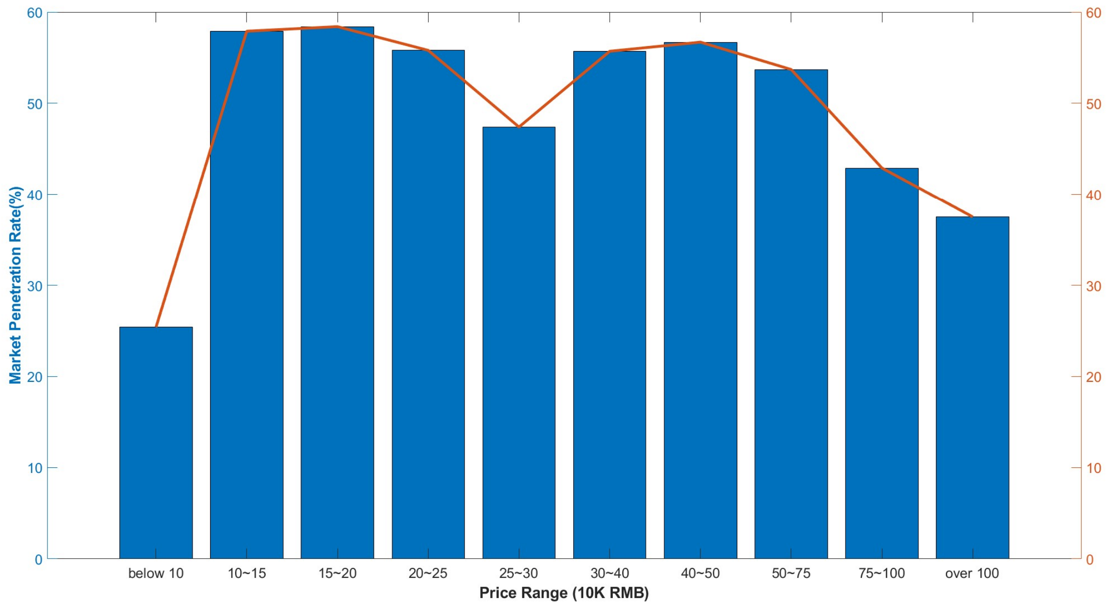

Figure 10 The market penetration rate of smart cockpits in China
(Equal Ocean, 2021a)

6.6 Industrial Network Elements and Related Interactions

As shown in Fig.11, no matter public charging stations and private ones the number of charging stations in China continues to increase from 2015, and the current number has been more than 2 million. Due to the close relationship between EVs and charging infrastructure, charging station manufacturers and operators are significant actors in the industrial network of EVs. For some leading enterprises related to charging station manufacturing, they extend their business to the charging station operation, which means they can have the advantage of equipment costs in the operation market. For example, TGOOD and Star Charge are charging station manufacturers, but also act as charging station operators to respectively capture 28.7% and 17% of the charging station operation market in 2020; meanwhile, State Grid, as the largest power grid operator in China, also has the charging station operation business and capture 23.3% of the charging station operation market in 2020 (LeadLeo, 2020). Charging station operators can not only manage charging stations, but also offer guide service for EV users. The EV users are informed where there are available charging stations to charge their EVs or supply power to the grid, which can improve use experience. In 2018, State Grid, Southern Power Grid, TGOOD and Star Charge cooperated and established a joint company to optimize power and charging resources (China Economic Weekly, 2021). Therefore, cooperation with the power grid, charging station manufacturing and charging station management are the interactions of industrial network elements with the infrastructure elements. As for the business extension between manufacturers and operators, it is the one type of inner self-interaction for the industrial network elements. The charging guide service provided by charging station operators to EV users is the interaction of industrial network elements with the market and user elements.

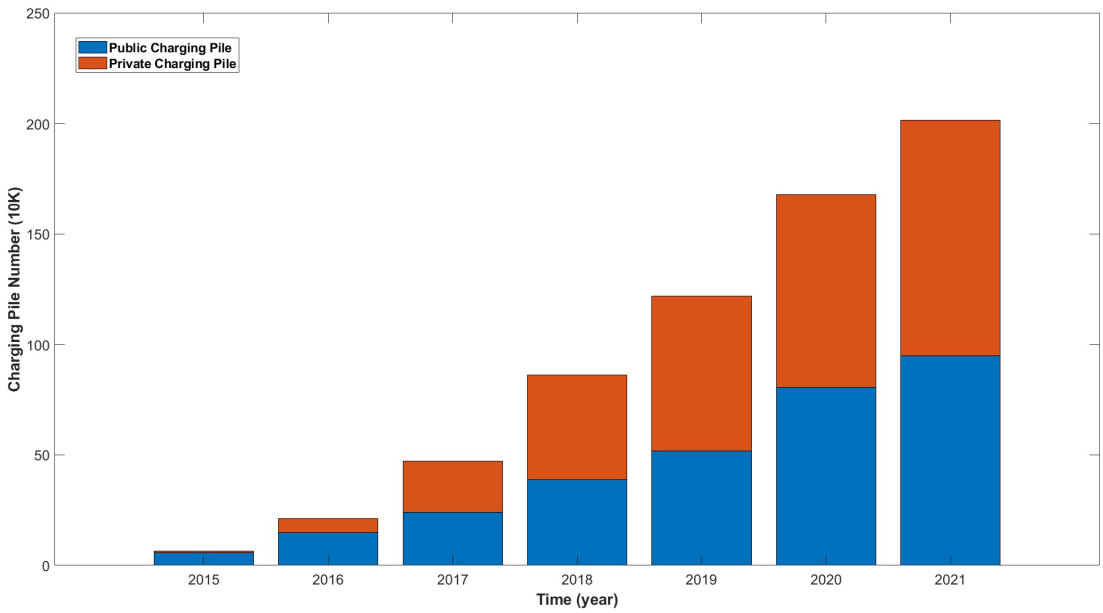

Figure 11 The market penetration rate of smart cockpits in China (EVCIPA, 2021a)

Power battery manufacturers, electronic hardware manufacturers, smart cockpit system developers and electric motor manufacturers act as upstream suppliers in the EV industry chain for EV manufacturers. Power battery manufacturers (e.g. CATL), electronic hardware manufacturers (e.g. Infineon Technologies) and electric motor manufacturers (e.g. Founder Motor) supply power batteries, powertrain electronics and electric motors, respectively. Power batteries, powertrain electronics and electric motors are three crucial parts of EVs to fulfill traveling functions. With these suppliers, EV manufacturers can only focus on vehicle design and integration, but some EV manufacturers can self-manufacture power batteries, powertrain electronics and electric motors, such as BYD Auto. As for the smart cockpit system, its application involves hardware support from electronic hardware manufacturers (e.g. Intel) and software support from system developers (e.g. Huawei), and it fulfills the functions of improving the driving experience. Some EV manufactures also self-manufacture and self-develop the related hardware and software, such as NIO and XPeng. Therefore, the supply chain can be seen as another type of inner self-interaction for the industrial network elements, and the joint support required by the smart cockpit system is the interaction of industrial network elements with the technology elements.

6.7 Market and User Elements and Related Interactions

The smart cockpit system brings diverse product functions and application scenarios to vehicle users and thus reshapes the user mind, and users expect a new driving experience instead of a traditional ICE-vehicle driving experience. Meanwhile, at the consumer perception level, purchasing EVs is attached with a new value of reducing carbon emissions. The EV purchase costs are also decreased due to purchase subsidies, power battery price decrease and credit trading revenue of EV manufacturers. EV user experience is largely improved by EV privileges, increasing EV range, gradually sufficient charging infrastructure and convenient charging guide service. Therefore, reshaped user mind, newly added value, decreased purchase costs and improved user experience work together to make consumers gradually tend to choose EVs and prompt the diffusion of EVs, which can be confirmed by the increasing EV ownerships, sales and shares in China shown in Fig.7. The promotion process is the self-interaction of market and user elements.

Based on the above analysis of the niche element interactions and niche-regime interactions, sub-question 3 *How do niche elements interact with each other?* can be answered.

(1) The policy elements interact with market and user and techno-scientific knowledge elements. The EV purchase subsidies reduce the car purchase costs, and the credit policy allows EV manufacturers to gain additional revenue to set a lower price. They both make EVs more affordable for consumers. The exemption for travel restrictions and license restrictions improves EV users' experience. The R&D layout and related funding for the research institutes prompt knowledge accumulation and update.

(2) The infrastructure elements interact with market and user elements, which shows in the form of charging stations offering charging services for EV users. There is also self-interaction of infrastructure elements, because charging stations can increase the peak load of the power grid and affect grid stability.

(3) The culture elements interact with market and user elements, which shows in the form of the public concern of carbon emission issue making EV application and consumption given a new value, namely moral satisfaction.

(4) The techno-scientific knowledge elements interact with market and user, technology and industrial network elements. The research on advanced power batteries reduces manufacturing costs and price of EVs, and it also enlarges EV range and improves technical performance. Meanwhile, advanced power battery, V2G and related fast-charging technologies and V2X all serve as the knowledge basis of actors involved EV industry.

(5) The technology elements interact with market and user elements. The EV range enlarging can improve the user experience. Meanwhile, the smart cockpits can offer more product functions and expand more application scenarios for users, which lead to user mind and perception of vehicles being reshaped.

(6) The industrial network elements interact with market and user elements, infrastructure and technology elements. The charging station operators offer guide

service for EV users about where there are available charging stations to charge EVs or supply power to the grid, which can improve the user experience. The charging stations, as the necessary infrastructure for EVs, are manufactured by related manufacturers in the industrial network, and the charging station operators manage the infrastructure and cooperate with power grid operators to optimize power and charging resource allocation. The application of smart cockpit systems depends on hardware support from electronic hardware manufacturers and software support from system developers, which shows the interaction with technology elements. Meanwhile, there is also self-interaction of industrial network elements, such as charging station manufacturers extending the business to serve as operators and component manufacturers and system developers acting as upstream suppliers for EV manufacturers.

(7) The market and user elements self-interact with themselves. Reshaped user mind, newly added value, decreased purchase costs and improved user experience work together to prompt EV diffusion, which can be seen as the self-interaction of market and user elements.

The above answers explain how niche elements interact with each other to support the development and diffusion of EVs. Like regime element interactions, due to the existence of interrelationships of niche elements, the niche element interactions similarly allow element dynamics caused by landscape interactions to affect other niche elements and generate more element dynamics. This chapter analyzes the interrelationships of niche elements by analyzing their interactions, and what dynamics are generated via these interrelationships and how they participate in the niche-regime interactions to affect the socio-technical transition for EVs in China are discussed in Chapter 8.

7 Interactions of Niche Elements with Regime Elements

This chapter aims to answer sub-question 4 *How do niche elements interact with regime elements?* Besides the inner interactions of the niche cluster, namely the element interactions, the niche cluster is also interacting with the dominant regime, and the interactions between the niche cluster and regime are called the cross-level interactions or niche-regime interactions, which is shown in Fig.12. As mentioned above, the niche cluster and dominant regime act as two socio-technical systems, which respectively serve and support EVs and ICE vehicles, and the two systems can affect each other via the niche-regime interactions and thus can co-develop. The socio-technical transition of EVs cannot be simplified and treated as the technology substitution but should be seen as a process of industry environment reshaping, industry layout adjustments and industry resource reallocation, and the process is closely related to the niche-regime interactions, which is detailed in the following.

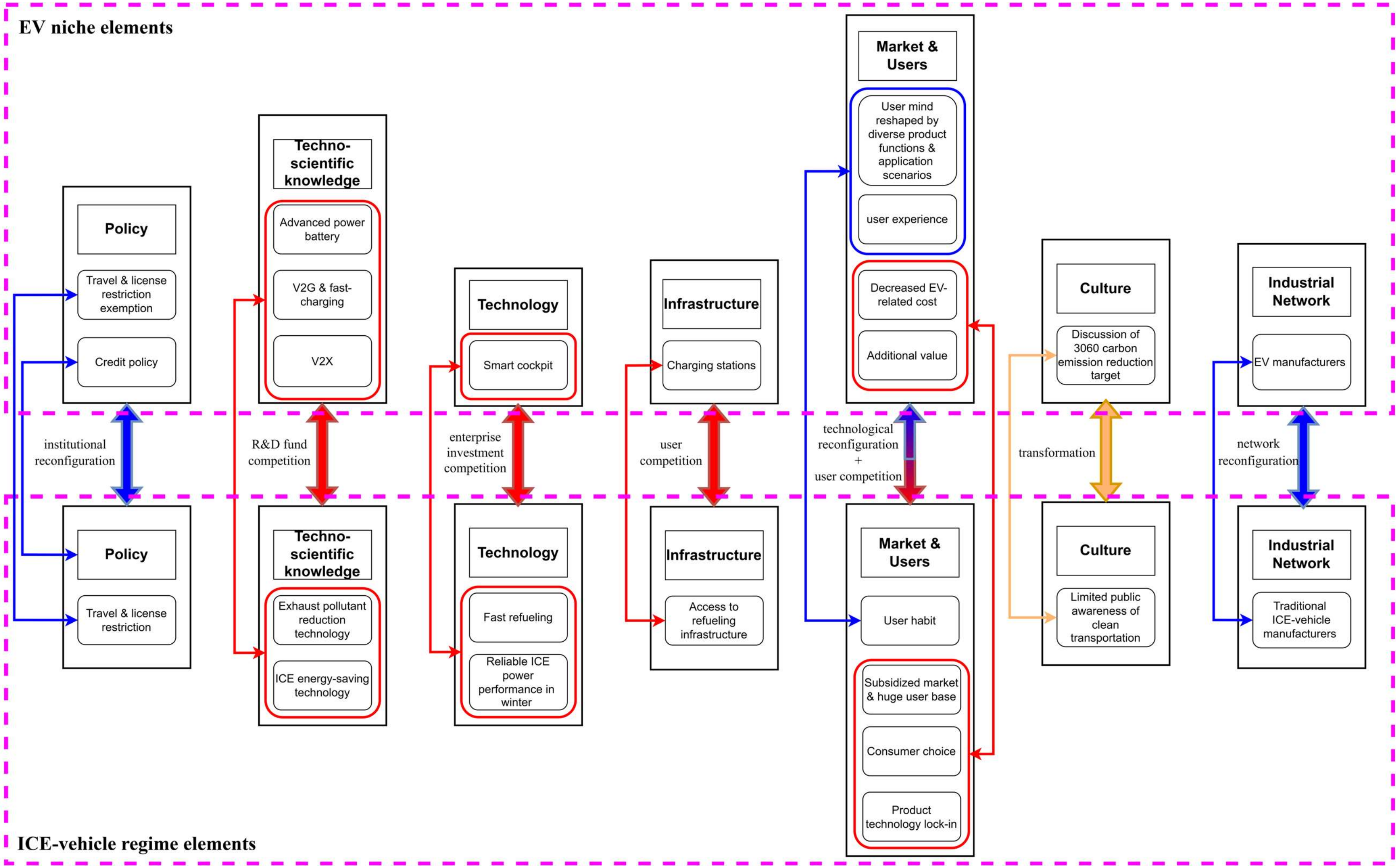

Figure 12 The niche-regime interaction map

Three types of niche-regime interactions are proposed in the thesis, which are reconfiguration, transformation and competition. Reconfiguration means something novelty is added into the original structure, and the novelty is introduced into the blank fields not covered by the original structure instead of replacing some parts of the original structure. Reconfiguration can be the process of novelty from the niche cluster being supplemented into the dominant regime or novelty from the regime being integrated into the niche cluster. Conversely, transformation means some parts of the original structure are completely replaced by something novelty and thus change from one state to another, and the two states are opposite and incompatible. For the case in this thesis, transformation is the process of some parts of the regime being replaced by some parts of the niche cluster. Unlike reconfiguration and transformation, competition refers to the process of the niche cluster and dominant regime competing for limited and desired resources.

The reconfiguration interaction can be observed in policy, industrial network and market and user elements. Inspired by the concept of anchoring (Elzen et al., 2008), the reconfiguration is classified in three types, namely institutional, network and technological reconfiguration. The niche-regime interaction of policy elements is the institutional reconfiguration, which means new policies and rules are added into the regime or niche cluster. As the rule and regulation foundation of NEV credit trading, Measures for the Parallel Administration of the Average Fuel Consumption and New Energy Vehicle credits of Passenger Vehicle Enterprises were proposed in 2018 and partially adjusted in 2020, and it starts to be implemented from 2021 (Central Government Portal, 2020a). Before the credit policy is proposed, there are not any policies or rules involving the credit trading mechanism in the ICE-vehicle regime, and the credit policy is actually a product that initially aimed to serve EVs. Based on the above analysis of the policy content, the core aim of the credit policy is prompting EV development and offering the opportunity for EV manufacturers to gain additional revenue by selling NEV credits, therefore it can be seen as originating from EVs' niche cluster. However, when offering the opportunity for EVs, it restricts ICE-vehicle manufacturers' business operations and makes them face more costs, which means it subsequently becomes related with ICE vehicles. For example, FAW-Volkswagen, as a traditional ICE vehicle manufacturer, had to pay for offsetting more than 1180000 CAFC credits in 2020 (MIIT, 2021a). Therefore, the credit policy is introduced into the blank fields not covered by the ICE-vehicle regime instead of abolishing and replacing the original policies or rules. Similarly, the travel and license restrictions were initially proposed in major cities around 2013 when the smog issue became more serious and caused widespread public concern. The initial aim of these restrictions is to reduce ICE-vehicle exhaust pollutant emissions and alleviate the resulting smog issue, and thus these restrictions are initially related to the ICE-vehicle regime. Subsequently, the restriction policy becomes related to EVs, and the government specifically states EVs are exempted from these restrictions to prompt EV diffusion, such as Measures to Encourage NEV Purchase and Use in Shanghai, which allows EV users to gain travel priority and get free car licenses (Shanghai Municipal Government, 2021). The credit policy added into the ICE-vehicle regime makes the regime cannot work efficiently to support ICE vehicles, and the exemption policy added into the EV niche cluster prompts EV development. Therefore, the institutional reconfiguration actually reshapes the policy part of the environment of the whole vehicle industry, which means ICE vehicles and EVs are both affected. The similar phenomenon can also be observed in the network and technological reconfiguration. The niche-regime interaction of industrial network elements can be seen as the network configuration. The network configuration refers to new actors originally not involved in the production, sales or use network being integrated into the network, namely the network expands. Power battery manufacturers, electronic hardware manufacturers, smart cockpit system developers and electric motor manufacturers are common upstream suppliers in the EV supply chain. However, due to traditional ICE-vehicle manufacturers having richer technology accumulation in some aspects than EV manufacturers, they can currently participate in this supply chain by offering EV manufacturers automotive chassis. For example, in 2021 Chang'an

Automobile, a traditional ICE-vehicle manufacturer announced that they have started to cooperate with CATL and Huawei to start EV business in the form of a joint company sharing advantage technologies and resources (Xinhua Net, 2021b). The new actors from the ICE-vehicle regime are integrated into the EV niche cluster, and they are actually playing the role of boundary bridgers proposed by Negro and Hekkert (2014). Therefore, the network reconfiguration actually changes the supply chain and adjusts the industry layout for both ICE vehicles and EVs. For the socio-technical transition for EVs in China, the technological reconfiguration is mainly concentrated in the niche-regime interaction of market and user elements. Based on the research by Elzen et al. (2008), the technological reconfiguration can be a process of technical concepts becoming defined by the related actors, and thus here it refers to vehicle users' perception and mind of the vehicle-related concept are gradually changed. Vehicle users' habits are initially cultivated by ICE vehicles, and their main perception and mind of a vehicle or driving usually only contain speed and range. But EVs expands their perception and mind by more diverse functions and application scenarios, such as smart human-vehicle interaction and driving-assistance. User perception and mind currently not only contain the concept of speed and range, but also contain how smart the car is, and this can be confirmed by the market demand analysis for vehicle consumers, which shows that smart user experience also becomes a significant factor to incentive purchase a vehicle in China (Equal Ocean, 2021a). The potential consumers for both EVs and ICE vehicles are mostly overlapping, and user perception and mind origins from EVs are discussed, shared and spread among these potential vehicle consumers, and thus the application of ICE vehicles is also affected. Therefore, the above process is the technological reconfiguration, namely something novelty origins from the EV niche cluster is added into the ICE-vehicle regime. Similarly, the user part of the industry environment is reshaped.

The second type of niche-regime interactions is transformation, which can be observed in the cross-level interaction of culture elements. As the above analysis based on the data of Baidu Index and Sina Weibo (CEEP-BIT, 2019, Huang et al., 2022), before the “3060” commitment, the public awareness of clean transportation was quite limited, and the public tended to pay more attention to common pollutant emissions but thought the carbon emissions do not matter; after the “3060” carbon emission reduction target is proposed, the discussion of carbon emissions makes the public confront the issue and believe it needs to be addressed urgently. The limited public awareness of clean transportation is a part of the ICE-vehicle regime, and the discussion and concern of carbon emissions are a part of the EV niche cluster. The former is gradually replaced by the latter, and thus the public opinion changes from disregarding to attaching importance, which shows the transformative interaction. The transformation makes the public opinion changes, and ICE vehicles’ carbon emission issue and EVs’ carbon emission reduction benefit both attract public attention. Therefore, the transformation reshapes the public opinion part of the industry environment.

The last type of niche-regime interactions for this case is competition, and the competitive interaction between the EV niche cluster and ICE-vehicle regime mainly focuses on limited industry resources necessary for the development of both EVs and ICE vehicles, such as R&D funds, enterprise investment and users. The competition for R&D funds can be observed in the cross-level interaction of techno-scientific knowledge elements. The research in EV-related technologies, such as advanced power battery, V2G, fast-charging and V2X, is not strongly related to the technologies applied in ICE vehicles, such as exhaust pollutant reduction and energy-saving ICE. Therefore, it is almost impossible for these technologies to share R&D funds and take joint research, and they have to compete with each other for the limited funds. For example, compared to the 2012-version policy portfolio of energy saving and pollutant emission reduction offering funds for ICE-related research, the 2021-version one no longer explicitly contains research funding plans for ICE vehicles but proposes a target that by 2025 NEV sales will reach roughly 20% of total new vehicle sales (Central Government Portal, 2012c, 2021b), which shows at the level of national research funds EVs become the winner of the competition with ICE vehicles. The competition for enterprise investment can be observed in the cross-level interaction of technology elements. Some product characteristics and technical performance are unique to the specific technical path. For example, the smart cockpit system is applied for EVs because EV power sources can be controlled in real-time by electronic devices without any response lags, but fast refueling and reliable power performance in winter are the technical advantages of ICEs compared to power batteries. Therefore, for vehicle manufacturers, specific product performance is bound to the corresponding technical path, and they have to choose one path to invest in from EVs and ICE vehicles due to the financial pressure. In this situation, EVs and ICE vehicles have to compete for enterprise investment. Actually, between 2014 to 2019 in China, the establishment of EV brands exceeded one hundred, and the amount of financing disclosed to the public exceeded 200 billion yuan (Equal Ocean, 2021b), which shows EVs are gradually capturing the investment from ICE vehicles. The competition for users can be observed in the cross-level interaction of both infrastructure elements and market and user elements. As for the infrastructure elements, the oil pipelines and terminal refueling stations serving ICE vehicles and the charging stations and power grid serving EVs are two almost separate energy sub-systems, and the energy consumption for vehicle transportation is the market that they both target. When vehicle users consume more power, the refueling infrastructure will be used less, and thus the two infrastructure systems are competing for users. As shown in Fig.7, the EV market share increases a lot from 2017, and in 2020 11 out of every 100 cars sold were EVs, which shows the charging infrastructure is capturing potential users from the refueling infrastructure. The niche-regime interaction of the market and user elements is also the process of competing for users. The subsidized market allows ICE manufacturers to set a low price to attract consumers to choose ICE vehicles, and the resulting huge user base can create steady revenue for ICE manufacturers when they pay for the vehicle maintenance service. The process somewhat contributes to product technology lock-in. But decreasing EV-related costs and the newly added value of carbon emission reduction allow EVs to directly compete with ICE vehicles at the price level and consumer preference level, which can help EVs grab potential users, break technology lock-in and further prompt EV diffusion, which can also be confirmed by the EV market share increase shown in Fig.7. The process of competing for users at the price level and consumer preference is also the competitive interaction.

Based on the above analysis of the niche element interactions and niche-regime interactions, sub-question 4 *How do niche elements interact with regime elements?* can be answered. Reconfiguration, transformation and competition are three types of niche-regime interactions proposed in this thesis. Reconfiguration and transformation reshape the policy, user and public opinion part of the environment of the whole vehicle industry. Meanwhile, they also change the supply chain and adjust the industry layout. Competition make related resources, such as R&D funds, enterprise investment and user bases, are reallocated between EVs and ICE vehicles. Therefore, niche elements interact with regime elements in the above three forms. Meanwhile, this chapter also shows that industry environment reshaping, industry layout adjustments and industry resource reallocation as the crucial aspects of the socio-technical transition for EVs in China are related to the three types of niche-regime interactions. This chapter proposes the niche-regime interaction mechanism, and how element dynamics participate in the niche-regime interactions to affect the socio-technical transition for EVs in China is discussed in Chapter 8.

8 Dynamics of Regime and Niche Elements

This chapter aims to answer sub-question 5 *How does the dominant regime change?* and sub-question 6 *How does the niche cluster change?* The changing process of the ICE-vehicle regime and EV niche cluster can be studied by analyzing element dynamics based on the landscape interactions, element interactions and niche-regime interactions. As the dynamics are listed by Hofman and Elzen (2010) for the electricity system, the introduction of target group policies (policy element), Dutch horticulture firms ever as electricity consumers starting to install small gas engines (user and market element), the reinforced transport function of the European electricity grid (infrastructure element), the increasing pressures from social groups aiming to change the power regime (culture element), the new coalitions of electricity distributors and industrial actors (industrial network element) and the large application of cogeneration of heat and power technology (technology element), etc. are all element dynamics. Therefore, it can be summarized that dynamics of regime elements can be new policies, technology progress, public opinion changes, infrastructure improvement and enterprise business adjustments, etc., and these related items are categorized into different elements. For a certain element, if there are any obvious changes in size, quality, extent, range, structure, network, mechanism and nature, etc. for the above related items, it can be regarded as element dynamics. Landscape factors apply pressure or influence on regime and niche actors, and these actors have to make responses. These actors' actions change the states of elements, or these actions are themselves element dynamics. Element interactions within the regime and niche cluster are the interrelationships of different elements, and as detailed in Chapters 5 and 6 these interactions represent how an element affect or act on another one in the form of setting rules, influencing consumer behavior, manufacturing products, offering services, providing knowledge and technology, acting as the knowledge basis and forming supply chains and industry networks, etc. Therefore, when element dynamics are initially caused by the landscape interactions, and these dynamics can further generate more element dynamics via element interactions. Because there are interrelationships of elements, and when one element changes it is possible for another one interacting with it or affected by it to change with it. Meanwhile, element dynamics can act as prerequisites and contents of the niche-regime interactions to affect the EV socio-technical transition, or only act as parts of the original regime to help sustain the dominant status of ICE vehicles or parts of the original niche cluster to help EV develop. Therefore, based on the interaction mechanism proposed in Chapters 4 to 7, what element dynamics emerge and their effect on the socio-technical transition are two key aspects discussed in this chapter.

8.1 Dynamics of Policy Elements

Before the smog issue was widely concerned by the public, the policy elements of the ICE-vehicle regime mainly consisted of policies encouraging ICE-vehicle consumption, which aim for economic stimulus. In 2012, the total output value of the vehicle industry in China accounted for 10.2% of the gross domestic product, and 19 million vehicles were produced in 2012 with only 13300 EVs produced (Central Government Portal, 2012a; NBS, 2014). Therefore, in the stage before the smog issue was concerned by the public, encouraging ICE-vehicle consumption actually acted as an effective measure for the government stimulate the economy. However, also in 2012, Ambient Air Quality Standards (GB3095-2012) was promulgated and PM2.5 was first listed in the standards, indicating the smog issue started to be widely concerned by the government and the public in China. Subsequently, the smog issue, as an emerging landscape factor, worked with energy security affected by geopolitical conflicts, another already existing landscape factor, to generate policy element dynamics of both the ICE-vehicle regime and EV niche cluster. The smog issue directly affected public health, which can be observed in a short period, and thus it led to great public opinion pressure, forcing the government to take the lead and start reacting. The process of the smog issue causing pressure and the government reacting and implementing new policies is the interaction of the landscape factor with the regime and niche elements, and new policies as element dynamics are the results of the interaction, or in other words, policy element dynamics are generated by the interaction. As for the policy element dynamics of the ICE-vehicle regime, the policy portfolio of energy saving and pollutant emission reduction proposed in 2006 was updated as a new version in 2012, and it contained more funding for related research and stricter vehicle fuel consumption limitations and vehicle pollutant emission regulations (Central Government Portal, 2012c). Meanwhile, the geographical coverage of travel and license restriction policy original only implemented in Beijing and Shanghai was expanded for reducing ICE-vehicle exhaust pollutant emissions and alleviating the smog issue, such as Guangzhou started to implement the restriction policy in July 2012 (People Net, 2012), which is a type of policy element dynamics caused by the landscape developments. As for the policy element dynamics of the EV niche cluster, Energy-saving and New Energy Vehicle Industry Development Plan (2012-2020) was proposed in 2012, which contains a series of EV encouragement and promotion policies to reduce vehicle pollutant emissions, mainly involving EV purchase subsidies and research funding plans (Central Government Portal, 2012b). The update of energy saving and pollutant emission reduction policy portfolio, as the policy element dynamics, only acts as parts of the ICE-vehicle regime to help sustain the dominant status of ICE vehicles, and fuel economy improvement and exhaust pollutant emission reduction driven by policies can attract more consumers. Similarly, the EV encouragement and promotion policies also only act as parts of the EV niche cluster to help EV develop, and the technical performance improvement and purchase costs decrease driven by policies are beneficial to EV diffusion. The above policy element dynamics are not involved in the niche-regime interactions, but the geographical expansion of travel and license restriction policy participates the niche-regime interactions, namely the institutional reconfiguration. In the cities where the travel and license restrictions are implemented, the initial aim of the restriction policy is to reduce ICE-vehicle exhaust pollutant emissions and alleviate the resulting smog issue, and thus these restrictions are initially related to the ICE-vehicle regime. Subsequently, the restriction policy becomes related to EVs, because the government specifically states EVs are exempted from these restrictions, which aims to prompt EV diffusion. Until 2019, in more than 30 major cities including all super tier-1 cities (Beijing, Shanghai, Guangzhou and Shenzhen), EV users are exempted from travel restrictions and license restrictions applied to ICE vehicles to prompt the application of EVs (iCET, 2019). The exemption of travel restrictions and license restrictions, as a type of privileges, can convenience a lot for users and thus incentive consumers choosing EVs (Ma et al., 2019) which create the window of opportunity for EVs. Via the institutional reconfiguration, the restriction exemption policy is introduced into the EV niche cluster. ICE vehicles face policy restrictions, but EVs are exempted and thus gain the policy benefits, which means the institutional reconfiguration reshapes the policy environment of the whole vehicle industry. Without travel and license restrictions being expanded to some cities, the exemption policy cannot work in these cities. Therefore, the policy element dynamics act as prerequisites and contents of the institutional reconfiguration to reshape the industry policy environment and make EV users benefit, which further prompts the EV socio-technical transition.

Climate change and global warming caused by carbon emissions, as a new landscape factor, raise public concern in China after the smog issue is alleviated a lot. Climate change is an internationally recognized issue that needs to be addressed by all of humanity, and China has become the largest emitter of CO_2 in the world, which means the Chinese government is under tremendous international pressure. Therefore, the government starts to implement new policies serving carbon emission reduction. The process of climate change causing pressure and the government reacting and implementing new policies is similar to that of the smog issue, which is also the interaction of the landscape factor with the regime and niche elements, and policy element dynamics are generated by the interaction. For coping with the new landscape developments, in 2020, at the 75th session of the UN General Assembly, the Chinese President made a commitment that China will take stronger measures to peak carbon emissions by 2030 and strive to achieve carbon neutrality by 2060, which means a lot of policy element dynamics are subsequently generated. As for the policy element dynamics of the ICE-vehicle regime, the policy portfolio of energy saving and pollutant emission reduction was updated again in 2021, and compared to the previous version it currently puts more emphasis on reducing energy consumption to serve the target of carbon peaking by 2030. It still contains stricter vehicle fuel consumption limitations and vehicle pollutant emission regulations but no longer explicitly contains research funding for ICE vehicles, and it also proposes a target that by 2025 NEV sales will reach roughly 20% of total new vehicle sales (Central Government Portal, 2021b). As for the policy element dynamics of the EV niche cluster, Energy-saving and New Energy Vehicle Industry Development Plan (2021-2035) was proposed in 2021, and compared with the version of 2012-2020 the most worthy point of the current one is that vehicle credit policy started in 2018 is seen as a crucial measure to prompt EV diffusion (Central Government Portal, 2020a). These policy element dynamics shows though lowering fuel consumption of ICE vehicles is still an ongoing work promoting EVs to reduce carbon emissions becomes a higher priority work, because with only lowering fuel consumption of ICE vehicles the “3060” target (carbon peaking by 2030 and carbon neutrality by 2060) cannot be reached. Meanwhile, the credit policy is also involved the niche-regime interactions, namely the institutional reconfiguration. Before the credit policy is proposed, there are not any policies or rules involving the credit trading mechanism in the ICE-vehicle regime, and the credit policy is a product that initially aimed to prompt EV development by allowing EV manufacturers to sell NEV credits and gain additional revenue. But when offering the opportunity for EVs, it makes ICE-vehicle manufacturers have to pay for purchasing NEV credits, and thus it subsequently becomes related to the ICE-vehicle regime. The fact also confirms this: Tesla obtained more than 860000 NEV credits in 2020, which were roughly valued at \$270 million based on the credit price 2020; conversely, FAW-Volkswagen, as a traditional ICE vehicle manufacturer, had to offset more than 1180000 CAFC credits in 2020 (CATARC, 2021; MIIT, 2021a). Therefore, the credit policy leads to EV manufacturers’ financial benefits and ICE-vehicle manufacturers’ financial burdens. Via the institutional reconfiguration, the credit policy that initially aimed to serve EVs is introduced into the ICE-vehicle regime, and the policy element dynamics also act as prerequisites and contents of the institutional reconfiguration to reshape the industry policy environment, which encourages EV manufactures and further prompts the EV socio-technical transition.

8.2 Dynamics of Culture Elements

The smog weather in several Chinese cities in June 2016, the widespread smog in northeast China in October 2013 and the smog covering almost the entire central and eastern parts of China in December 2013 attracted the public attention a lot at that time, and a series of widespread smog weather made the public focus more on pollutant emissions compared to the past. The public as actors whose health is directly affected by the smog issue responds to the landscape factor in the form of public opinion concern, which shows the interaction of the landscape factor with the regime and niche culture elements. The rise of public concern on the smog issue itself is the culture element dynamics, and thus the logic of landscape developments generating the culture element dynamics is applicable. The new Ambient Air Quality Standards (GB3095-2012), the update of energy saving and pollutant emission reduction policy portfolio and the ICE-vehicle travel and license restrictions are government responses to the smog issue, and these policy element dynamics also generates culture element dynamics via element interactions in the ICE-vehicle regime. Because no matter in the new Ambient Air Quality Standards (GB3095-2012) or the updated energy saving and pollutant emission reduction policy portfolio, the definition of pollutants is limited to NOx, SO2, PM10 and PM2.5, etc. but does not include CO_2. As the analysis in Chapter 5, the policy elements can interact with the culture elements by leading and shaping the public opinion, and thus the public awareness of pollutants is affected by these policies. The fact that policy dynamics (new and updated policies) emphasize NOx, SO2, PM10 and PM2.5, etc. but ignore CO_2 leads the public to focus more on these pollutants listed in standards and regulations and ignore the carbon emission issue. This can be confirmed by the fact that the post hotness of low-carbon and green consumption on Sina Weibo was low during this period (Huang et al., 2022). Meanwhile, the implementation of travel restrictions and a series of propaganda make the public associate ICE vehicles with the smog issue and further treat the ICE-vehicle exhaust emissions as one of the smog sources. The above process shows how policy element dynamics make public awareness change and generate culture element dynamics, namely more focuses on pollutants listed in standards and regulations. Therefore, the landscape developments and policy element dynamics both generate culture element dynamics via landscape interactions and regime element interactions, respectively. The public perception is shaped as such: ICE-vehicle exhaust consisting of NOx, SO2, PM10 and PM2.5, etc. is one of the smog sources, and if the exhaust issue is resolved, the smog issue can be alleviated and the clean transportation target can be reached. Based on the research by Wang, Sun, Yang and Yuan (2016), at that time most citizens believe that taking public transportation can alleviate the smog issue and thus is environmentally friendly, but they ignore the carbon emission issue. The shaped public awareness, as the culture element dynamics, becomes parts of the ICE-vehicle regime to help sustain the dominant status of ICE vehicles, and thus the carbon emission issue is ignored by consumers when they purchase ICE vehicles with exhaust treatment devices absorbing pollutants.

Climate change and global warming as landscape developments drive the proposal of the “3060” target in 2020, which subsequently leads to a lot of discussion about carbon peaking and carbon neutrality in China. The public starts to pay more attention to carbon emissions compared to the past, and the typical evidence is the willingness to pay (WTP) for carbon emission reduction or offsetting increases by 107.7% from 2014 to 2021 (Duan, Yan-Li, & Yan, 2014; Tao, Duan, & Deng, 2021). Even considering citizen income increase and inflation, the increase of WTP is still considerable and can indicate the increasing public concern about carbon emissions. The increasing public concern about carbon emissions is the culture element dynamics of the EV niche cluster, which are generated via landscape interactions. Because it is climate change and the national carbon reduction target that makes the public start to be widely concerned about carbon emissions. The culture element dynamics are also involved in niche-regime interactions, namely transformation. The limited public awareness of clean transportation and emissions is a part of the ICE-vehicle regime, and it serves ICE vehicles and sustains their dominant status by making consumers ignore the vehicle carbon emission issue. However, the increasing public concern about carbon emissions, as the culture element dynamics of the EV niche cluster, gradually replaces the original public awareness and attitude in the process of the transformative interaction, which is confirmed by the above data analysis of Baidu Index and Sina Weibo (CEEP-BIT, 2019, Huang et al., 2022). Therefore, the culture element dynamics of the EV niche cluster are prerequisites and contents of the transformative interaction to reshape the public opinion environment for the whole industry, which makes the public more willing to choose EVs and further prompts the EV socio-technical transition.

8.3 Dynamics of Techno-scientific Knowledge Elements

The update of energy saving and pollutant emission reduction policy portfolio, as the policy element dynamics of the ICE-vehicle regime caused by the landscape developments (the smog issue and energy security), generates the techno-scientific knowledge element dynamics of the ICE-vehicle regime via regime element interactions. As shown in Chapter 5, the policy elements can interact with the elements of techno-scientific knowledge in the form of providing research funding. The updated policy portfolio (2012 version) focuses more on the research on energy saving and pollutant emission reduction, and thus the updated policy portfolio enlarges the funding support for it and lists it as the key funded project of the National Science and Technology Major Project and National Science and Technology Plan (Central Government Portal, 2012c). The increase in funding support from policies is also a part of policy element dynamics, and it leads to research progress and knowledge accumulation, which are the techno-scientific knowledge element dynamics. This can be corroborated by the actual effect that total vehicle pollutant emissions per year in China continued decreasing and vehicle fuel consumption per year only increases by 95% from 2009 to 2019 even the number of vehicles increased by more than three times in these years, which is shown in Fig.5. The research progress and knowledge accumulation, as the techno-scientific knowledge element dynamics, are the basis of improving ICE vehicles' energy-saving and pollutant emission reduction performance, and with the smog issue being alleviated by pollutant emission reduction efforts including vehicle exhaust pollutant reduction the public concern about ICE-vehicle exhaust pollutant emissions decrease a lot, which can confirmed by the Baidu Index that hotness value of public concern about the smog issue increased from 2012, peaked in 2015 and subsequently went down a lot (CEEP-BIT, 2019). Therefore, the techno-scientific knowledge element dynamics help ICE vehicles through the crisis caused by the smog issue and act as parts of the ICE-vehicle regime to sustain the dominant status of ICE vehicles.

As discussed above, the policy portfolio of energy saving and pollutant emission reduction updated in 2021 does not explicitly contain research funding for ICE vehicles but proposes a target that by 2025 NEV sales will reach roughly 20% of total new vehicle sales (Central Government Portal, 2021b). Meanwhile, Energy-saving and New Energy Vehicle Industry Development Plan (2021-2035) highlights the three-vertical and three-horizontal R&D layout and mentions offering funding support for researchers in significant fields, such as electrification, network-linking and intelligence (Central Government Portal, 2020a). The policy element dynamics caused by climate change include that at the national level the R&D funds for the whole vehicle industry are gradually captured by EVs. Besides the above policy element dynamics caused by climate change, Energy-saving and New Energy Vehicle Industry Development Plan (2012-2020), as the policy element dynamics caused by the smog issue, also contains R&D funding plans for EV-related research (Central Government Portal, 2012b). Therefore, via the interaction of policy elements with the techno-scientific knowledge elements (offering R&D funds), the techno-scientific knowledge element dynamics are generated, which means the research on advanced power batteries, V2G and related fast-charging technologies, V2X and smart interaction, etc. experiences rapid progress. As shown in Fig.9, the energy density of ternary batteries and lithium iron phosphate batteries both increased by 28% from 2016 to 2020, but the price of power batteries decreases by at least one-third from 2015 to 2020, which shows the rapid progress. Meanwhile, as shown in Fig.13, both the numbers of V2G-related and V2X-related literature in Chinese are overall in an upward trend from 2013 to the present, which also shows the rapid progress. The techno-scientific knowledge element dynamics also act as prerequisites and contents to participate in the niche-regime interaction, namely the competition for R&D funds. The research progress of EVs and ICE vehicles both depend on R&D funds. Therefore, the continuous research advances of EVs crowd out the R&D funds required by ICE-vehicle research. The fact also confirms this: the National Key Research and Development Program consists of 18 vehicle-related projects; three of them are related to FCVs or HEVs, and the rest is all related to EVs, but no one is related to ICE vehicles (MOST, 2021). Therefore, the niche-regime interaction of the techno-scientific knowledge elements is actually the competition for R&D funds between EV research and ICE-vehicle research, which makes the limited funding resources reallocated, and thus EV-related research can receive more funding support and the EV socio-technical transition are prompted.

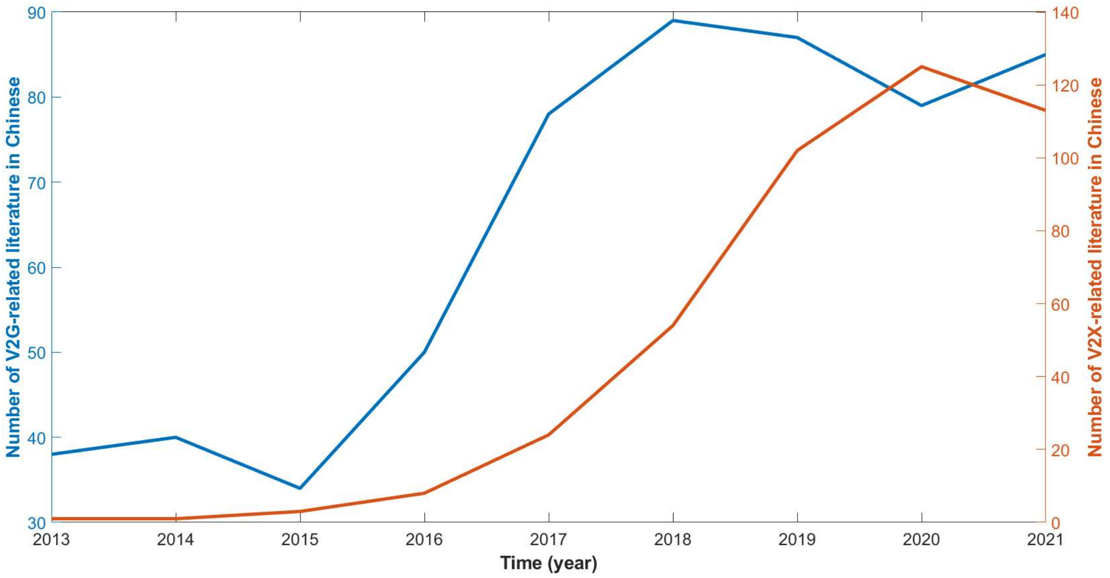

Figure 13 Numbers of V2G-related and V2X-related literature in Chinese
(data from China National Knowledge Infrastructure)

8.4 Dynamics of Technology Elements

As discussed above, the smog issue and energy security act as landscape developments to cause policy element dynamics, which includes the update of energy saving and pollutant emission reduction policy portfolio in 2012. Meanwhile, via the element interactions, the policy element dynamics further generate the techno-scientific knowledge elements, namely the research progress of exhaust pollutant emission reduction and fuel economy for ICE vehicles. Similarly, via the element interactions, the dynamics of policy and techno-scientific knowledge elements also generate the technology element dynamics, which are mainly changes in technical performance or product characteristics. Based on the analysis in Chapter 5, in the ICE-vehicle regime, the policy elements interact with the technology elements by establishing regulations to impose requirements for specific technical performance, and the techno-scientific knowledge elements interact with the technology elements by acting as a knowledge basis to improve technical performance. The updated policy portfolio of energy saving and pollutant emission reduction (2012 version) required the average fuel consumption of passenger cars to decrease from 8 liter fuel/100 km to 6.9 and raised the market access threshold of exhaust pollutant emissions for ICE vehicles (Central Government Portal, 2012c). Meanwhile, the research progress of crucial energy-saving and pollutant emission reduction technologies for ICE vehicles, such as turbocharged, direct-injection in the cylinder, idle start-stop and exhaust pollutant absorbing, acted as a knowledge basis for the subsequent improvement of technical performance, and this causes an annual continuous decline of fuel consumption and exhaust pollutant emissions shown in Fig.5. The policy element dynamics (stricter fuel consumption regulations) and the techno-scientific knowledge element dynamics (research progress) both work on improving the practical product performance. The improvement of product performance somewhat changes product characteristics of ICE vehicles, which means the disadvantages of high pollutant emissions and high fuel consumption as the "short board" of ICE vehicles are compensated to a certain extent. Therefore, the technology element dynamics (changes in product and technology characteristics) compensate for ICE vehicles' disadvantages and act as parts of the ICE-vehicle regime to sustain their dominant status.

Energy-saving and New Energy Vehicle Industry Development Plan (2012-2020) is the policy element dynamics mainly caused by the smog issue, and version 2021-2035 of the plan is the policy element dynamics mainly caused by climate change. Similarly, via the element interactions, these policy element dynamics also generate the techno-scientific knowledge elements, namely the research progress of advanced power batteries, V2G and related fast-charging technologies, V2X and smart interaction, etc. The techno-scientific knowledge element dynamics (EV-related research progress) further act as a knowledge basis to generate the technology element dynamics (improvement of technical performance and smart level for EVs). The fact is that the average range of EVs improved from less than 250 km in 2017 to close to 400 km in 2020 (as shown in Fig.9), and the overall market penetration rate of smart cockpits in China has reached over 50% by 2021 (Equal Ocean, 2021a). The crucial disadvantage of EVs, range anxiety, is gradually compensated by enlarging EV range, and the application of smart cockpits also becomes an advantageous characteristic of EVs. Subsequently, these techno-scientific knowledge element dynamics act as prerequisites and contents to participate in the niche-regime interaction, namely the competition for enterprise investment. For vehicle manufacturers, specific technical performance and product characteristics are bound to the corresponding technical path, and they have to choose one path to invest in from EVs and ICE vehicles due to the financial pressure. In this situation, EVs and ICE vehicles have to compete for enterprise investment. Although the issues of exhaust pollutant emissions and fuel consumption of ICE are alleviated to a certain extent, in the long run, this alleviation is not sufficient to continue to meet the public expectations for reaching the “3060” target in the future. Meanwhile, the range and smart level of EVs are greatly improved, which are mostly concerned by consumers. Therefore, corporate capital is gradually favoring investment in EVs, though the low-temperature effect and charging time of their power batterie are still the disadvantages of EVs in the competition with ICE vehicles. The actual situation also confirms this, as shown in Fig.14, the enterprise investment for EVs in China increased from 1.47 billion RMB in 2014 to 82.71 billion RMB in the first half of 2021. Therefore, the niche-regime interaction of the technology elements is actually the competition for enterprise investment between EV technical path and ICE-vehicle technical path, which makes the limited investment resources reallocated. EVs receive more enterprise investment and more EVs are produced, which prompts the EV socio-technical transition.

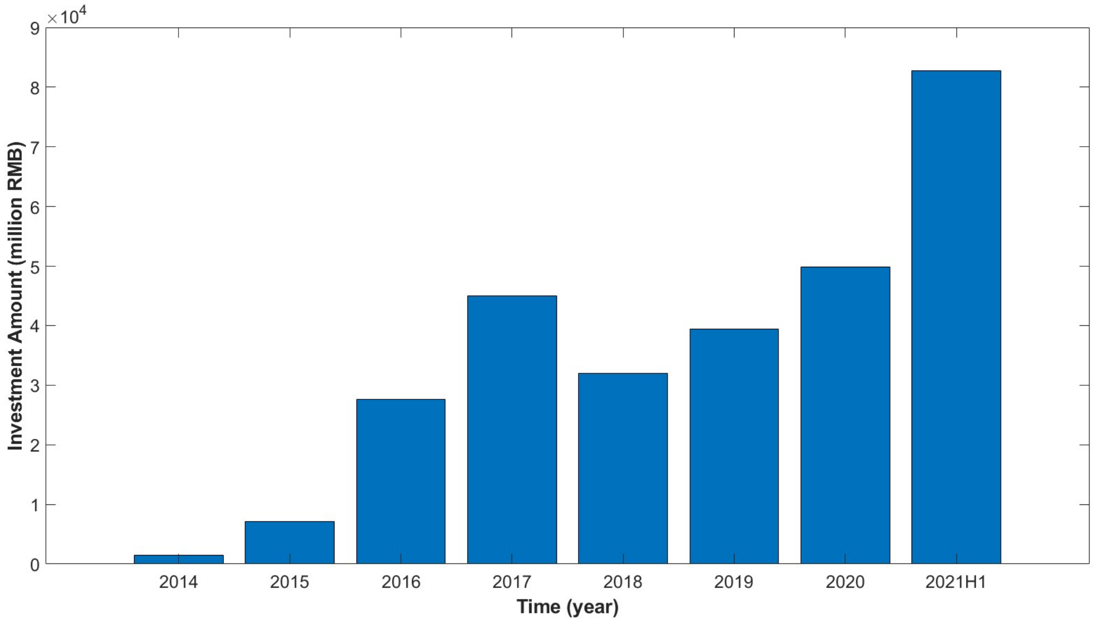

Figure 14 EV enterprise investment amount in China

(Intelligence Research Group, 2021)

8.5 Dynamics of Industrial Network Elements

Climate change makes ICE vehicles, as one of the most significant carbon emission sources, become a main focus of the related policy. Although the current policy environment still allows ICE-vehicle manufacturers to produce and sell their cars, policy uncertainties in the future, such as ICE-vehicle ban, are what ICE-vehicle manufacturers worry about and fear. Therefore, climate change act as landscape developments to apply pressure on ICE-vehicle manufacturers in the form of creating policy uncertainties for them. Under this landscape pressure, ICE-vehicle manufacturers as affected actors to respond, and the industrial network element dynamics emerge, namely ICE-vehicle manufacturers actively start EV-related business and diversify their revenue sources to hedge the risks of policy uncertainties, such as Chang'an Automobile's EV business. Besides the cooperation with CATL and Huawei that started in 2021, they are also cooperating with an EV manufacturer (NIO) to start another EV brand, and they complement each other's strengths (Xinhua Net, 2021b), such as the matured and reliable automotive chassis of Changan Automobile and advanced smart cockpits of NIO. ICE-vehicle manufacturers' EV-related business makes them act as new actors being integrated into the EV industry or supply chains, which means the industrial network element dynamics actually act as prerequisites and contents of the network configuration. The regime-niche interactions gradually change the industry layout for both ICE vehicles and EVs, which allows EVs as niche technologies to diffuse both in ICE-vehicle and EV Enterprises and further prompts the EV socio-technical transition.

8.6 Dynamics of Infrastructure Elements

As analyzed above, climate change as landscape developments generates the policy element dynamics of EV niche cluster, and via the element interactions the policy element dynamics further generate the techno-scientific knowledge element dynamics, which refer to the research progress of advanced power batteries, V2G and related fast-charging technologies, V2X and smart interaction, etc. Based on the element interactions of the EV niche cluster discussed in Chapter 6, the techno-scientific knowledge elements can interact with the industrial network elements, while the techno-scientific knowledge elements can interact with the infrastructure elements, which means V2G and related fast-charging technologies and V2X act as the knowledge basis for charging station manufacturers and operators to produce charging stations and optimize their operation. When the research progress of V2G and related fast-charging technologies and V2X as the techno-scientific knowledge element dynamics is applied for the practical production, more high-performance charging stations are produced and operate at a more efficient status to optimize the whole charging system, which is the infrastructure element dynamics. Therefore, the techno-scientific knowledge element dynamics generate the infrastructure element dynamics via the element interaction, namely applying research progress for the practical production. However, the optimization of the whole charging system operation requires more charging stations to be connected with the network and more EV users to actively participate in the network operation to gain larger optimization flexibility and perform better, because the efficient operation of the charging infrastructure system depends on a large number of users. These users usually used to be ICE-vehicle users bundled with the refueling infrastructure system. Therefore, the infrastructure element dynamics of the EV niche cluster also participate in the niche-regime interaction, namely user competition, to reallocate limited resources. Actually, until 2020, the V2X-based smart charging station system built by the State Grid has become the largest EV charging system in the world, accessing more than 1.03 million charging stations, covering 29 provinces and 273 cities and serving 5.5 million EV users (SASAC, 2020). The user resources are reallocated in the process of user competition, and thus the EV charging infrastructure is cultivating a larger user base, which is beneficial to EV diffusion and can prompt the EV socio-technical transition.

8.7 Dynamics of Market and User Elements

Based on the element interactions of the EV niche cluster analyzed in Chapter 6, the technology elements and infrastructure elements can interact with market and user elements via offering products and service, improving user experience and reshaping user mind, and this allows the dynamics of these elements to generate market and user element dynamics. Based on the above product analysis of smart cockpits developed by Huawei, the application of smart cockpits allows drivers to control almost everything in vehicles through gesture and voice and send commands to fulfill diverse functions in different scenarios, such as real-time navigation, adaptive cruise, lane departure warning, automatic lane change, collision Warning, pedestrian detection and automatic parking, etc. The application of smart cockpits is a significant indication of the technology element dynamics (improvement of smart level for EVs). When experiencing the smart level of EVs (the interaction via offering products and service), the users' perception of "vehicle" is expanded from traditional fields, such as driving, speed and range, etc., to new minds, such as human-vehicle interaction and smart assistance, etc. The expanded or reshaped user perception is a part of market and user element dynamics, and the above process shows how technology element dynamics generate them. The enlarged EV range as a part of technology element dynamics also generates market and user element dynamics, namely market competitiveness increase, by improving user experience, and these dynamics subsequently become parts of the EV niche cluster. Meanwhile, the V2G and V2X-based charging stations as the infrastructure element dynamics make users experience the charging service different from refueling ICE vehicles and users can gain financial benefits by fulfilling demand response for the charging system and grid, which shows the interaction of infrastructure elements with market and user elements. The experience with economic incentives is gradually cultivating new user habits, such as being accustomed to the bidirectional flow of power, information and finance with the charging system, and the new user habits is also a part of market and user element dynamics. For example, based on the research of EV user charging behavior in China, with the support of networking and sharing information 86.8% of EV users choose to complete one charge in the cross-operator form. (EVCIPA, 2021b), which is in stark contrast to the user habit, completing one refueling in one station, cultivated by ICE-vehicle use. Therefore, the infrastructure element dynamics (the V2G and V2X-based charging system) generate the market and user element dynamics (new user habits) via the element interaction (offering charging service and new user experience). Some above market and user element dynamics also further participate in the niche-regime interactions. Since the potential consumers for both EVs and ICE vehicles are mostly overlapping, and the user mind and perception changed by smart cockpits and the user experience of charging service can be discussed, shared and spread among these potential vehicle consumers, and thus the new user mind, perception and experience all take the technological configuration and reshape the user part of the whole vehicle industry environment, which prompts the EV socio-technical transition.

Similarly, the culture elements, techno-scientific knowledge elements and policy elements can also generate the market and users element dynamics via element interactions. As analyzed in Chapter 6, public opinion as the culture elements can shape value identity and affect consumer behavior, and consumer behavior is categorized as the market and user elements; research progress of EV-related technologies and subsidies as techno-scientific knowledge elements and policy elements can lower manufacturing and purchase costs to improve price competitiveness of EVs, which is also categorized as the market and user elements. The increasing public concern about carbon emissions as the culture element dynamics of the EV niche cluster reshapes consumers' value identity and makes purchasing EVs attached with a new value, namely the environmental responsibility and moral satisfaction of carbon emission reduction, and thus they become significant factors of EV purchase intention, which can be confirmed by the research by He, Zhan and Hu (2018). The research progress of EV-related technologies (e.g. power batteries) and EV encouragement and promotion policies (e.g. purchase subsidies and credit trading) decrease EVs' manufacturing costs and purchase costs, and the fact is that the pricing of EVs in China has decreased by 47% since 2011 (JATO Dynamics, 2021). Therefore, newly added value and decreased EV costs are parts of the generated market and user element dynamics. Meanwhile, oil price volatility acts as a landscape factor to generate market and user element dynamics. Vehicle consumers are quite sensitive to fuel costs, and even short-term oil price increase can directly increase their financial burden, which makes them tend to choose EVs for reducing fuel costs (Soltani-Sobh, Heaslip, Stevanovic, Bosworth, & Radivojevic, 2017), such as the recent gasoline and diesel price increases of more than 60% in China (Central Government Portal, 2022). Thus, the pressure of oil price rise makes vehicle users have to make responses, which shows the landscape interaction with market and user elements, and vehicle users' actions (choosing EVs) are the result of the interaction and also a part of market and user element dynamics. The above market and user element dynamics also participate in the niche-regime interactions, and newly added value, decreased EV-related costs and desire of hedging against fuel price volatility all make EVs gradually become attractive for ICE-vehicle users, which further helps EVs capture users from the subsidized ICE-vehicle market and break technology lock-in. The process of user competition and reallocating resources allows

EVs to gain more users than in the past and prompts the EV socio-technical transition.

This chapter applies the interaction mechanism proposed in Chapters 4 to 7 to answer sub-question 5 *How does the dominant regime change?* and sub-question 6 *How does the niche cluster change?* What element dynamics emerge and their effect on the socio-technical transition are two key aspects focused on in this chapter. Overall, the landscape developments cause some element dynamics of the ICE-vehicle regime and EV niche cluster, and via element interactions these element dynamics affect other elements and generate more dynamics. Some element dynamics involve only one of the ICE-vehicle regime or EV niche cluster and become parts of the regime or niche cluster to sustain ICE vehicles' dominant status or help EVs develop. However, other element dynamics act as prerequisites and contents of the niche-regime interactions to affect the EV socio-technical transition. The **policy** element dynamics include the updated policy portfolio, travel and license restriction exemption, national industry development plans and credit trading, and they take the institutional reconfiguration to reshape the policy part of the industry environment. The **culture** element dynamics are the public awareness of vehicle emissions and clean transportation that is reshaped twice, and they take the transformation interaction to reshape the public opinion environment of the vehicle industry. The **techno-scientific knowledge** element dynamics include the research progress of ICE-related and EV-related technologies, and they take the R&D fund competition to reallocate limited funding resources. The **technology** element dynamics include the technical performance improvement and product characteristics changes, and they take the enterprise investment competition to reallocate investment resources. The **industrial network** element dynamics refer to ICE-vehicle manufacturers starting EV-related business, and they take the network reconfiguration to change supply chains and industry layout. The **infrastructure** element dynamics are the optimized operation of the whole charging system, and they take the user competition to reallocate infrastructure user resources. The **market and user** element dynamics include reshaped user mind and perception, new user experience, newly added value, decreased EV-related costs and desire of hedging against fuel price volatility, and they take the technological configuration and user competition to reshape the user part of the whole industry environment and reallocate vehicle user resources. The above processes of industry environment reshaping, industry layout adjustments and industry resource reallocation all favor EVs, and thus prompt the socio-technical transition for EVs in China.

9 Discussion

9.1 The MLP Framework and Niche-regime Interactions

According to the research by Geels and Kemp (2007), niche dynamics can be observed in a progressive process that learning processes with niche technologies on multi-element dimensions first emerge, subsequently elements supporting niche technologies link together and interact with each other, and finally niche technologies break through and change the regime. However, this thesis focuses on EV development in China in a period from 2012 to the present, when there are already niche elements interacting with each other and EVs as a niche technology have been maturely commercialized and are experiencing rapid growth in the ownership and market share, and thus niche dynamics of niche formation or the learning process are not studied. Rather than focusing on the whole progressive process of niche formation, niche growth and niche breakthrough in the original MLP framework, the MLP framework applied in this thesis intends to analyze supporting element dynamics of niche growth. Therefore, the concept of the niche cluster is proposed to describe and represent a system consisting of supporting elements and the niche technology, which can avoid treating the niche technology as a separate entity interacting with the regime and ignoring element details. For the case of EV development in China, the EV niche cluster and ICE-vehicle regime are like two interacting socio-technical systems, and due to that the niche cluster and regime both consist of supporting elements (technology, market & user, culture, infrastructure, industry network, policy and techno-scientific knowledge) the concept of the niche cluster allows us to analyze niche-regime interactions element by element.

Three niche-regime interactions (reconfiguration, transformation and competition) are proposed and applied for the case study, and the niche-regime interaction mechanism intends to unify and integrate some previous empirical analysis and conceptualized results. Firstly, as for **reconfiguration interactions**, the concept of reconfiguration is first proposed by Geels and Schot (2007), and it is used to identify a socio-technical transition pathway, which represents the scenario that niche innovations are adopted into the regime to resolve local problems. A similar concept is proposed by Smith (2007), namely translation, which means niche elements being selectively integrated into the regime. This thesis aims to analyze the niche-regime interactions in the dimensions of all elements, and thus the concept of reconfiguration is adjusted as a process of novelty from the niche elements being supplemented into the regime or novelty from the regime elements being integrated into the niche cluster. Compared to the unidirectional concept of reconfiguration applied to identify the socio-technical transition pathway, the adjusted concept describes a bidirectional interaction between the niche and regime at the element dimensions, which allows us to examine if there are interactions for each element. The bidirectional and muti-dimension characteristics fit the previous research, such as Mylan et al. (2019) argue that the niche-regime interactions can be bidirectional and have effects at different dimensions, and Proka et al. (2020) also think identifying different dimensions of interactions is necessary. Meanwhile, the reconfiguration interactions are further divided as three categories, namely institutional, network and technological reconfiguration. The proposal of the three categories is inspired by the concept of anchoring proposed by Elzen et al. (2008), and they define anchoring as the links or interactions between niche and regime elements and conclude that anchoring contains three forms, namely institutional, network and technological anchoring. The definitions and categories of the three anchoring forms are integrated into the categories of reconfiguration interactions to serve the analysis of niche-regime interactions. Among three categories of reconfiguration interactions, the network reconfiguration fits the most previous literature's analysis, and in this thesis it refers that the ICE-vehicle regime actors participate in the EV niche cluster, which is consistent with the concepts of boundary bridgers proposed by Negro and Hekkert (2014), bridging strategies proposed by Berggren et al. (2015) and intermediary projects by Nykamp (2017). Meanwhile, it is also consistent with the results of empirical analysis by Diaz et al. (2013), Smink et al.

(2015), Bui (2018) and Warneryd and Karltorp (2020), namely incumbent regime actors actively participate in niche innovation actives is a common situation of niche-regime interactions. Secondly, as for **transformation interactions**, the concept of transformation is also proposed by Geels and Schot (2007) to identify a socio-technical transition pathway, which represents the scenario that regime actors change the directions and paths of the dominant technology's innovation activities to cope with the pressure when landscape pressure emerges but niche technologies are still not sufficiently developed. However, the concept of transformation proposed by Geels and Schot (2007) is not applicable for analyzing the niche-regime interactions, and thus a new definition of transformation interactions is proposed in this thesis to serve the analysis, which refers to the process of some parts of the original structure being completely replaced by something novelty (not introducing the novelty to supplement the blank fields not covered by the original structure). Thirdly, as for **competition interactions**, a lot of previous research has involved the competition interactions, such as the empirical analysis by Kemp et al. (2011), Dijk (2014), De Laurentis (2015), Pant (2016), Maye and Duncan (2017), Schäfer and König (2018), Pekkarinen and Melkas (2019) and Ruggiero et al. (2020); the research conclusions tend to be consistent at the type of interactions, and they call the interactions as competitive, oppositional, resistant or confrontative interactions. The definition of the interactions in this thesis is not different from previous research, which refers to the process of the niche cluster and dominant regime competing for limited and desired resources. The above niche-regime interactions are proposed as a part of the interaction mechanism to explain how and why dynamics of the socio-technical transition emerge.

In this thesis, the niche-regime interactions are only shown in the forms of the interactions of the same types of niche and regime elements, but it is possible that there are interactions of different types of elements. For these cross-linkages, it is still sufficient for the current framework to explain them. For example, the credit policy (niche policy element) can apply revenue and financial pressure on ICE-vehicle manufacturers (regime industrial network element). Based on the framework in this thesis, the explanation can be that the credit policy (niche policy element) is first integrated as a part of regime policies (merged with the ICE-vehicle fuel economy regulations into the parallel credit administration measures) via the institutional reconfiguration (one of the niche-regime interactions), and subsequently the parallel administration measures of CAFC and NEV credits (that are both regime and niche policy elements) affect the ICE-vehicle manufacturers (regime industrial network element) via the element interaction within the regime. Therefore, the cross-linkages between the niche and regime levels can be explained as **Niche Element A – Regime Element A – Regime Element B** instead of **Niche Element A – Regime Element B**. If all these cross-linkages are proposed as niche-regime interactions, there will be as many niche-regime links as element interactions within the regime or niche, which makes it quite hard and a huge work to categorize and conceptualize them. Therefore, the framework of niche-regime interactions is proposed as such in this thesis.

With the niche-regime interactions, an integrated landscape-niche-regime interaction mechanism can form to allow us to analyze the cross-level interactions of the MLP framework, which is shown in Fig.15. The landscape factors impose pressure on the regime and niche cluster, and the niche cluster bidirectionally interacts with the regime. The landscape pressure is the driving source of the socio-technical transition for EVs in China, and the niche-regime interactions allow the EV niche cluster and ICE-vehicle regime to co-develop in an adaptive and competitive form, which requires element dynamics of the two socio-technical systems to emerge, because the co-development is neither necessary nor possible if all elements do not change. Therefore, element dynamics act as prerequisites and contents of the niche-regime interactions, and the co-development also allows EVs to gradually gain socio-technical advantages and leads to the increasing EV penetration in the vehicle market, which shows how the transition takes place.

Besides the above, a conceptualization of the effects of niche-regime interactions on the socio-technical transition is also taken based on the case of EV development in China. Three types of effects are proposed, namely industry environment reshaping, industry layout adjustments and industry resource reallocation. The conceptualization is essentially conducted with enterprises at the core. Firstly, the industry environment includes the policy environment, public opinion environment and user mind environment for the case of EV development in China. The policy environment determines what policy benefits or interventions enterprises will receive, such as the credit policy bringing additional revenues for EV manufacturers or restricting the production of ICE-vehicle manufacturers. The public opinion environment determines if the products of enterprises can be consumed with the support or resistance of the public, such as EV consumption being supported by ethical responsibility of environmental protection and moral satisfaction. The user mind environment refers to a collection consisting of potential consumers' perception of the use and performance, etc. of one type of products, and it determines if the products of enterprises can be identified as the products meeting their needs by potential consumers, such as an EV with a smart cockpit rather than an ICE vehicle without it can meet the need for car intelligence. Secondly, the industry layout refers to the actors involving production and supply and the resulting chains or networks, and it determines the position of an enterprise in the chains or networks and the business scope in the industry, such as ICE-vehicle manufacturers starting EV business can change the industry layout. Thirdly, industry resource involves enterprise investment, user bases and R&D funds in this case, and it is significant for enterprises to decide to invest in which technical paths with limited funds, capture users to take more market shares and cooperate with research institutions receiving more national R&D funds. Therefore, industry environment, industry layout and industry resources are actually crucial indicators of an industry, and that is also why their changes are conceptualized as significant aspects of the socio-technical transition.

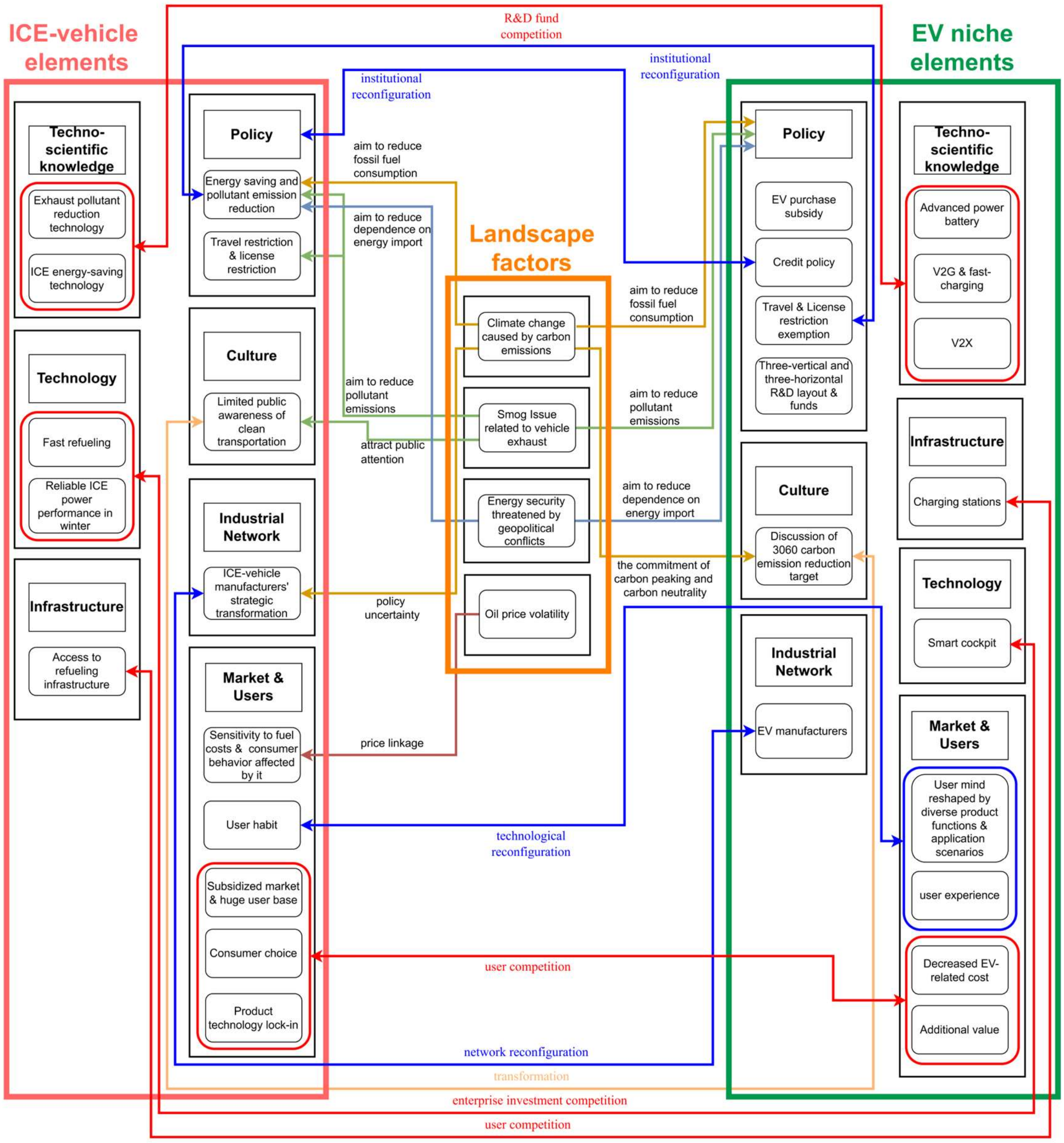

Figure 15 The landscape-niche-regime interaction map

9.2 The case of EV Development in China

This thesis focuses on the case of EV development in China, and thus some main findings and insights that are highly relevant to the case are proposed in this sub-chapter. There are four findings, involving the smog issue and related policies, the "3060" target and related policies, the transformation of public environmental perception and EV intelligent and networking development. The dominant landscape factor of EV development in China experiences a change from the smog issue to climate change, and the change shows the differences in dominant landscape factors between EV development in China and other countries at the early commercialization stage, namely air pollution acts as the external pressure source for China but climate change does for other countries. Meanwhile, due to the change in dominant landscape factors, there is a transformation in the public perception of emission definitions, which may be different from the situation that the concern of carbon emissions does not experience changes in other countries. As for the intelligent and networking development of EVs, compared to other sustainable technologies' developments in performance, it is not only improving EVs' performance but also changing the user mind of driving. Therefore, these findings discussed in this sub-chapter all involve some differences in this case from other cases, and that is why compared to other findings merely supported by collected data and information and empirical analysis in this thesis they are particularly validated by interviews. In the following, for each topic and finding, the analysis based on this case is first proposed, and subsequently they are discussed and validated based on interviews, and finally they are compared with the previous literature and insights to discuss their generalizability.

The smog issue and related policies

The smog issue emerging in 2012 as a landscape factor offers EVs in China a window of opportunity to develop. Before the smog issue, although with the support of the three-vertical and three-horizontal R&D layout proposed in 2001 and the 'Ten Cities Thousand Vehicles' plan proposed in 2009 there were already some pilot projects of

EVs and resulting technology accumulation, it was still hard for EVs to penetrate the market without public expenditure procurement. But the travel and license restrictions for ICE vehicles to alleviate the smog issue and subsequent restriction exemptions for EVs made some consumers who could not stand restrictions to become EV users, which enlarged the niche market of EVs. The traffic and license restrictions that originate during the period of rampant smog are still being implemented nowadays to promote EVs.

As for the insight that the smog issue acts as a window of opportunity for early commercialization of EVs in China, the interview validates it. Based on the interview, the travel and license restrictions for ICE vehicles aiming to alleviate the smog issue promote EV commercialization in China, but the early commercialization scenarios of EVs and the resulting growth in the EV number are limited, such as the transportation in golf courses, in-port logistics and confined industrial parks (Interviewee Y, personal communication, June 5, 2022). Therefore, it can be known that although the early commercialization of EVs in China does not start from the mainstream passenger car market the smog issue and restriction policies are significant drivers to the early EV applications. Meanwhile, the interview with the business manager of an EV enterprise validates that the traffic and license restriction exemptions are the crucial motivation for consumers to purchase EVs, because the interviewee mentions that a lot of consumers exactly express their dislike with two to three years of queuing for car licenses and travel restrictions with salespeople when they buy EVs (Interviewee F, personal communication, June 5, 2022). Thus, it can be known that the travel and license restrictions for ICE vehicles and the restriction exemption for EVs are still being implemented nowadays as effective measures to serve EV development.

Wu et al. (2021) propose climate change, carbon reduction targets and energy shortages, etc. as landscape factors when applying the MLP framework to analyze the NEV development in China. Compared with the research by Wu et al. (2021), in this thesis the smog issue in the period from 2012 to 2018 is seen as a dominant landscape factor in the early commercialization of EVs in China, and the travel and license restriction policies for alleviating the smog issue created potential consumers at that period. The insight that the window of opportunity is opened by the smog issue is also valid for other sustainable innovations in China, because solar and wind generation were ever applied to reduce coal-burning generation and alleviate the smog issue, and their installation also experienced an increase after the smog issue emerged (Zhu, Xu, & Pan, 2019), and they currently serve carbon peaking and carbon neutrality in China. Meanwhile, the travel and license restrictions for ICE vehicles and restriction exemptions for EVs can also be implemented in other countries to incentive consumers to purchase EVs, because vehicle application scenarios and some factors of consumer behavior may tend to be similar in different countries.

The "3060" target and related policies

Climate change and the "3060" target are the immediate cause of EV prosperity in China. EVs are not only treated as an auxiliary measure of the frame of energy saving and pollutant emission reduction but are seen as a crucial policy focus to reach the "3060" target. Especially, the increasing NEV credit trading and the long-term plan for the ban on the sales of ICE vehicles generate the enthusiasm of the market and enterprises, because compared to mere EV subsidies rejecting EVs currently means fines, revenue loss and even losing the entire market for vehicle manufacturers.

The interviews reveal why the 3060-related policies, namely the NEV credit trading and the long-term plan for the ban on the sales of ICE vehicles, can foster EV prosperity in China. The credit policy is continuously compressing traditional ICE-vehicle manufacturers' profit margins and thus limiting their production scales, and it also lowers the confidence of the capital market and investors for traditional ICE-vehicle enterprises and their financing abilities, which may cause problems in their capital chains (Interviewee F, personal communication, June 5, 2022). Meanwhile, there is a plan held by the government to ban the sales of ICE vehicles in 2035, and the increasingly stricter fuel economy standards are a progressive pavement for the plan, especially the current fuel economy requirements for passenger cars have been raised to the level where it is hard to meet by ICEs alone (Interviewee Y, personal communication, June 5, 2022). Therefore, traditional automakers actually face the increasing pressures from financing capacity and technical requirements, and that is why they have to start the electrification transformation, which causes the prosperity of EVs on the production side. The two policies both aim to serve the “3060” target and curb climate change, and thus the interviews about these policies also validate that after the smog issue is mostly alleviated climate change is acting as the most significant landscape factor for EV development in China.

Xue, You and Bi (2012) also propose energy supply security, environmental stresses and oil prices, etc. as landscape factors, but they do not analyze their emerging and affecting time and which one dominates. Compared with their research, this thesis proposes that energy security and oil price act on the entire transition process but do not play a significant role, and the smog issue emerged as a dominant landscape factor in 2012, and after the smog issue is mostly alleviated, climate change acts as the last and most significant landscape factor to affect the transition process. The research by Tyfield (2014) and Tyfield and Zuev (2018) are both focused on the impact of political and power elements on the EV development in China, and they hold that top-down technology plans issued by the government are not sufficient to completely drive the transition process. As for the role of the government, Rao (2020) holds that the government should implement purchase subsidies and government procurement. This thesis agrees with that relying solely on top-down government technology plans and financial subsidies is less effective in promoting the development of EVs. Compared with their research, this thesis further proposes related policy-making recommendations for the government: Policy-making should empower the market and apply market mechanisms to allocate resources to support EV development, rather than merely offering subsidies under government leadership, and thus it is more efficient to both implement the credit trading policy and EV purchase subsidy policy. The insight that climate change acts as a landscape factor of energy transition and related analysis in this thesis can be generalizable to sustainable innovations in China and other countries, and actually including China most of countries treat applying EVs and other sustainable innovations (e.g. solar and wind generation) as crucial measures to cope with climate change. Meanwhile, the Zero Emission Vehicle (ZEV) program in America is quite similar to the credit policy in China, and it similarly requires vehicle manufacturers to sell EVs and allows them to gain tradeable credits (ARB, 2022), which means the analysis of the credit policy in this thesis can be generalizable to EV development in other countries where similar policies are implemented. As for the relationship between fuel economy regulations and EV development, the generalizable analysis in other countries depends on if the related technical requirements are raised to a sufficient level and how quickly they are raised.

The transformation of public environmental perception

The transformation of the public opinion from disregarding carbon emissions to attaching importance shows the significance of landscape developments. The limited public perception of emissions and clean transportation shaped by the smog issue and the related air quality regulations is gradually transformed after the smog issue is alleviated and resolved, and CO2 starts to become a new public concern, which is a beneficial public opinion environment for EV development.

During the period of rampant smog, the public consensus of environmental protection formed as such, harmful pollutant emissions are the reason why ICE vehicles are not environmentally friendly; the public consensus starts to gradually change till the proposal of the “3060” target, and the public starts to concern of carbon emissions (Interviewee Y, personal communication, June 5, 2022). The interview Y’s views validate that there is a transformation of public perception of emissions in progress, and carbon emissions are entering the field of public attention compared to the past when the public only focuses on harmful pollutant emissions. But it is worth noting that the public perception transformation may not be crucial for the EV development in China, at least in terms of motivating consumers to choose EVs the public perception and opinion cannot impose a stronger impact compared to other factors, which is validated by the interviewee's sales experience, namely there is almost no consumer who buys an EV simply for the sake of environmental considerations, but they care more about price concessions, policy favors and product performance (Interviewee F, personal communication, June 5, 2022).

For the impact of public perception and public opinion, Xue, You and Shao (2014) hold that convenience, freedom and comfort are more significant drivers than environmental pursuits for Chinese consumers to purchase vehicles. Compared with their research, this thesis not only validates the less dominant status of environmental protection as a driver of vehicle consumption, but also captures the transformation of public perception of vehicle emissions and public opinion on environmental protection, and the large mitigation of the smog issue and the increasing focus on climate change are explained as the reason of this transformation. The insight about public perception and opinion transformation and the smog issue shaping limited public perception is also generalizable to other energy technologies in China. For example, the pollutant emissions of coal-burning generation were ever treated as smog sources, and ultra-clear emission coal-burning generation (almost without emissions of NOx, SO_2, PM10 and PM2.5) was similarly also seen as a clean power source by the public, because before the "3060" commitment the public perception of emissions in China was limited. The analysis of the public opinion transformation may not be valid for the cases in other countries, and that depends on air quality and the specific regulations of emissions in those countries.

EV intelligent and networking development

Intelligent and networking development is a noteworthy tendency for EVs in China. The intelligent development allows drivers to interact with their cars more efficiently, and more application scenarios of smart cockpits emerge; the networking development represented by V2G and V2X bidirectionally links EVs with the grid and charging infrastructure platforms on the power and information flow to optimize power resource dispatch and serve drivers. The intelligent and networking development integrates humans, vehicles, roads and infrastructure as a whole system, which changes user experience, cultivates user habits and reshapes user mind.

The interview with the business manager reveals the links between EV intelligent development and user experience. The smart cockpit system can assist in the driver's driving decisions and making charging plans, and thus it makes driving more convenient and smarter than before; users will naturally bind the comfortable experiences and services with driving, which can change the user mind of driving (Interviewee F, personal communication, June 5, 2022). Therefore, EV intelligent development represented by the smart cockpit system mainly changes the driving experience of users and make them change their perception of driving. Meanwhile, as interviewee Y’s views, EV networking development represented by V2X and V2G mainly affects users’ charging habits. There have been a lot of V2X and V2G projects serving EV networking development in China, and the charging habits of users are being reshaped by these networking platforms and services, such as users’ charging time and frequency can be flexibly adapted to assist in the optimal operation of the power system (Interviewee Y, personal communication, June 5, 2022). Thus, it is validated that EV intelligent and networking development changes user experience, habits and mind of driving and charging.

Wu et al. (2021) also think that software-defined vehicles should be a significant development direction of EVs, and artificial intelligence rather than things like horsepower and mechanical performance gradually becomes more core elements of a car. Compared with their research, this thesis further analyzes the impact of EV intelligent development on users, and finds that intelligent development represented by the smart cockpit systems is cultivating new user habits and reshaping user mind. The analysis of technological reconfiguration and intelligent and networking development is only valid in EV fields, because V2G, V2X and smart cockpits are bundle with EVs' technical characteristics or application scenarios, and actually these technologies aim to serve EVs. For the countries where intelligent and networking development of EVs emerges, the similar analysis logic may be applied, such as Europe with a V2X market size of $2405.1 million in 2020 (Research and Markets, 2021), and the development can bring changes of user experience, user habits and user mind.

9.3 Recommendations for Stakeholders

Based on the analysis of the case of EV development in China, there are several recommendations for related actors. For the government, firstly, it is more efficient to combine the market mechanism (credit trading) with EV purchase subsidies for EV promotion, because the former can impose revenue and financial pressure on ICE-vehicle manufacturers, drive them to start EV business and also give EV manufacturers the opportunity to gain the additional revenue, and the latter can encourage consumers to choose EVs and enlarge market demand for EVs. Therefore, it is necessary to increase fuel economy requirements and make the traditional ICE-vehicle manufacturers have to offset more negative credits, which incentive and accelerate their electrification transformation, so that the enterprise investment for EVs and EV supply can be further enlarged. Meanwhile, offering more purchase subsidies to the consumers of low to mid-priced EVs is also necessary, which aims to make EVs affordable for more vehicle consumers and enlarge EV demand. The combination of increasing credit trading and more EV purchase subsidies will both increase the supply and demand of EVs to increase their market share. Secondly, the three-vertical and three-horizontal R&D layout and related research funds offered by the government are significant for knowledge accumulation, technology progress and technical performance improvement. Therefore, it is necessary to offer more national research funds for crucial technologies, such as EV range enlarging, fast charging of power batteries, intelligent human-vehicle interactions and networking system optimization. Lastly, travel and license restriction exemptions are a significant factor to incentive consumers to choose EVs. Thus, the travel and license restrictions for ICE vehicles and restriction exemptions for EVs can be implemented in more cities to create potential consumers for EVs, which similarly aims to enlarge EV demand.

For enterprises, strategic transformation, business cooperation and product improvement can be their subsequent focuses. Strategic transformation means that traditional ICE-vehicle manufacturers start EV business to hedge the risks of policy uncertainties and seize EV business opportunities. The traditional ICE-vehicle manufacturers have mature R&D teams and technology accumulation in automotive general technologies, and they also have established a complete set of vehicle sales channels. But they do not have technical advantages in electric motors, power batteries and electronic control systems, and thus a more favorable way for them to start their first step of electrification transformation is to jointly develop and produce EVs with motor and battery manufacturers and control system developers. Business cooperation means that EV manufacturers, charging station manufacturers, charging station operators and smart cockpit developers can cooperate to a set of driving and transportation solutions consisting of related products and services for end consumers. For example, EV manufacturers and charging station manufacturers take joint sales activities and sell EVs and private charging stations to consumers as a product portfolio, which can both increase the penetration rates of EVs and charging infrastructure. Meanwhile, charging station manufacturers can pre-install information interfaces with public charging station platforms managed by charging station operators in private charging stations, and with the authorization of charging station owners this allows the new mode of private charging station sharing, which will improve the access to charging resources for EVs. Similarly for the smart cockpit developers, they can pre-install information interfaces with charging station platforms in the smart cockpit system to support vehicle and driving information sharing, which fulfills the modes of V2G and V2X. Product improvement means that based on user feedback EV manufacturers choose to cooperate with component manufacturers and smart cockpit software developers to improve product performance or independently develop related components and system software, such as developing more affordable product designs to apply fast charging technologies and increase charging speed, developing high energy density and large capacity power batteries to enlarge EV range or increasing the rate of smart cockpit adoption in low to mid-priced EVs.

For vehicle consumers, electrification, intelligent and networking development of vehicles are inescapable trends relevant to their transportation needs. For vehicle users whose driving is mainly for intra-city commuting, choosing EVs as an alternative to ICE vehicles is a quite beneficial user strategy. Currently, the crucial EV performance (i.e. range and charging speed) can totally satisfy these users' transportation needs, and they can also be supported by a series of policy favors (e.g. restriction exemption and purchase subsidy). Besides that, in the face of continuous rise in gasoline prices, the cost of choosing EVs for urban commuting will be significantly lower than that of ICE vehicles. For consumers who plan to purchase EVs, EVs with smart cockpit systems are a more cost-effective option than those without any intelligent systems. Although EVs equipped with smart cockpit systems are usually more expensive, the smart cockpit systems can not only improve driving experience but also will become a basic requirement of access to the networking infrastructure supported by information sharing. For EV users, if their driving and vehicle data can be collected and shared with the networking platforms, V2X systems can make more intelligent decisions to optimize traffic guides and allocate charging resources. Actually, data security can be ensured via data masking, and thus they could be more tolerant of information sharing and help the networking development, which can also facilitate their transportation.

Besides that, adapting new charging modes is also necessary for them, such as splitting a 100% charge into multiple sessions and fulfilling the multiple charges at different charging stations, and EV users will be also motivated by economic incentives to adapt these charging modes, which act a part of demand response to optimize the grid operation.

9.4 Limitations and Further Research

In this sub-chapter, the limitations of this thesis are analyzed and the possible methods to improve them are thus proposed. Meanwhile, several potential directions for further research are also discussed.

Limitations

Firstly, as discussed in chapter 9.1 on the niche-regime interactions, the cross-linkages of different types of elements are not included and analyzed in this thesis though they can be explained by the current framework. But there may be some missed relevant insights of this case due to the not fully included cross-linkages. Take the cross interactions between niche technology elements and regime techno-scientific knowledge elements, EVs and their related technologies receive increasing enterprise investment, which may inspire researchers specializing in traditional automotive technologies to begin the cross-disciplinary research that related to both ICE vehicles and EVs, such as hybrid power technologies. This situation can be explained by the current framework: EV-related technologies capture more enterprise investment from ICE-related technologies via competition interactions, and the connections (e.g. knowledge transmission) between researchers specializing in traditional automotive technologies and ICE-vehicle enterprises starting the electrification transformation indicate for researchers technological routes that enterprises are eager to develop and promising research directions. The analysis of similar situations to the above cross-linkage and insights are not included in this thesis, and thus the possible method to improve this limitation is to apply the current framework to enumerate all possible cross-linkages and analyze them. Secondly, as discussed in chapter 9.2, only findings involving differences in this case from other cases are particularly validated by interviews, and other findings, such as landscape interactions, element interactions and niche-regime interactions are supported by collected data and information and empirical analysis. Since the data and information collected are not from a single source and they only involve one or several elements or interactions, it is feasible to analyze whether and how certain elements interact with each other based on them, but it is difficult to compare which of these interactions plays a more significant role in the socio-technical transition. Because the data and information from the single source cannot cover all elements and interactions, and it is also difficult to develop a consistent statistical caliber or comparison criteria for the data and information from multiple sources, hence there is the above limitation in this thesis. The possible method to improve it is to validate all these interactions through the interviews with cross-disciplinary experts and let them have their knowledge and experience to judge the significance of these interactions, and all their judgments and reasons can be applied for forming and supporting the final analysis results.

Further research

Firstly, there are only two socio-technical systems in this thesis, namely the ICE-vehicle regime and EV niche cluster, and the interaction mechanism consists of landscape interactions, element interactions within the regime and niche cluster and niche-regime interactions. But the technical paths of vehicles do not only include dominant ICE vehicles and thriving EVs, but also include HEVs and FCVs. As niche technologies in the vehicle field, HEVs and FCVs may constitute competitive relationships with EVs because of some resources they all need but are in short supply, such as potential users, or cooperative relationships with EVs when challenging ICE vehicles' dominant status. Therefore, the research on the interactions of different niche clusters (i.e. EVs, HEVs and FCVs) may be necessary, and the interactions will extend the interaction mechanisms in this thesis and adapt the MLP framework as a framework applicable for multi-technical paths, which can help deepen the understanding of the socio-technical transition of vehicles in China. Secondly, more conceptualized niche-regime interactions can be added or the existing niche-regime interactions can be examined via empirical analysis based on other cases. Due to the niche-regime interactions in this thesis being proposed based on the case of EV development in China, the conceptualization cannot include all types of niche-regime interactions of other cases, and thus further addition or examination is necessary. For example, some technological progress of ICE vehicles can also be applicable for HEVs, such as in-cylinder structure optimization of ICEs, and when it comes to the techno-scientific knowledge elements they can share R&D resources in a cooperative form instead of the competition interactions observed between EVs and ICE vehicles. The resource sharing or R&D cooperation may be further analyzed and conceptualized as a type of niche-regime interaction. For another example, through pipeline renovation the existing refueling stations for ICE vehicles can be upgraded to the infrastructure of gasoline and diesel refueling and hydrogen refueling, which can both serve ICE vehicles and FCVs. For the infrastructure elements, there is a symbiotic relationship between CE vehicles and FCVs, which may be further analyzed and conceptualized as a niche-regime interaction. Lastly, the effect of niche-regime interactions on the socio-technical transition of EVs in China can be conceptualized with other stakeholders at the core, such as the government, users and even multiple actors. The conceptualization in this thesis is essentially conducted with enterprises at the core, which means that how the business operations of enterprises are affected by the niche-regime interactions is the specific focus to analyze the niche-regime interactions' effects on the socio-technical transition of EVs in China. Therefore, industry environment, industry layout and industry resource, etc. that are directly related to how enterprises develop, produce and sell products are captured to analyze. But for other stakeholders, the analysis and conceptualization will be different. For example, compared with the enterprises that only care about business operations, the government is usually concerned with the effective mobilization of all related actors in the socio-technical transition process, and thus when with the government at the core how related actors' interests and behaviors are affected by the niche-regime interactions will be the specific analysis focus, such as whether research institutions will reorient their research, whether the public will support it, whether companies will be incentivized to invest in the technologies that the government plans to develop and whether local governments will actively cooperate with the central government's planning guidelines, etc. For another example, if with consumers at the core, how consumer behavior factors are affected by the niche-regime interactions will be the specific analysis focus, such as product performance, product prices, consumption attitudes and social aesthetics, etc. Therefore, it is possible that new insights and conceptualized results can be gained when switching the perspective of stakeholders.

10 Conclusion

This thesis aims to study the socio-technical transition for EVs in China from the perspective of interactions and dynamics, and based on the MLP framework a set of interaction mechanisms is proposed to explain how dynamics emerge and affect the socio-technical transition. The mechanisms include three parts, namely the interactions of landscape factors with the regime and niche elements, the element interactions within the regime and niche cluster and the niche-regime interactions. Based on the analysis of Chapters 4 to 8, six sub-questions are answered in the following.

1. *How does the pressure from landscape developments affect the dominant regime and niche cluster?*

   There are four landscape factors found in this thesis, namely climate change, smog issue, energy security and oil price. Energy security and oil price act on the entire transition process, and EVs are seen as an alternative to ICE vehicles by the government to reduce the dependency on oil imports and by the vehicle consumers to reduce fuel costs. But the international energy supply is not tight for the vast majority of the time and the pressure of oil price rise can be alleviated by high economic growth, therefore these landscape factors play a less significant role. Before climate change emerges as a landscape factor in China, the smog issue is a dominant landscape factor. It emerged in 2012 and directly affected public health, and the health hazards can be observed in a short period. Therefore, the ensuing widespread public concern led to great public opinion pressure, forcing the government to take the lead and start reacting. On the one hand, the travel and license restriction policy for ICE vehicles creates potential consumers for EVs, namely those who cannot stand the inconvenience of these restrictions, and thus EVs gained a window of opportunity for early commercialization. The interviews also validate that the smog issue acts as a window of opportunity for early commercialization of EVs in China, such as the EVs applied for transportation in golf courses, in-port logistics and confined industrial parks. On the other hand, the environmental performance of ICE vehicles is also improved due to the stricter vehicle pollutant emission regulations and technological progress of vehicle pollutant emission reduction funded by the government. Satisfied with the improvement in environmental performance and the subsequent great alleviation of the smog issue, the public also ignored the carbon emissions of ICE vehicles. After the smog issue is mostly alleviated, climate change acts as the last and most significant landscape factor for EV development to emerge in China. For coping with climate change, the government starts to treat EVs as an effective measure of reducing carbon emissions. The policy portfolio of energy saving and pollutant emission reduction is adjusted by the government and does not only contain stricter vehicle fuel economy requirements and vehicle pollutant emission regulations, but also proposes a target that by 2025 the sales of new energy vehicles (NEVs) will reach roughly 20% of total new vehicle sales. Meanwhile, Energy-saving and New Energy Vehicle Industry Development Plan (2021-2035) is proposed, and a series of policies, such as EV purchase subsidies, travel and license restriction exemptions, vehicle credit trading and deepening the R&D layout, is also proposed, improved or enlarged to encourage EV development. the "3060" target of carbon emission reduction directly causes a wide range of public concern and discussion about carbon emissions, and the public focuses on carbon emissions more than before. Meanwhile, the government's targets and actions for coping with climate change make ICE-vehicle manufacturers face more policy uncertainties, and thus they start to take strategic transformation, such as starting EV business or participating in the EV supply chain. The interviews also validate that climate change and the "3060" target are the immediate cause of EV prosperity in China and the NEV credit trading and the long-term plan for the ban on the sales of ICE vehicles both play a significant role of motivating traditional automotive enterprises to start electrification transformation. In a word, energy security and oil price are secondary landscape factors, and the smog issue and climate change emerge in succession as dominant landscape factors. The pressure from landscape factors acts on crucial actors, namely government, car manufacturers, consumers and the public, and thus these actors have to make some responses, which lead to element dynamics of the ICE-vehicle regime and EV niche cluster.

2. *How do regime elements interact with each other?*

(1) The policy elements interact with culture, technology, techno-scientific knowledge and market and user elements. The policy portfolio of energy saving and pollutant emission reduction leads and shapes the public opinion and makes the public usually ignore the issue of carbon emissions, because the related regulations on vehicle emissions are limited to harmful pollutants. The interviews also validate that during the period of rampant smog the public consensus on environmental protection shows in the form of the concern of harmful pollutant emissions instead of carbon emissions. The policy portfolio also requires car manufacturers and fuel suppliers to apply energy-saving and pollutant-reducing technologies and supply high-quality fuel. Meanwhile, the policy portfolio encourages research on energy-saving and pollutant-reducing via R&D funds. Besides the above policy portfolio, the government offers purchase subsidies to ICE-vehicle users for driving the vehicle consumption and stimulating the economy.

(2) The infrastructure elements interact with market and user elements. Well-established refueling stations and quick and convenient refueling experience cultivate ICE-vehicle users' habits.

(3) The culture elements interact with market and user elements. The public concern about vehicle emissions focuses on NOx, SO_2, PM10 and PM2.5, etc., but CO_2 related to global warming is ignored. The limited public perception of vehicle emissions makes most consumers ignore the carbon emission issue when they purchase ICE vehicles.

(4) The technology elements interact with market and user elements, and also with industrial network elements. The low manufacturing and purchase costs affect consumers' choices and incentive them to choose ICE vehicles. The fast refueling

and reliable power performance shape user habits, which cannot be compatible with EVs when charging and power battery technologies are less advanced. The pollutant emission reduction technologies of ICEs allay the concern of ICE-vehicle users on harmful pollutant emissions. Meanwhile, the sunk costs caused by the investment for energy-saving technologies make car manufacturers reluctant to switch to EV products. The huge investment for ICE-related technologies is also a huge capital barrier to entering the vehicle industry and leads to high industry concentration, which means there are no economic incentives for ICE-vehicle manufacturers to adopt new technologies though .

(5) The industrial network elements interact with market and user elements, and also with policy elements. The high industry concentration means a large market share and scale effects, which allows traditional car manufacturers to resist the diffusion of EV technologies and causes product technology lock-in to some extent. The economic stimulus based on ICE-vehicle industries and vehicle consumption becomes a type of policy path dependency.

(6) The techno-scientific knowledge elements interact with technology elements. The research on vehicle exhaust treatment and energy saving improves the technical performance of ICE vehicles, especially ultra-clean exhaust emissions and high fuel economy.

(7) The market and user elements self-interact with themselves. The subsidized market and huge user bases can generate steady profit flow for ICE-vehicle manufacturers, and there is no economic incentive for them to shift to EVs. It is challenging for EVs to cater to user habits shaped by fast refueling and reliable power performance when charging and power battery technologies are less advanced. The consumer choices are distorted by limited public perception of clean transportation and EVs' carbon emission reduction benefits are ignored. Meanwhile, the diverse varieties of ICE vehicles make the vehicle market fragmented, and thus there is financial pressure for EV manufacturers to develop more varieties of EV

products and penetrate the market. All these factors can delay EV development and cause product technology lock-in.

3. *How do niche elements interact with each other?*

(1) The policy elements interact with market and user and techno-scientific knowledge elements. The EV purchase subsidies reduce the car purchase costs, and the credit policy allows EV manufacturers to gain additional revenue by cross-enterprise NEV credit trading, which can be seen as disguised cost reduction for EV manufacturers. These policies both make EVs more affordable for consumers. The exemption for travel and license restrictions improves EV users' experience and help them avoid inconvenience. The interviews also validate that a lot of consumers dislike two to three years of queuing for car licenses and travel restrictions and thus choose EVs. The R&D layout and related funding for the research institutes prompt knowledge accumulation and update.

(2) The infrastructure elements interact with market and user elements, and also self-interact. The charging stations offer charging services for EV users, which means the availability and performance of infrastructure has a direct impact on the EV users' experience or habits, such as with V2G and V2X platforms integrating charging stations EV users can participate demand response of the grid. Meanwhile, a large number of charging stations also increase the peak load of the power grid and affect grid stability.

(3) The culture elements interact with market and user elements. The increasing public concern of carbon emission issue makes EVs given a new value, namely moral satisfaction. EV consumers believe that EV consumption and application can help reduce carbon emissions, therefore they can gain extra moral satisfaction, which attracts potential consumers to choose EVs to a certain extent.

(4) The techno-scientific knowledge elements interact with market and user, technology and industrial network elements. The research on advanced high-capacity and high-energy density power batteries reduces manufacturing and purchase costs of EVs, and it also enlarges EV range and improves technical

performance. Meanwhile, V2G and related fast-charging technologies help charging station manufacturers and operators increase their products' charging speed and operation flexibility. V2G and V2X help optimize charging resources and improve traffic guide services. The interviews also validate that a lot of V2G and V2X projects in China allow the charging time and frequency of EV users to be flexibly adapted for assisting in the optimal operation of the power system.

(5) The technology elements interact with market and user elements. The EV range enlarging can improve the user experience. Meanwhile, the smart cockpit systems can offer more product functions and expand more application scenarios for users, and this cultivates new driving habits and reshapes user mind and perception of vehicles, which means more users' emphasis is placed on an intelligent driving experience. The interviews also validate that EV intelligent and networking development offers a more comfortable and convenient user experience, cultivates new driving and charging habits and thus changes user mind of vehicles.

(6) The industrial network elements interact with market and user elements, infrastructure and technology elements. The charging station operators offer guide service for EV users about where there are available charging stations to charge EVs or supply power to the grid, which can improve the user experience. The charging stations, as the necessary infrastructure for EVs, are manufactured by related manufacturers in the industrial network, and the charging station operators manage the infrastructure and cooperate with power grid operators to optimize power and charging resource allocation. The application of smart cockpit systems depends on hardware support from electronic hardware manufacturers and software support from system developers, which shows the interaction with technology elements. Meanwhile, there is also self-interaction of industrial network elements, such as charging station manufacturers extending the business to serve as operators and component manufacturers and system developers acting as upstream suppliers for EV manufacturers.

(7) The market and user elements self-interact with themselves. The above reshaped user mind, newly added value, decreased purchase costs and improved user experience work together to prompt EV diffusion.

4. *How do niche elements interact with regime elements?*

There are three types of niche-regime interactions, namely reconfiguration, transformation and competition. **Reconfiguration** is the process of novelty from the niche cluster being supplemented into the dominant regime or novelty from the regime being integrated into the niche cluster. The niche-regime interaction of policy elements is the institutional reconfiguration, such as the credit policy and travel and license restriction policy. The credit policy that initially serves EV development is merged with fuel economy regulations of ICE vehicles into Measures for the Parallel Administration of the Average Fuel Consumption and New Energy Vehicle Credits, which can both affect ICE vehicles and EVs. The interviews also validate that the credit policy is actually compressing traditional automobile manufacturers' profit margins and thus limiting their production scales. The travel and license restrictions for ICE vehicles are initially proposed to alleviate the smog issue, but subsequently the government specifically states EVs are exempted from these restrictions to prompt EV diffusion. The niche-regime interaction of industrial network elements is the network configuration, such as traditional ICE-vehicle manufacturers having richer technological accumulation in automotive general technologies than EV manufacturers participate in the EV industry by offering EV manufacturers automotive chassis. The niche-regime interaction of market and user elements is the technological reconfiguration. Vehicle users' habits are initially cultivated by ICE vehicles, and their main perception and mind of a vehicle or driving usually only contain speed and range. But EVs expands their perception and mind, which not only contain the concept of speed and range, but also contain how smart the car is. **Transformation** is the process of some parts of the original structure being completely replaced by something novelty and thus changing from a state to another opposite or incompatible one. The niche-regime interaction of culture elements is the transformation. After the “3060” carbon emission reduction target is proposed, the public perception and opinion of clean transportation and vehicle emissions change from focusing more on harmful pollutant emissions but ignoring the carbon emissions to discussing and attaching importance to the carbon emissions. The interviews also validate that there is a transformation of public perception and opinion, which means the changes from focusing on pollutant emissions but disregarding carbon emissions to attaching importance to carbon emissions. **Competition** is the process of the niche cluster and dominant regime competing for limited and desired resources, such as R&D funds, enterprise investment and users. At the level of national research funds, EVs gradually capture more funds and become the winner of the competition with ICE vehicles. The number of EV brands and the amount of related financing are both increasing, and EVs are gradually capturing the enterprise investment from ICE vehicles. The systems of oil pipelines and terminal refueling stations serving ICE vehicles and the charging stations and power grid serving EVs are two almost separate energy sub-systems, and the charging infrastructure is capturing potential users from the refueling infrastructure. Decreasing EV-related costs and the newly added value of carbon emission reduction allow EVs to directly compete with ICE vehicles at the price level and consumer preference level, which can help EVs grab potential users. Therefore, reconfiguration and transformation reshape the policy, user and public opinion part of the environment of the whole vehicle industry and change the supply chain and adjust the industry layout, and competition makes R&D funds, enterprise investment and user bases reallocated between EVs and ICE vehicles.

5. *How does the dominant regime change?*

   Sub-question 5 is answered with sub-question 6 together in the following.

6. *How does the niche cluster change?*

   When element dynamics are initially caused by the landscape interactions, and these dynamics can further generate more element dynamics via element interactions. Because there are interrelationships of elements, and when one element changes it is possible for another one interacting with it or affected by it to change with it. The **policy** element dynamics include the update of the policy portfolio of energy saving and pollutant emission reduction (containing increasingly strict regulations of fuel economy and vehicle pollutant emissions), the enlarging of travel and license restriction exemptions, the update of Energy-saving and New Energy Vehicle Industry Development Plan (containing the improved R&D layout) and the credit trading policy, and they take the institutional reconfiguration to reshape the policy part of the industry environment. The **culture** element dynamics are the public awareness of vehicle emissions and clean transportation that is reshaped twice, namely disregarding carbon emissions and attaching importance on carbon emissions, and they take the transformation interaction to reshape the public opinion environment of the vehicle industry. The **techno-scientific knowledge** element dynamics include the research progress of ICE-related technologies (vehicle exhaust pollutant absorbing, turbocharged, cylinder direct-injection and idle start-stop) and EV-related technologies (advanced power batteries, V2G and related fast-charging technologies, V2X and smart interaction, etc.), and they take the R&D fund competition to reallocate limited funding resources. The **technology** element dynamics include the technical performance improvement and product characteristics changes, such as EV range enlarging, charging speed increase, EVs' intelligent and networking development, fuel economy improvement and ultra-clean vehicle exhaust, and they take the enterprise investment competition to reallocate investment resources. The **industrial network** element dynamics refer to ICE-vehicle manufacturers starting EV-related business, such as Chang'an Automobile cooperating with CATL and Huawei to start the independent EV brand and cooperating with NIO to start the joint EV brand, and they take the network reconfiguration to change supply chains and industry layout. The **infrastructure** element dynamics are the optimized operation of the whole charging system, which means more charging stations are connected with and more EV users participate in the network to give the charging system larger optimization flexibility and make it perform more stably and efficiently, and they take the user competition to reallocate infrastructure user resources. The **market and user** element dynamics include reshaped user mind and perception (focusing more on vehicle intelligence), new user experience (intelligent driving and networking services), newly added value (moral satisfaction of carbon emission reduction by driving EVs), decreased EV-related costs and desire of hedging against fuel price volatility, and they take the technological configuration and user competition to reshape the user part of the whole industry environment and reallocate vehicle user resources.

Based on the above answers, the main research question **How is the socio-technical transition for EVs in China taking place?** is answered in the following. Energy security affected by geopolitical conflicts and oil price volatility are landscape factors existing throughout the whole transition process, because the dependence of China on external energy supply in the transportation sector has overall grown since the turn of the century. Meanwhile, the smog issue emerging in 2012 is the landscape that dominantly acts on the early transition process. Although ICE vehicles survived through the crisis caused by the smog issue, the smog issue opens a window of opportunity for EV early commercialization. After the smog issue is largely alleviated, climate change caused by carbon emissions and the "3060" target proposed in 2020 are the dominant landscape factor that drives the transition. Via the interactions of landscape factors with the regime and niche elements, all these landscape factors actually drive the socio-technical transition from the source by putting pressure on the government, car manufacturers, consumers and the public, etc. Therefore, these stakeholders have to make responses, such as the introduction of new policies, business adjustments, choosing more cost-effective technology alternatives and changes in public perception of emission issues, and their actions are or further generate element dynamics of the ICE-vehicle regime and EV niche cluster. The element dynamics caused by landscape factors further generate more dynamics of other elements via the element interactions within the regime and niche cluster. Some element dynamics involve only one of the ICE-vehicle regime or EV niche cluster and become parts of the regime or niche cluster to sustain ICE vehicles' dominant status or help EVs develop. For example, the element dynamics (e.g. technological progress of ICEs and vehicle exhaust treatment) directly and indirectly generated by the smog issue help ICE vehicles survive through the crisis caused by the smog issue and sustain ICE vehicles' dominant status. But other element dynamics act as prerequisites and contents of the niche-regime interactions to further drive the transition process. The ICE-vehicle regime and EV niche cluster can be seen as two socio-technical systems interacting with each other, and the niche-regime interactions include reconfiguration (institutional, network and technological), transformation and resource competition (research funds, enterprise investment and users). Via the niche-regime interactions, element dynamics reshape the industry environment, change the industry layout and reallocate industry resources, which makes EVs gradually gain socio-technical advantages and helps EVs quickly penetrate the vehicle market. The process of EVs gaining advantages and penetrating the vehicle market is the socio-technical transition for EVs in China, and the interaction mechanisms and element dynamics generating analysis explain how the transition takes place.

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Appendix: Interview Transcripts

The smog issue and related policies

-Is the policy of traffic and license restrictions for ICE vehicles to cope with the smog issue a special opportunity for the development of EVs? Why?

-The traffic and license restrictions are still implemented in some cities, what might be the purpose of this?

-What is the impact of the restriction policy on EV development?

Interviewee Y: The traffic and license restrictions for ICE vehicles did promote EV commercialization to a certain extent, but the resulting growth in the EV number was very limited. Due to the underperforming technologies of power batteries and EV range at that time, it was difficult for passenger car users to meet their driving needs through EVs. Therefore, the early commercialization scenarios of EVs were mainly the transportation in golf courses, in-port logistics and confined industrial parks. These users usually need to drive vehicles each weekday, and the scenarios do not require a large range, but the restriction policy interrupts their use and makes them can only drive on odd or even dates, and thus they have to choose EVs. EVs played little role in relieving the smog issue at that time, because the total EV number was limited, and also had little impact on the passenger car market. Compared to the past, facing the restriction policies, more passenger car users are choosing EVs, and one of the reasons is that the related technologies have become relatively mature. For example, nowadays EVs have a larger range, and electric passenger cars driving in urban areas can drive for a week with only one day and night charge, which means there is no range anxiety for these users.

Interviewee F: Nowadays, many cities in China are still implementing the restriction policy, on the one hand to control traffic flow and ease congestion, and on the other hand to serve the national policy goal of promoting EVs. The government is imposing travel and license restrictions on ICE vehicles, and meanwhile offering EVs great policy favors. These policy favors are actually leading consumers to choose EVs, and these policies also have a great impact on the market sales of EVs. When buying EVs, a lot of consumers communicate with salespeople and mention that they want to get licenses as soon as possible and do not want to be restricted by the travel restriction policy. Consumers dislike two to three years of queuing for car licenses and travel restrictions, and EVs exempt them from these restrictions and inconvenience, and thus they are willing to choose EVs, even if there are problems such as slow charging of EVs.

The 3060 target and related policies

-Is the proposal of the 3060 commitment a special opportunity for the development of EVs? Why?

-Take the credit trading policy as an example, what is the impact of the policy serving the 3060 target on enterprises? Such as vehicle manufacturers.

-Is there any connection between the motivation of traditional vehicle manufacturers to take electrification transformation and the 3060 target?

Interviewee Y: The credit policy puts pressure on ICE-vehicle manufacturers, but the pressure is only financial. Although the enterprises may face reduced revenues, the financial pressure alone is not sufficient to make traditional car manufacturers start their electrification transformation. In addition to the credit policy, the increase in fuel consumption requirements by the government for passenger cars actually plays a crucial role in pushing these enterprises to make the choice of electrification transformation. Technically speaking, the fuel economy requirements for passenger cars are gradually being raised to the level where they cannot be met by ICEs alone, and car manufacturers are forced to choose the HEV or EV technology paths, otherwise the ICE vehicles they produce will not be able to enter the market due to the fuel economy requirements, which is not only financial pressure but a complete inability to make sales. In fact, even with the HEV path alone, automakers can easily reduce the average fuel consumption per vehicle to half of the current fuel economy requirements, which is very tempting for car manufacturers. The Chinese government has a plan to ban the sales of ICE vehicles in 2035, and the increasing fuel economy standards are actually a progressive pavement for the sale ban plan. Therefore, traditional car manufacturers are taking electrification transformation both to cope with the financial pressure of the credit policy, the increasing fuel economy requirements and the sale ban plan. It is estimated that in ten years, the proportion of ICE vehicles in the new cars sold in the market will be almost zero, and NEVs will dominate.

Interviewee F: A large part of carbon emissions in China comes from the transportation industry, and thus the “3060” target cannot be reached without the promotion of EVs, and the credit policy is aimed at vehicle manufacturers and incentive them to start EV business. As traditional ICE-vehicle manufacturers, they have to spend money on purchasing other enterprises’ NEV credits, which may not be a big amount compared to the total output value of the enterprise. However, as long as they expand the production of ICE vehicles, the cost of purchasing NEV credits will also increase, and thus this policy is limiting its production scale. After the implementation of the credit policy, the top six traditional ICE-vehicle manufacturers’ expenses for credit offset continue to increase last year and this year, which is a quite negative signal for their shareholders or investors, because this means their profit margins are being continuously compressed. The auto industry in China is policy-driven, and through the credit policy the government is actually informing companies that the government's planned development direction of the auto industry is NEVs. The policy signal is affecting the confidence of the capital market and investors for companies that do not start NEV business, and these companies’ share prices may fluctuate as a result. In the past few years, a lot of investment institutions, such as fund management companies, tend to invest in the field of NEVs, but rarely in the field of traditional ICE vehicles. In other words, for traditional ICE-vehicle manufacturers, it is hard for them to gain more money to expand the market, and this financing difficulty will cause problems in their capital chains.

The transformation of public environmental perception

-Does the smog issue have an impact on shaping the environmental awareness of the public in China? Why?

-How does the public perceive the impact of ICE vehicles on the environment?

-How does the public perceive the issue of vehicle emissions? Such as harmful pollutant emissions and carbon emissions

Interviewee Y: The smog issue has a great impact on the environmental cognition of the public in China, and when the smog issue was serious the public formed an inherent cognition of the emission problem. Basically, it can be said that the public consensus was such at that time: environmental protection is to reduce the emissions of harmful pollutants (i.e. NOx, SO2, PM10 and PM2.5), and ICE vehicles are not environmentally friendly because of their harmful pollutant emissions. But with the technological advancement of automobile harmful pollutant emission reduction, technically speaking, the concentration of harmful pollutants in the vehicle exhaust is decreased a lot and almost the same as the atmosphere, and that is one of reasons why the smog issue can be greatly alleviated. Therefore, the public does not think the ultra-clean emissions of ICE vehicles are not environmentally friendly. In recent years, especially after the proposal of the “3060” target, there has been a gradual transformation in the public perception of environmental protection from the focus on harmful pollutant emissions to the focus on carbon emissions. Despite there being a tendency for this transformation, it is incomplete, and there is still room to increase the public attention to carbon emissions compared to the public attention to harmful pollutant emissions during the smog period.

Interviewee F: After the “3060” target is proposed, the media is always reporting the related discussion of experts and scholars, which has a subtle influence on the public, and the public begins to realize that carbon emissions are an urgent problem to be solved. Consumers usually know that EVs are more environmentally friendly, and individual awareness of environmental protection will affect consumer behaviors, but the impact is not large, which depends on their willingness to pay extra for environmental protection. If EVs are several times more expensive than ICE vehicles, even if consumers support environmental protection, it is unlikely to buy EVs; or if the EV range is too low, people will still not choose EVs. The salespeople have never seen a consumer who buys an EV simply for the sake of environmental considerations, and the consumers usually care more about price concessions, policy favors and product performance.

EV intelligent and networking development

-Take the intelligent cockpit as an example, what is the impact of EV intelligent development on the market and users?

-Take V2X and V2G as an example, what is the impact of EV networking development on the market and users?

-Will the driving habits of EV users be affected by technological characteristics? Why?

Interviewee Y: Compared with traditional ICE vehicles, EVs have a larger on-board battery capacity, which can support more energy-consuming and complex electronic systems. Meanwhile, it is also easier to implement intelligent designs and solutions because EVs' control systems are more responsive. Since the increase in the charging station number can cause power fluctuations in the grid, it is inevitable that the grid institutions step into the charging station industry and form joint operation platforms with charging station operators to optimize power resources. Therefore, there are currently a lot of V2X and V2G projects in China. Under the service of these platforms, the charging habits of different users are being changed in different directions: For the users of private passenger cars and private stations, they adapt to longer charging hours compared with refueling time, such as charging one day and one night per week; for taxi drivers who frequently use public charging stations, they usually charge twice a day, and they sometimes do not fully charge at once to save time, and choose to charge at multiple charging stations. ICE-vehicle drivers are usually able to adapt to EVs quickly because EVs provide comfortable user experiences that ICE vehicles cannot provide before, such as lower noise, safer and more fuel-efficient. On the contrary, many users who have driven EVs cannot adapt to the noise and low comfort of ICE vehicles. However, some ICE-vehicle drivers are difficult to adapt to EVs, such as long-distance driving and cross-city travel users, and the current EV range cannot meet their driving needs, and thus they still choose ICE vehicles regardless of the convenience and comfort brought by the networking and intelligent development or EVs themselves.

Interviewee F: Almost every EV manufacturer is developing smart cockpits, and the smart cockpits are actually applying artificial intelligence in the field of driving, which makes the human-vehicle interaction more friendly to users. The number and types of information interactions between smart cockpits and drivers are more complex than the traditional cars. For example, the smart cockpits can detect the vehicle surroundings to inform drivers of the location, speed and road and traffic conditions, which can assist in driving and even help make driving decisions. This large amount of data collection can help the smart cockpit system self-training to become more intelligent, coupled with the responsive electronic control system of EVs, the drivers' control of cars is almost at the instantaneous level. If V2G and V2X platforms gain access to the data collected by smart cockpits, the data will support decision-making for better traffic guidance and allocation of charging resources. This requires a lot of real-time data collection and analysis, but it is almost impossible for traditional cars to support collecting such data, and thus it is necessary for cars to be equipped with the smart cockpit system. The smart cockpit system is not only improving the driving experience and making the vehicles more intelligent, but also laying the data foundation for networking development. Meanwhile, the smart cockpits' deep binding with cars will change user habits and user mind. For example, with V2G and V2X, the smart cockpit system can help drivers plan where to charge, how long to charge, and even book the charging station in advance. This system makes driving more convenient and smarter than before, and thus once users get used to smart cockpits, they will naturally bind the comfortable experiences and services with driving, which changes driving habits and user mind.