

Leapfrogging attempt by creating Institutional Windows of Opportunity in the Chinese Electric Vehicles sector

Abstract—The techno-economic paradigm shift in the automobile industry gave a promising opportunity for developing countries to enter Electric Vehicles sector at its initial stage, and consequently leapfrog towards leadership. In comparison with old successful attempts—e.g., LCD screens—, EV sector is more complexed. It requires specific infrastructure, and it is highly dependent on vertically integrated sectors, such as battery production and development. In 2009, China introduced a set of policies to leapfrog with rather optimistic production goals, which were not achieved. The policy was modified in 2012 and two years later, the production trajectories went up. This paper analyzed the policy and technological development in two periods, and the results showed critical shortcomings in the first period. Additionally, the insufficient policy cannot dictate the market, contrary, the market will create its own path to cover demand. In China, instead of catching-up in EV, the market for Low-speed EV developed.

I. INTRODUCTION

Electrical vehicles (EV) probably is among the most innovative and dynamic industrial fields worldwide at the moment, and one with significant technological ramifications throughout many different branches of industry. The EV industrial field advances on a global scale, as producers of vehicles, suppliers of components and services, and a wide range of potential entrants survey opportunities in such disparate areas. China promotes an ambitious electric mobility program with two primary objectives: to reduce urban air pollution and to enhance the competitiveness of its national automotive industry [1]. A range of industrial policies is being applied, and several pathways to electric mobility are being explored in parallel. The goals set in the first EV policy in 2009 were not achieved [2] and the government introduced a new plan in 2012 for the period of next eight years. Two years later the sector awoke and continued to develop according to new policy's goals, see Figure I. An obvious explanation would give credit to improved and better policies, however, looking at the electric vehicles as just a new cycle in the automobile industry, different stages demands different strategy [3]. Thus, this paper will explore whether the catching-up is a result of improved policies or a more appropriate timing—state of technology.

Following the global evolution of this field attracts a lot of interest from academics as well as from decision-makers in industry, finance, and politics. A key theoretical framing for understanding the global adaptation and innovative dynamics of electrical vehicles has been the so-called catching-up hypothesis. It primarily depicts innovation as a process of technological adaptation, where the in socio-economic terms most advanced and mature societies provides the spring bed for the development of technologies, and where other

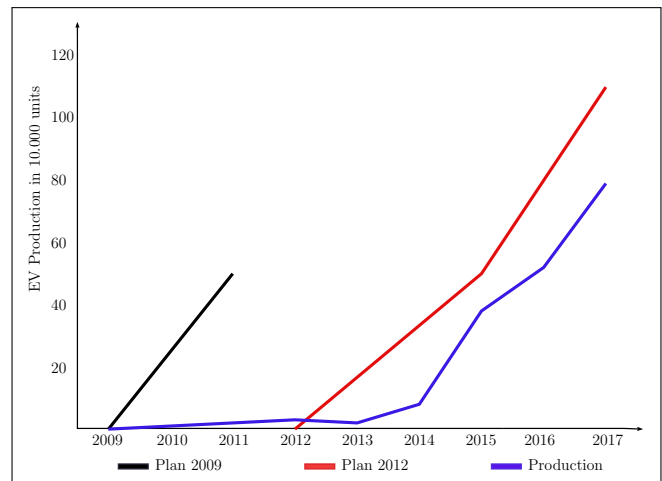


Fig. 1. Plans and realized production [4]

economies follow suit, as the technology advances and these countries build sufficient capacity to absorb technological progress [5], [6].

At its origin, the catching-up hypothesis suggested that countries dealing with backwardness towards leading nations have an opportunity for faster growth and consequently, to catch-up with the frontier. With the focus on the country level, "...if advanced technology at any time is heavily scale-dependent and if obstacles to trade across national frontiers, political or otherwise, are important, large countries will have a stronger potential for growth than smaller ones [7, p.393]. In spite of this potential, the catching up process is complicated and hard to replicate. Consequently, there are only a few developing countries—e.g., Japan, Korea, China—that managed to get developed in last few decades. Moving the level of analysis from macro to mezzo level shows that due to the differences in sectors, a country that catches up in some sectors could fail in others [8], [9].

The catching-up on the industry (sector) level often results in the leadership change or at least in market share changes [10], [11]. The industries with a stable and incremental technology change are controlled by leaders, and therefore it is hard for latecomers to enter the markets successfully. However, due to the industry cycles and different opportunities, the market can be disrupted [12]. The sectors' economic developments vary due to different characteristics, and therefore they need customized policies, access to knowledge, possibilities to learn, intellectual property, workforce, etc. [13].

This paper aims to analyze Chinese EV policies in two

periods, the first from 2009-11 and the second from 2012-14, on both national and local level. Policies are technology sensitive [14]; thus its replication from other industries does not result in the same manner. The adopted framework from Binz et al. [14] divides policies' target to Knowledge, Market Access, Financial Investments, and Technology Legitimacy. The original framework contained the policy-mix for catching-up in three different industry types: design-intensive, complex product systems and process-intensive. Only the later was used in the adopted framework (Table I), as it suits EV sector's characteristics.

This paper is structured as follows. Section two reviews the catching-up literature, focusing on sectoral catching-up, windows of opportunities and catch-up cycles. After the Data and Methods are presented, the fourth section introduces the automobile industry, followed by in-depth analysis of the Chinese domestic EV regulations and policies. Section six compares the state of technology between both periods and finally, the conclusion summaries and discusses the policy issues raised.

II. THEORY: SECTORAL CATCHING UP AND WINDOWS OF OPPORTUNITIES

A. Sectoral Catching-up

The catching-up on the sectoral level is highly studied in the high-tech with frequent technological changes, e.g. mobile phones [13], [15]. Nevertheless, there are examples of old or long-term evolution industry analysis, like wine industry [12], steel and iron [10]. The shift from the macro level to mezzo perspective required the use of sectoral innovation system framework, which identifies three main elements—actors, knowledge base, institutions. Yet, despite significant differences between sectors, the successful catching-up requires a dynamic interplay between both, national and sectoral innovation system [13].

Following Schumpeterian hypothesis, different sectors characteristics give advantages to firms of different sizes. In capital-intensive, concentrated and advertising-intensive, larger firms are in better position to innovate. Contrary, in sectors at the early stage of its life-cycle, less-production intensive with a higher share of R&D employees, smaller firms tend to be more innovative [16]. Therefore, in the long-evolutionary sectors big and concentrated firms played an important role in countrys catching up. Korean catching-up in iron and steel sector based on the success of a state-owned company POSCO and few "chaebols" (conglomerates), which were given state support and guarantees for bank loans [10]. Similarly, many big automobile producers in China are state-owned and some the result of joint-ventures with foreign multinationals [17]. On the other hand, medium-sized firms in Korea have to adapt their R&D to the sectors specifics and rely on open innovation [18].

Big firms in catching-up need skilled labor and good supply chains to maintain growth, improve efficiency and innovate, thus it is important to have good regional support-clusters [19]. Especially vertical links between suppliers and producers, which often operates in different sectors.

Although sectors have different characteristics, they influence each other, yet ones catching-up does not guaranty success for others, for instance, China successfully catch-up in telecommunication equipment but not in semiconductors [9]. Similarly, Korean automobile sector and machine tools sector [20].

The benefits of a local cluster may present a threat of locking-in, thus pipelines for knowledge transfer are essential [21]. Likewise, focusing only on domestic markets tempers the view on foreign knowledge and the variety of demand needs [22]. Characteristics of sectors and the state of local demand may influence the development of the sectors, as it was the case in Wind power and solar PV sector in China [23], [24]. The first one in the early stage focused on the domestic market and later more actively went internationally, as on the other hand solar PV first develop in a foreign market and then on domestic.

A major role in sectoral catching up plays government and its policies, which can promote interactions between actors, stimulate production and support internationalization [13], [25]. In time of technical change and potential market disruption, government should move from "linear model", where it is mostly limited to supporting basic R&D, towards "sequential linear model" that allows it to intervene in all sequential development phases with financial support, market introduction, creating standards etc., and finally government can move towards "interactive model", that intervene in all segments at any time [26]. Additionally, sectors specifics and countries unique macro position defines the catching-up strategy [27]. Thus, its role is to build infrastructure and enables education, support local firms and creates a friendly environment for international venture capital, give subsidies for firms and customers and if needed tax stimulations [22]. Sectors specifics dictate governments to use different policies to achieve catching-up [14], moreover, as the country lowers the gap towards front-runners in specific sectors, the policy has to adopt as well [28]. For example, Korean catching up in the electronics industry stopped in the middle of 1990s after two decades of very fast development, as they failed to use technology diversification strategies and built-up on the existing technological learnings [28].

Finally, an important role for sectoral catching-up through knowledge creation and skilled labor lays on education, research at universities and public laboratories [29]. Especially in the early stages, the channel for developing countries to acquire new technologies and organizational forms goes through students and researchers with advanced training abroad. Local institutions are crucial in sectors, which products demand local specifics, such as agriculture and medicine, where practices and knowledge cannot be directly copied. In manufacture intense sectors, local institutions need to provide trained engineers and applied scientists [29].

B. Windows of Opportunities

The change in sector's leadership can occur due to "techno-economic paradigm shift" [30] in the maturity phase in the product life-cycle. The higher costs for technological

and structural adjustments put forerunners in a disadvantaged position, and contrary latecomers can skip this and go lighter and faster in a new technological system. This convenient moment—Windows of Opportunities—for latecomers, does not automatically lead towards catching up [31]. Nevertheless, the opportunity to catch-up can emerge even without technological change but with endogenizing windows through the policy, as it happened in India’s pharmaceutical catching-up [32]. Additionally, latecomer may catch-up or even forge ahead due to the windows opened by others—exogenous-e.g., the Korean firms using foreign knowledge to leapfrog in display industry [33]. Moreover, windows can emerge due to the increased or changed demand [15], so three different types of windows were identified: technological; demand; institutional [3]. Batteries are a crucial element in electric vehicles. Therefore, vertical integration between both sectors plays an essential role in the development of EV sector [17]. Thus, one’s slower progress hinders the development of other. On the other hand, taking over the battery sector and covering most of the world’s demand might endogenize demand window of opportunity.

C. Catching-up cycles

Literature provides various models that studied different economic and production stages and cycles. In the second part of the twentieth century, scholars researched the patterns for developing countries’ catching-up. Wild-geese-flying pattern model [34], analyzed Japanese process from entering international markets as less developed till becoming a highly industrialized country. Venrons Product Lifecycle theory, Rowstows theory of the stages of economic growth and others were the foundation for [30] techno-economic paradigm shift and consequently, the opportunity to catch-up. The catching-up cycle framework builds upon Venrons theory, by adding the latecomers opportunity to take over R&D and innovation, and not only production [3]. It consists of four stages—entry, gradual catch-up, forging ahead, falling behind. As actors in sectoral systems are interconnected, the sector changes in each stage, therefore latecomers need to adapt their strategy to the stage. In “entry stage”, latecomer can use its macro advantages—e.g., natural resources, low labor costs, a low value of local currencies—, yet in the “gradual catch-up stage” this has to be supplemented with learning and building of capabilities. In the “forging ahead stage”, latecomer has to take over the leadership, whether by using the existing Windows of Opportunity or by creating one and is often caused by a stage-skipping or path-creating [13].

III. DATA AND METHODS

The data used in this paper consists of national and local policies regarding electric vehicles in China between years 2009 and the end of 2014. The policies were collected from “China Association of Automobile Manufacturers” website [4] and captures all policies, regulations, and news that include term “new energy vehicles”—NEV. This term is used by the Chinese government to designate electric vehicles in

policies, and it only consists of battery electric vehicles and plug-in hybrid electric vehicles. In total, 294 entries were found, among them, 113 were dated in the period between 2009 and the end of 2011, the remaining 181 entries fall in the period 2012 and the end of 2014. The data was first translated from Chinese into English and later reviewed. Additionally, different academic articles and reports about electric vehicles were used.

IV. AUTOMOBILE INDUSTRY

Automobile industry plays an essential role in many countries’ economy, and due to its scale-intensity, governments support its development [25], [26]. The mass production started in the U.S. and was later spread across traditional European countries, followed by another triumphant entrance by Japan [35]. Through the decades, the global oligopolistic structure was created with many latecomers that managed to catch up [13], e.g., South Korea. In last period, automobile sector industry started a technological paradigm shift, as decarbonization of the world economy demands cleaner ways of transportation [17].

A. Chinese catching-up in automobile sector

Chinese automobile sector for passenger cars started to develop after the reform in 1978, and since then its production gradually increases. In 1990, China produced 42 thousand cars, ten years later 607 thousand and in 2006 3,8 million and the share of passenger cars compared to total vehicles first time went above 50 percent with less than hundred thousand cars in export [36]. In 2017, China was the biggest car manufacturer in the world with 34% share with the production of 24,8 million and with 891 thousand passenger cars exported. Among them, more than 10% are electric vehicles. However, among exporters, China only takes 20th place with one percent in global export, which indicates that Chinese automobile sector relies solely on the domestic market [37]. In 2016, Iran (19,3%), India (9,5%) and Vietnam (6,8%) were leading destination countries for Chinese vehicle exports. [4]. From the catching-up cycle perspective, the automobile sector has “*coexistence of the old and the new leaders*” situation, where latecomer became a leader but shares leadership with old traditional leaders. China did not take any market share from traditional leaders—e.g., USA, Germany, Japan—, nevertheless, they managed to fill the new demands from growing domestic market.

The unregulated sector of Micro EV allowed the Chinese manufacturers to create their path towards electrification by producing Low-speed Electric Vehicles. Only in 2014, more than 2 million units were produced [38], which are not included in the official NEV statistics.

V. DOMESTIC EV REGULATION IN CHINA

The Chinese government introduced a series of different regulations to spur electric vehicle sector with four primary goals: technological upgrading, energy security, local pollution reduction and solving carbon emission. The alternative to fuel vehicles policy in China was first introduced in 1991

TABLE I
POLICY MIX FOR CATCHING-UP PROCESS-INTENSIVE PRODUCT INDUSTRIES

System Resource	Policies for Process-intensive products
Knowledge	Government-funded basic science and R&D programs Supporting the quick translation of new technologies to the manufacturing process Support for entrepreneurial experimentation in private start-ups Support imports of capital equipment, turn-key plants, and/or knockdown kits
Market Access	Promotion of domestic markets: Policies aimed at creating domestic mass markets to facilitate economies of scale in production Promotion of export market: Establishment of export processing zones with state-of-the-art trade infrastructure Intervention to decrease factor costs (raw materials, capital costs, labor costs, energy costs)
Financial investments	Providing low-cost loans for plant expansion, equipment purchase Creating a supportive private equity and venture capital system
Technology Legitimacy	Adopting international quality certification&standards systems Mobilizing policy/public support based on success stories in export markets

Source: [14]

and was updated in every coming five-year plan since the transportation was recognized as a crucial factor to meet nation's energy and air quality goals. During the tenth five-year plan—starting in 2001—an R&D strategy for EV was introduced for fuel-cells, hybrid, and pure electric vehicles. High financial investment in R&D continued in the eleventh five-year plan, supplemented with the first commercial market development [39].

In 2006, the State Council introduced "The National Medium and Long-Term Program for Science and Technology Development (2006-2020)", which included electric vehicle sector. Chinese development plan for these 15 years period relied on indigenous innovation, leapfrogging, promoting development and leading the future. Indigenous innovation was described as *"...enhancing original innovation, integrated innovation, and re-innovation based on assimilation and absorption of imported technology, in order to improve our national innovation capability."* [40, p.9]. This policy was supported with the restricted EV import and demand for better technology transfer from foreign firms, yet it resulted in lower technology import [2].

A. Period 2009-2011

In the years of global economic crises, the Chinese government introduced a policy package to spur the economy and its primary element was the "Plan on Shaping and Revitalizing the Auto Industry". In addition to the environmental goals, the government saw an opportunity to leapfrog and consequently catch-up in the automobile sector by taking a leading position in electric vehicles. At that time policymakers acknowledged three main bottlenecks—market, technology, supporting facilities. This policy from 2009 aimed at a production of 500 thousand EVs and an increase of share for "non-fuel" vehicles to a 5% of total passenger vehicles sold till the end of 2011. The stimulation was also directed to the whole automobile sector and planned to expand own-brand vehicles on a domestic market to 30% and the export increase to 10% of the production [1].

The supporting policy by Ministry of Finance & Ministry of Science and Technology proposed "The Ten Cities, Thousand Vehicles Program" with fiscal instruments to encourage the development of EV sector, starting with 13 pilot cities, where central government provided a one-time fixed amount of subsidies for purchase EV vehicles. Local governments had to establish grants for supporting facilities and its maintenances. EV producers had to give the warranty for three years and 150,000 kilometers, additionally, car parts producers had to provide a specific scale of production capacity [41]. In July 2009, the Ministry of Industry and Information Technology announced a regulation for EV manufacturers and placed EV products [42] into different technical stages—initial, development, mature—and according to stages, different management methods were adopted.

Announced classification arose with skepticism, as lithium-ion batteries were placed only in the development stage and favored Nickel-metal hydride batteries [43]. The manufacturers had to provide necessary production capacities and consistency, additionally, products had to meet regulations for safety, environmental protection, theft prevention, and were not allowed to infringe the intellectual property rights of others [42].

In 2010, four ministries introduced an extension [44] to subsidy regulations from 2009 and it covered the private purchase of EV and battery leasing. Subsidies could go up to 50,000 yuan/hybrid EV and 60,000 yuan/pure EV and the regulation were limited to first 50 thousand EVs.

In 2011, regulation for strengthening EV pilot projects was launched to get understanding of why EV is still in the initial stage of large-scale production. Pilot cities had to conduct comprehensive and systematic investigations on all tasks and establish accident warning information system, to increase EV legitimacy [45]. As a result, improvements launched at the end of 2011 directed to establish fair competition on the market and to clean up existing local policies that are discriminatory to foreign products. Furthermore, EV manufacturers had to speed up the development and production,

improve sale and after-sale services. A battery recycling system with tracking systems had to be established by both EV and battery manufacturers [46]. In December 2011, the National Development and Reform Commission revised a "Foreign Investment Catalog" that characterizes FDIs into three groups: encouraged, permitted, and restricted. In the revised catalog, the conventional automobile investments were removed and investments in EV were placed in the "encouraged" group [47].

According to Howell et al. [2], the results were far short of the goals with less than 12 thousand EVs on the roads—6% global share—at the end of 2012 and approximately 40 thousand—8 thousand privately owned vehicles—at the end of 2013. Besides the global problems, e.g., battery costs and low mileage range, China had four additional problems that slowed down the progress. China lacked the capacity to create or transfer state of the art EVs technology and the trade barriers hindered foreign companies to properly enter the market. Moreover, China's trade barriers between its province blocked the creation of sufficient supply value chains, and finally, the governments focus towards high end EVs, resulting in overlooking fast developing low-speed EVs. Contrary to governments plan to leapfrog and overtook leading position, China had fallen behind in EV readiness. Krieger et al. [48] measured it by considering both countries supply and demand side, and China who was only behind United States and France in 2010 had been overtaken by Japan and Germany in 2012.

The 5 billion-Yuan subsidy fund could cover more than 83 thousands vehicles, but the results were disappointing. By estimates only 500 vehicles were privately owned, e.g., Shanghai had only 10 electric vehicles. The main reasons were a higher price than conventional vehicles and inconvenience in the daily use [?]. In addition to the state policies, municipal governments introduced their own stimulus. In Beijing, the buyers of electric cars were excluded from the license plate lottery, which goal was to cut new car sales in the congested city [49].

B. Period 2012-2014

The unsuccessful policy from 2009 showed weaknesses, which were addressed in "Energy Saving and New Energy Auto Industry Development Plan 2012-2020". Its premises were that technological and transformational upgrading in the automobile sector is an important task for economic growth and international competitive advantage [2]. The goal was to reach production of 500 thousand EVs in 2015 and 2 million in 2020. The policy also addressed the pollution of vehicles with internal combustion and its fuel per 100 kilometers should decrease to the international advanced level in 2020 [50]. The policy proposed five groups of tasks:

1) Energy-saving and EV technology innovation project

Raise the support for developing core technologies for enhancing industrial competitiveness by linking national science and technology programs with technological innovation system. Especially the technical innovation of power battery,

as they were the cutting-edge technology. The government guided enterprises to invest more in R&D and promote cross-industry collaboration. To ensure that, shared test platforms, development databases and common collection of relevant patents should be established.

2) Scientific planning of industrial layouts

The industry needed to have conditions to implement R&D into production; therefore the task was to develop new EVs' production capacities according to the actual needs of the industry and market. The principal goal was to establish battery cluster with large-scale production companies (10 billion watt-hours) with continuous innovation capabilities.

3) Improvement of pilot demonstrations

To meet new production goals, the scope of pilot cities had to increase to large and medium-sized cities, supported with new subsidy policy. As there was still missing the dominant model for battery handling, new business model innovation was encouraged for battery leasing, charging and replacement services. Additional to current types of EVs, new alternatives to fuel had to be still researched (e.g., fuel cell EV).

4) Charging facilities construction

A new overall development plan for charging facilities had to be included in any modern urban transportation system planning, and pilot cities had to use government's offers and actively attract other social funds.

5) Improvement of standards and support policies

With aim of accelerating EV sector, the government allocated funds to technological development, standard setting, and market application by building technological innovation system that integrates production, study and research. This was supported by improved "punishment" policies for vehicles powered by fuel. The plan also included support (e.g., risk compensation) for financial institutions to actively participate in EV projects. A multi-level talent training system included talents from different disciplines (e.g., product development, business management, IPR, electrochemistry, vehicle engineering) and encourage companies, universities and scientific research institutions to recruit talents from abroad. Accompanied with stimulated international collaboration between manufacturers, universities and research centers, the inflow of missing knowledge could be generated. Additionally, the government supported enterprises in internationalization processes such as trademark registrations and acquisitions.

Ministry of Finance and Ministry of Industry and Information Technology introduced supporting policy [51] with additional funds. The first supported technological innovation in the EV sector and the second newly designed and developed EV models. Funds could be assigned to different technological teams, that combines industry, academia and research industry. To ensure projects continuity, funds had been disbursing in batches, 40% after plan implementation,

TABLE II
EV POLICIES IN RESEARCHED PERIODS

Time period	Type of policies	Specific Policy and rationale
2009-11	Knowledge	State Council 2009 - IPR - Manufacturers must have patents for their products
	Market access	MIIT 2009 - EV solutions classified by technical stage MF&MST 2009 - 10/1000 pilot cities program MST&MF&MIIT&RC 2011a - improve competition and speed up manufacturing NDRC 2011 - EV placed in FDIs catalogue in the "encouraged" group MF&MST 2009 - 10/1000 pilot cities program MST&MF&MIIT&RC 2011b - investigation why pilot cities do not progress Shanghai EV zone 2011 - international demonstration zone
	Financial investments	MF&MST 2009 - subsidies for EV purchase and EV manufacturers MF&MIIT&RC 2010 - subsidies extension
	Technology legitimacy	MF&MST 2009 - warranty for 3 years of 150,000 km MST&MF&MIIT&RC 2011b - establishing accident warning information system
2012-14	Knowledge	State Council 2012 - Scientific planning of industrial layouts MF&MIIT 2012b - companies should have 3% share of R&D in their income State Council 2014 - Strengthening of technological innovation 863 plan - National grant for R&D and Innovation
	Market access	State Council 2012 - New production plan State Council 2012 - building charging facilities; improving standards State Council 2012 - supporting internationalisation (trademark registration & acquisitions) CAAC 2013 - encouragement for private purchase - granting car licenses MF&MIIT&RC 2013 - increase in number of pilot cities MF&MIIT&RC 2013 - 30% of public vehicle purchase has to be EV State Council 2014 - elimination of local protectionism, improving quality, business model innovation MF&MIIT&RC 2014b - every new parking area need to have EV charging MIIT 2014 - the number of pilot cities increased to 39 cities MF&MIIT&RC 2014a - new grant for cities with outstanding performance
	Financial investments	State Council 2012 - support for financial institutions for supporting EV projects MF&MIIT 2012a - additional funds for tech. innovation and new EV models MST&MF&MIIT&RC 2013- additional subsidies for pilot cities MF&MIIT 2014 - tax exemption for EV purchase
	Technology legitimacy	MF&MIIT 2012b - firms should have ISO9001, ISO/TS 16949 quality certification MF&MIIT&RC 2014b - public and educational activities for promotion EV

50% after mid-evaluation of the project is passed, and last 10% at the end. The same ministries supplemented this policy with additional application conditions [52]. Companies should have strong R&D capabilities, which input in the last two years accounted for at least 3% of the main business income. They should also have key-parts supply systems and after-sale service systems and their production should pass ISO9001 and ISO/TS 16949 quality system certification.

In the frame of above-described policies, additional subsidies for pilot cities to accelerate the development of EV sector were proposed in 2013 [53]. To be subsidized, pilot cities had to have a cumulative number of EV not less than 10 thousand vehicles in megacities and 5 thousand in other cities in the period between 2013-15. The number of foreign brands shall not be less than 30% and the obstacles for foreign brands had to be removed. The purchase of new vehicles by public institutions should not contain less than 30% electric vehicles and EV manufacturers could also gain subsidies for each EV sold.

In September 2013, the State Council issued the "Air Pollution Prevention Action Plan", which included the promotion of EV in public sector and encouragement for private purchase with financial subsidies and granting car licenses. Additionally, more than 60% of all public buses in Beijing, Shanghai, and Guangzhou had to be electric or "clean fuel" [54]. At the end of 2013, the government decided to increase

the number of pilot cities and in the first batch of 30 megacities or regions [55] and half a year later introduced new policies for public EV purchase [56]. The share of new EV vehicles purchased gradually increased from 30% set in 2013. The charging facility ratio towards EV had to come closer to 1:1 and every new parking areas had to consist EV charging facilities. Finally, both public and educational activities had to increase awareness of the importance of promotion of the EV for the environment.

Five years after the first major plan and two years after the second plan, the State Council announced the third plan [57], consisting of 25 specific points divided in six chapters: construction of charging facilities; guide manufacturers to innovate their business models; public services promotion; policy improvement; elimination of local protections; strengthening of technological innovation and product quality. The novelty was proposed tax exemption for EV [58], that were introduced at the end of the year and it covered the period between 2014-17. The plan was accompanied with two additional policies at the end of 2014, the first was 2nd batch of pilot groups [59] and it increased the number to 39. The second one was related to constructing new charging facilities [60] and it worked as a reward to pilot cities with outstanding results and without local protectionism. The grant had to be used in further charging facilities development.

C. Local policies

The EV policy in China followed their development formula with the experimental strategy on localized pilots to initiate systematic reforms. Based on the central metaphor of Chinese gradualism "*crossing the river by feeling for the stones*", the strategy allows to test different models of development, and are later reflexed back into the national policy [61], [62]. Thus, the policy comes from the national government–Top-down–and from the local government–Bottom-up–approach, where each pilot city could choose their strategy, as seen from the table III.

The pilot cities used their characteristics and designed specific models with different business models. Beijing–State Leadership model–used strong public and private collaboration experiences to build EV industrial base. [61] Shanghai–Platform-Led Business Innovation model–created international demonstration zone to attract private investments and established EV rental business. This was the only internationally orientated program and included testing zones, data collection, and a network of science, EV manufacturers and energy suppliers [63]. In Shenzhen, the local government actively promoted EV industry development and introduced financial leasing model to reduce the purchase costs. Hangzhou decided to start renting both, vehicles or only batteries. Additionally, they implemented battery switching. And finally, Changqing invested in fast-charging batteries [61].

In August 2011, two years after the project started, all pilot cities were far from the plan. In average, the progress of pilot cities was 26% [64] and the national government intervened with a policy to strengthen pilot projects [45]. The city with the highest progress (55% of the plan) was city Hefei, whose local policy from 2010 gave additional 10 thousand yuan per EV on top of the national subsidy. The strategic alliance for technological innovation was formed with 24 manufacturers, key universities, research institutes and financial institutions. The aim was to increase collaboration and to build their brands [65]. In 2012, the "The Ten Cities, Thousand Vehicles program" came to an end and the national government should transfer them into a nationwide policy. Due to the diversity of the pilot projects, the standardization was hindered. Therefore, the city pilot strategy did not manage to jump-start a national EV industry and consequently to leapfrog [61].

VI. STATE OF TECHNOLOGY

In 2009, policymakers were aware of bottlenecks–market, technology, supporting facilities–in EV sector and the policy should address them. Despite the subsidies, in the following years, customers did not demand electric vehicles, mostly due to their shortages compared to the vehicles on internal combustion. In 2010, the batteries state of technology was not satisfactory. The manufacturing cost per kWh was between 3.4 and 5 thousand Yuan and it presented high part of the EV costs. The batteries life was between 3-5 years or circa 160 thousand kilometers, which was less than conventional vehicles [66]. By the February 2014, the battery production cost decreased to around 3.15 thousand Yuan per

kWh, which was still much higher than 2 thousand planned for 2015 [2].

The average Chinese EV in 2011 had an average range of around 160 kilometers [66] and this had not improved much in next two years. The best selling EV in 2013 (JAC iEV) had a range around 120 kilometers, and the second (BYD e6) around 160, with an option to used bigger batteries–62 kWh–and thus reached up to 300 kilometers [67].

The supporting infrastructure presented a crucial obstacle in sectors development. In 2010, pilot cities used different tactics to tackle it and at that time, charging stations were mainly developed for electric buses. Slow charging speed lowered bus's potential operating time and thus battery swapping model emerged. For normal operation, charging station had to had 60 percent more batteries than buses, for example charging station that covered 50 buses needed 80 additional batteries with 240 9kWh charging slots [66]. Due to high battery prices, the investment for charging facilities were high. Slow charging speed effected passenger EV as well, as charging took up to eight hours and many charging facilities could not entirely charge the batteries. Some pilot cities developed their own battery swapping systems, which decreased the EV purchase cost, yet customers had to pay monthly fees. If not subsidized, the fee were relatively expensive for users [2].

Another view on the technology development could be to compare it to manufacturing development. The data were obtained from "Catalogue of Recommended Models for Energy Saving and New Energy Vehicles, Demonstration, Extension and Application Projects", published monthly since June 2009 by the Ministry of Industry and Information Technology. The catalog contains all products and projects that are approved by central government and consequently are allowed to be supported by local governments [4]. As seen from the Figure II, the number of projects with electric or hybrid buses increased faster than passenger EV. The demand from pilot cities was mostly for electrification of public transport and not as much from private citizens. The new manufacturing projects were the result of demand and as there was no real demand for passenger cars, the car manufacturers did not see an opportunity in faster transition.

VII. CONCLUSION

The Chinese leapfrog attempt in 2009 counted on "indigenous innovation" and domestic market, contrary to Korea in LCD sector, who endogenize exogenous innovations, and by using foreign market became a leader [33]. Electric vehicles demand supplemented infrastructure and the development of vertically integrated sectors–batteries–, which is more complexed than TV sector that only demanded customers behavior change–legitimation. Due to the lack of domestic infrastructure, the EV manufacturing was not able to develop; therefore they should focus on foreign markets with a higher degree of EV readiness to faster achieve economy of scale that lowers costs. Contrary, in the first observed period, there was no policy support to export EV in foreign markets, see Table II. Except for Shanghai's International Demonstration

TABLE III
FIVE PILOT CITIES' STRATEGIES

Pilot	Model		Plan / Realisation 2012
Beijing	State Leadership	Creation of strong EV industrial base Public and Private collaboration	5000 / 1700
Shanghai	Platform-Led Business Innovation	EV exemption from car license plate lottery system International demonstration zone EV rental business	1700 / 1150
Shenzhen	Cooperative Commercialization	Financial leasing model for purchasing cost reduction Strong private firms support EV	4000 / 2400
Hangzhou	Flexible Rental	Promotion of its own plug standard EV battery rental to reduce purchase cost	4100 / 1500
Chongqing	Fast Charging	Battery switching Fast-charging batteries	2200 / 1000

Source: [61]

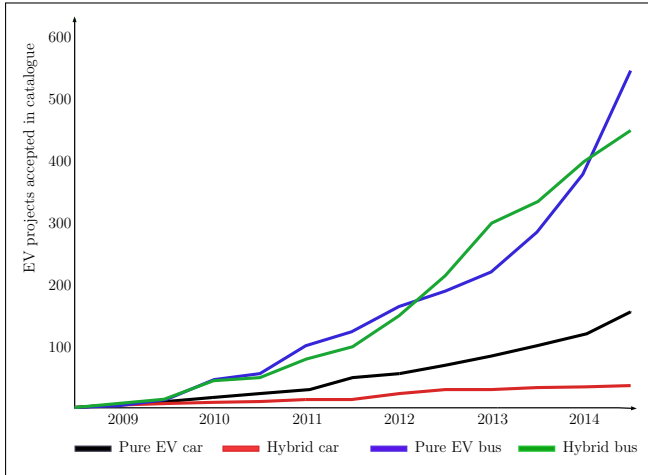


Fig. 2. Catalogue of Recommended EV Models [4]

Zone, there was not even local incentives to internationalize EV sector. Due to the import restrictions [40], the knowledge transfer from foreign markets was insufficient, which hindered R&D capabilities. The government addressed this in the 2012 plan, which supported internationalization processes with trademark registrations abroad and international acquisitions' support [50]. Moreover, in the supporting policy, the obstacles for foreign brands had to be removed [53].

The leapfrog strategy and its goals were promising, however, looking in-depth into policies arises many doubts. Correlating to different routes for latecomers to catch-up, the Chinese route could be seen as "Product Technology Pioneering Strategy", which try to use radical product technology innovation to find the dominant design [27]. The theory suggests latecomer country should reach the lead-market users and gather technological knowledge. In 2009, the government introduced a regulation which defined maturity stage of different EV solutions and assigned them different management strategy [42]. Considerably conservative regulations did not promote manufacturing state of the art technology, but to stay with older types. Additionally, focusing only on the domestic market left them far from the lead-market users, whose demand was for more efficient EV vehicles. Filling the local-less demanding-market did not

pressure manufacturers to innovate and consequently define the dominant design. Last but not the least, 2009 plan had relatively high production goals, which resulted in starting manufacturing before the R&D would come with suitable solutions that would be better for the market.

Another problem in searching for the dominant design was in the pilot strategy, which allowed local governments to find their way of development. The lack of national standardization resulted in different charging solutions that are not compatible. Consequently, the products were localized and this hindered inner-country trade and knowledge transfer. At the end of pilot projects, the variety of solutions could not be transformed into the national policy, or even match international standards. The standardization problem was first addressed in 2012 plan and encourage institutions to come with a unified system that is aligned with international standards.

All the EV policies addressed both EV sector and battery manufacturing sector at the same time. According to [9], vertically integrated sectors should be seen as two separate sectoral systems, which influence each other's development. Despite good lithium-ion battery production for mobile phones and similar products, the policy [42] placed all the EV with lithium-ion battery in the development stage and older Nickel-metal hydride batteries in the production stage. As different management methods supported both stages, this regulation affected the battery sector and its development.

The analysis of both periods showed that 2012 policy tried to solve the problems that appeared during the first period. It also changed the original leapfrog strategy to more slower catching-up approach, based on national innovation system—connecting institutions, industry, and science [50]. However, the comparison of the state of technology in China did not show significant improvement between both periods. Therefore, it is hard to evaluate, what changed the direction of production in years 2013-14, see Figure I. Finally, the insufficient catching-up policy in 2009, could not force the market to adopt, contrary, the market responded and created its path by producing LSEV for increasing local demand for private vehicles.

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