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E-mobility in China: Chance or daydream?

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Abstract

China is the fastest growing car market in the world. Both, government and industry alike have high hopes for the paradigm shift in mobility towards electric cars. China's industry might be able to catch up or leap-frog, once electric cars have hit the roads.

Taking the question if and how paradigm shifts occur as a starting point, this paper describes and assesses the current policies in electro mobility in China and puts them in relation to China's scientific and technological capabilities. The results show that a huge amount of public funding is involved, though spread over many programs and too many provinces. Though the scientific capabilities seem to be very promising, the technological capabilities – applying science to real-world issues – seem to lag behind. These findings let us conclude that the leap-frogging in mobility might not occur in the way the most optimistic spectators might want to see.

1 Introduction

Electric mobility has received significant political attention in the last few years around the globe, in developed and developing countries alike. It is seen as especially important to realize more environmentally friendly modes of transportation and as a tool to reduce carbon emissions, especially in large cities. It can therefore contribute to mitigate climate change in a certain way, especially when the energy comes from renewable sources. In China the State Council has declared the electric vehicle industry one of seven key emerging industries, which will make an above-average contribution to the national growth of GDP in years to come. In the Twelfth Five-Year Plan (12 FYP) from 2011-2015 the key emerging industries might have even increased in importance for the economy. In 2012, the Ministry of Industry and Information Technology (MIIT) and the Ministry for Science and Technology (MOST) both issued additional implementation plans with regards to electric vehicles and their future goals.

Even though these plans have rebalanced the goals with reality, the expectations in and for China for the development of new energy vehicles are still rather high and experts have no doubts that China will become the largest market for EVs in the world by 2020. As in all other countries as well, the development of the electric car market is at a very early stage and a number of technical problems need to be solved before the market will show a significant growth.

The market for cars with traditional combustion engines in China already outnumbered the US car market by total sales in 2009, with a year-to-year increase of 48%. In 2010 total automobile production in China reached 18.3 million units, an increase of 32.4%

compared with 2009.[3] A similar level of production was achieved in 2011 respectively with 18.4 million units.[4]

Considering car ownership per capita, there is still a huge potential for the development of the Chinese car market. Yet if this development will be solely born by traditional combustion engines as of today, the impact on China's CO_2 goals, on climate change, on its cities' air pollution and on people's health could be devastating. Bearing this in mind, the Chinese government strongly supports the development of its national electric car industry. While China has accepted the western countries' dominance in traditional combustion engine technologies as a fact, the government and scientists hope that China can leap-frog this technology and become directly involved in electric vehicle technologies, an area in which they want to become the world's leading player. Hence, the big question is, where does China currently stand, do its policies already have a visible or measurable impact. Both questions are especially interesting when comparing China with other countries engaged in electric mobility. This paper tries to give some answers to these questions, based on the concept of a technology shift, which we parallel with the theoretical discussion of paradigm shifts.

In the next section, the paper introduces some general theoretical considerations, which form the frame for our discussions. The subsequent section presents and assesses the current policies on electric mobility in China. The next two sections offer some empirical evidence of the scientific and technological capabilities of China. Section six details the opportunities and challenges for China in this context, before section seven discusses the findings and draws the conclusions for the future of electric mobility.

2 Theoretical background and research concept

The Chinese government and also Chinese industry as well as some national and international observers see a chance for China to catch-up with industrialized countries once the electric car ousts the traditional combustion engine. As new technologies become more important and traditional competences, so the line of argumentation, might diminish, the established actors cannot rely on their head-start. Some spectators even impute a head-start for China in batteries and therefore in total electric mobility.

A paradigm defined as the rules, theories, concepts and knowledge uses in a certain field, we see this technology shift even as a paradigm shift and we therefore base our

3 China Association of Automobile Manufacturers (2011).

4 http://www.echinacities.com/aroundtown/china-in-pulse/chinas-2011-car-production-surpasses-combined-output-of.html

analysis of China's opportunities in electric mobility mainly on three crucial studies of the concept of technological change and innovations by Kuhn (1996), Dosi (1982) and Utterback and Abernathy (1978; 1975; 1994). Even though many others have followed their views, we found that these three provide us with the best evidence for our study.

Kuhn describes a scientific revolution – which is a completely new way of thinking and theorizing – as a competition between different paradigms, where the current dominant paradigm is fading away and a new paradigm is gaining more and more ground. A paradigm is thereby defined as the theory and its applications and implications or as Kuhn (1996: 10) puts it: "… some accepted examples of actual scientific practice – examples which include law, theory, application, and instrumentation together – provide models from which spring particular coherent traditions of scientific research". In his eyes, a scientific revolution is a shift from one paradigm to another and not a revolutionary switch from the dominant theory from one day to the next, so scientific revolutions occur much more slowly. He also stresses that this scientific revolution deviates from "normal science" as he calls the improvement within a paradigm.

Analyzing the paradigm shifts in the big theories in physics and natural sciences of the past centuries, Kuhn points out that it is hardly the case that the supporters and proponents of the current paradigm change their mind, desert it and become proponents of the new paradigm. Instead, new scientists who are proponents of the new theory gain visibility, increase the numbers of their supporters, and thereby push back the stakeholders of the old paradigm. This is why he uses the term "revolution". It is not to emphasize how quickly paradigms overturn, but it is his notion that a new regime with new actors and new proponents arises, while the old regime diminishes.

Dosi (1982) in his seminal work applied Kuhn's idea of scientific revolutions to technologies. First of all he differentiated between continuous and discontinuous changes, where a discontinuous change corresponds to Kuhn's idea of a scientific revolution rather than a technological revolution. In addition, technical change also occurs in a more continuous way by small, incremental steps, which corresponds to Kuhn's "normal science". These continuous changes are usually planned and occur along a technological path, or as Dosi called it, "a technological trajectory" (Dosi 1982: 157). Dosi's main merit was to introduce the concept of path dependency, which means that the technological progress is usually not disruptive and that small technological steps rely on the technological progress of the past. In other words, technological paradigms have a strong exclusion effect: those who are active in a certain technological area are most likely to be the ones to considerably push technological development. At the same time, they avoid looking towards new technological possibilities (Dosi 1982: 153). Technological development is therefore strongly related to the position that a scientific team (a firm, or a country) has in relation to the technological frontier. If they are at the frontier, they cumulate more knowledge and know-how around their technology and are the ones who push it forward. This also explains why catching-up in existing technology paradigms for new players is extremely hard and rarely possible.

However, he also stresses that new players might appear on the scene when a new trajectory is implemented as he states that "[o]ften this period of emergence of new technologies is actually characterized by newly emerging firms, even in cases when the major technological advances were originally produced in established firms and institutions…" (Dosi 1982: 157). While Dosi's main focus was on the development of the technology and the technological path, Abernathy and Utterback (1978; 1975) had a broader perspective on the market and the diffusion of technology when they discussed product and process innovations and when they introduced the concept of radical and incremental innovation.

In the view of Utterback and Abernathy (1978; 1975; 1994) a technological breakthrough first of all occurs as a product innovation, which then undergoes technical improvements and maybe the integration of existing technologies, before it flows into a dominant design. The technology underlying this dominant design will then be incrementally improved and its market might shift from a market that competes on technology or quality to a price competitive market. In this process, incremental innovations whose first aim is to reduce the costs or slightly improve the existing technology will follow.

In line with Dosi's distinction of continuous and discontinuous change, Abernathy and Utterback (1978) discuss the effects of radical and incremental innovation on technological progress. This technological progress can be put on hold, when a technological lock-in effect occurs and other technological possibilities are neglected or not seen at all by the leading actors. If the dominant design that emerges is not the one that is followed by these particular actors, other actors will be in pole position to see their products diffuse the market. This again is in line with Kuhn's view of scientific revolutions, as well as with Dosi's concept of technological paradigms and trajectories.

In our opinion, we see a slow shift of the technological paradigm in mobility on the horizon. Still a long technological way might be ahead, yet an intermediate technological paradigm (plug-in hybrid cars) is already emerging, before slowly more and more electric vehicles populate the roads of this world. We would also call it a revolution in the Kuhnian (1996) sense and we would also expect a slow and insidious change towards this new industry or technological paradigm.

Following Kuhn and Dosi, the existing car manufacturers with a strong global position might not be the proponents of electric mobility as they still stick with the old technology. Their argument of the huge potential that still lies in the improvement of the combustion engine and the incremental innovation follows the theoretical outline without any doubt. Hence this opens the space for new and so far unseen actors. This, however, is one of the main arguments why leap-frogging in electric mobility might be possible and why China is seen as one possible leading country in the future.

Some spectators believe that China has a good chance to catch-up or even directly jump to the top of electric mobility due to its experience with electric bikes and scooters. They argue that especially battery technology, which is the core technology of electric mobility, even more so than power electronics, materials and chassis and related technologies, is seen as one of the core competences of Chinese industry. So, taking Dosi's concept of technological trajectories into account, China might be in a good position for the paradigm shift in electric mobility. Yet other observers doubt that it will be an easy task to transfer any useful knowledge from scooters to cars and that the challenges of car batteries are still quite different to those of scooters, as they typically cover a short distance every day and are recharged at home or at the work place.

However, to become successful in a broad range in a certain technology or industry and to even become a global leader, more than just mastering the technology is necessary. Besides, the question is, if the diffusion of the technology and – in this case – even more so, of complete products including sales channels, after sales services and a high quality and safety level can be achieved. According to the argumentation by Utterback and Abernathy this also holds for the new mobility paradigm. In this context a governmental intervention might just kick the technology and create a market for it, like in the field of renewable energy technologies, where governments use feed-in tariffs or other regulations and subsidies to foster the demand. In the case of electric mobility, the strong environmental regulations for example in California help to speed up the paradigm shift.[5]

Also Utterback and Abernathy might argue that the Chinese electric car industry is in a good position to become one of the world's leading countries in electric mobility. Those who have a second-mover advantage and are free of the past's intellectual and technological burden might prevail in the emergence of new technologies. Yet in Dosi's sense

[5] At the same time one could argue that those who are forced by such strict regulations to adapt in an early phase might gain a head-start in the new technology. Chinese car manufacturers play no role in the Californian car market, so the Chinese government needs to establish its own California-like regulations.

of the cumulative nature of technology progress there might be doubts that the relatively young Chinese car industry can catch up so quickly.

In the end, it is the question of mastering the technological challenges, yet this will not be enough. Another very crucial question is the diffusion of technology. Those technologies – or individual technological solutions – that diffuse faster or diffuse at all might become the dominant design, while others might drop out (e.g. the competing technological solutions in the new vehicle field like plug-in-hybrid, range extender, fuel cell, full electric vehicle or the more or less aborted hydrogen combustion).

The question which automatically arises here is *how are new paradigms selected?* Dosi has tried to answer this question and has especially pointed out the role of market and non-market influences[6], especially of institutional effects like policies and R&D investments (Dosi 1982: 155). He identifies industrial and social conflicts and argues that their trade-offs may define which technologies prevail in the end. Current policies for electric mobility clearly show that the Chinese government is trying to use its influencing power and cover up for the yet not existing or still rather weak markets in order to move towards this new technological paradigm faster than other countries while hoping to take the lead in it.

According to Dosi, the most important question related to the influence of policies is the unpredictable nature of innovation. It is almost impossible to evaluate *ex ante* which technology might become the leading trajectory or dominant design. This is enhanced by the fact that at this early stage the technology development heavily relies on the "multiplicity of risk-taking actors" (Dosi 1982: 157), which have to engage in competing technologies and designs. Nelson (2008: 486) argues in the same direction and states that in the early phase of technology progress or the development of a new paradigm there is a necessity for a number of competing alternatives. Hence policy intervention, which might tend to restrict this competition, might create new stumbling blocks for technological progress.

The following analysis of the Chinese policies towards new energy vehicles draws on the above described power of policies to influence the technological trajectories and the development of new paradigms. It is followed by an assessment of the current development by measurable and comparable indicators. By doing so, Dosi's finding of the relation of technological progress with a country's/firm's position regarding the technological frontier is reflected. We then relate the findings to an analysis of the current opportunities and challenges for the development of electric mobility in China.

6 Rosenberg (1976) calls this the "focusing device".

3 Policy Analysis

As in most other countries, there is not only one single policy dedicated to e-mobility in China, but many different policies from different ministries and agencies with different main targets influence the development of e-mobility. The current strategy of the Chinese government concerning the development of electric vehicles is supported mainly by three major policy fields: support for R&D, support for the related industry and the support of private and public consumption. The majority of these policies are industrial policies and they have been adopted by the State Council, the highest level of government, most notably the 12th Five-Year Plan (2011-2015) and the Plan for an Energy Efficient and New Energy Vehicle Industry (April 2012).[7]

The Ministry for Industry and Information Technology (MIIT) is in charge of these industrial policies. As the technology is still rather immature, the Ministry of Science and Technology MOST also significantly supports the research and development of electric cars, especially with the two large national R&D programs, 973 (for basic research) and 863 (for applied oriented research). Support of public and private consumption is stipulated by a number of demonstration projects, most notably the "Ten cities, one thousand cars" program and the five model regions for subsidies for private buyers. Public consumption is also targeted by the plans to set up the respective charging infrastructure. The three policy arenas will be described and analyzed in the following.

3.1 Industrial policies

In 2009 the State Council declared a fuel efficient and new energy vehicle industry one of the country's seven new emerging strategic industries. These seven industries are seen as most important for the country's economic development and they are expected to contribute with above-average growth rates to the national GDP. The electric vehicle industry is also explicitly mentioned as an important and strategic industry in the 12 FYP (2011-2015). In April 2012 the State Council released the "Development Plan for an Energy Efficient and New Energy Vehicle Industry (2012-2020)" as its current most important plan with regard to the development of the electric vehicle industry. The plan describes the industry's basic goals as well as some implementation guidelines for the goals of the 12 FYP. Both recent plans indicate the highest possible governmental support for the industry's development, both financially and politically.

Published by the State Council, the "Development Plan for Energy Efficient and New Energy Vehicles" was drafted under the responsibility of MIIT, but includes the support

7 For a more detailed analysis of China's electric vehicle policies see Tagscherer (2012).

of several other ministries and government agencies, e.g. Ministry of Commerce MOFCOM, Ministry of Science and Technology, Ministry of Finance MOF and the National Development and Reform Commission NDRC.

The goal of this plan is to support the whole industry chain of a fuel efficient and new energy car industry, including the development of standards and regulations, as well as for the three key components (power engine, electric drive and power battery) to reach world level. China intends to have around 500,000 electric cars (pure EV and plug-in hybrids) on Chinese roads (including buses, sanitation vehicles etc.) by 2015. The aim is for this number to increase to more than 5 million vehicles by 2020. In the plan hybrids without plug-in technology are excluded from this plan as well as from major government subsidies. The plan proposes that the sales of China's new energy vehicles are the world's number one by this time.

3.2 R&D policies

MOST started to support the R&D of new energy vehicles in a significant and visible way during the 10th Five-Year Plan (FYP 2001-2005), especially in its basic research program called "863". The R&D program supported three key technologies (called the three verticals): fuel cell, pure electric and hybrid technologies as well as the three key technology areas (three horizontals) of power engine, electric drive and power battery. The research was mainly conducted in R&D institutes, universities and in a few R&D departments of state owned enterprises (Sun 2010; Yun 2011). The investment for electric vehicles in the 10th Five-Year-Plan was around 290 million RMB (Gong et al. 2013: 211).

Fuel cell development, hybrid technologies and pure electric vehicles were also supported by MOST under the 11th FYP, again especially in the 863 program. Research and development of new energy cars are also part of the *"Mid-to-long Term plan for Science and Technology (2006-2020)"*, China's most important policy document regarding science and technology (Yun 2011).

During the 11th FYP China spent between 1.1 billion RMB on new energy vehicles. Together with enterprises' investments, this amount might be at 10 billion RMB (1.5 billion USD) in total, which is considered to be a rather small investment (Sun 2010: 30). Lin et al. (2010: 5) and Gong et al. (2013: 211) refer to 2 billion RMB and 1.5 billion RMB of R&D investment by the national government. There are no official numbers available of how much the local governments might have spent on R&D in these fields.

In March 2012 MOST released its "Special 12 FYP Plan for Electric Vehicle Technology Development", which can be seen as one of the implementation plans for the goals stated in the 12 FYP (MOST 2012). Even though some discussions were going on in the years before whether China should support pure EVs only or include plug-in hybrid cars, the new plan now supports both technology pathways. For the period until 2015 hybrids will be supported as a means of transition, before China is able to rely solely on pure electric cars. MOST's final strategy is clearly to develop pure electric cars, but as hybrids are closer to commercialization, they will be supported at the same time.

3.3 Support for public and private consumption

Policies for private and public consumption are implemented in two major demonstration projects, which will be described in the following.

Ten Cities, One Thousand Vehicles Program

In 2009 the government (Ministry of Science and Technology, Ministry of Finance, Ministry of Industry and Information Technology and NDRC) introduced the *"Ten Cities, one thousand vehicles Program"* to encourage the public use of electric cars through demonstration projects in different cities. In this plan, 1000 vehicles shall be introduced every year for three years in these ten cities. The number of participating cities quickly rose to 13 and by 2011 the total number of cities participating in this program reached 25[8]. It is still unclear whether the program will be continued after 2012.

Each city is responsible for the implementation of the project. The central government sets a certain set of framework conditions for its support, but the local governments need to implement the demonstration projects according to their own local needs and necessities. This leads to the fact that each city sets up its own policy to promote new energy vehicles, sets up own industrial alliances, creates its own guidelines for financial support and provides its own (additional) R&D funds. It also leads to the creation of many different standards on the provincial level. Most recently, MOST and MIIT have tried to urge the Chinese industry towards more national standard setting in electric car development (Zhen 2012).

Even though government regulations make open bidding necessary for these demonstration projects, eight city governments have purchased their vehicles from their local car manufacturers only. Some experts therefore worry, that local interests might conflict with the national industrial policies and that local protectionism violates central policies

8 These 13 cities are Beijing, Shanghai, Chongqing, Changchun, Dalian, Hangzhou, Jinan, Wuhan, Shenzhen, Hefei, Changsha, Kunming, and Nanchang (Lin et al. 2010; Yun 2011). Additionally Tianjin, Haikou, Zhengzhou, Xiamen, Suzhou, Tangshan and Guangzhou joined in 2010 and in 2011 another 5 cities joined the program.

(Lin et al. 2010: 16). There might be a risk of developing the same technologies at multiple places at the same time and wasting public money. Also some companies might be strongly supported, even though their technology level might never reach the national or the international standard and therefore weaken China's international competitiveness in the long term (Sun 2010).

For the cities, investing in the local automotive industry is basically an instrument to increase investment from outside into the city and it is therefore seen as an investment into the city's attractiveness. How effective these investments are with regard to the development of electric vehicles seems to be only a marginal concern.

Official numbers given by the cities or respective government agencies state that Shanghai, Changsha and Beijing together have already purchased more than 3,000 new energy vehicles and the total number in the 13 model cities has reached more than 5,500 cars. Yet non-government organizations estimate that in fact by 2010 there were about 2,000 new energy vehicles on China's roads (The Climate Group 2010b). Most of these e-vehicles are used as taxis and buses (Huo et al. 2010) and private consumption has still been left out so far. This is supported by the information that from the 100 BYD E6 ordered by the Shenzhen City government, by 2010 half of them had been delivered.

Pilot Project for Private Consumption

With the announcement of the *"New Energy Vehicle Demonstration and Promotion Notice"* in January 2009 the Chinese government paved the legal way for the implementation of financial subsidies for the purchase of public vehicles. Following this notice, the Ministry of Finance (MOFCOM), the Ministry of Science and Technology (MOST) and the National Development and Reform Commission (NDRC) introduced the first pilot project for private consumer subsidies *(Pilot Project for subsidies for the purchase of new energy vehicles*) in June 2010. In the six cities of Shanghai, Beijing, Shenzhen, Hangzhou, Changchun, Shanghai and Hefei consumers are able to get government subsidies for the private purchase of fuel efficient and new energy cars. For pure electric cars the subsidy is 60,000 CNY and 50,000 CNY for plug-in hybrid vehicles (China Daily 2010: 1; Yun 2011). In all other regions, purchases of private consumers are not yet intended, as the industry itself is not ready and the infrastructure is not yet in place to serve a bigger demand.

Local governments, e.g. in Shenzhen and Changchun, have implemented additional local subsidies to make the purchase even more attractive. In addition to the financial support on the national level, Shenzhen government offers up to 60% discounts on the local brands of new energy and fuel efficient vehicles.[9] Other support measures include the exemption from license plate auctions, one day per week driving restrictions, and the granting of preferential parking.

So far private consumption is still not in the main focus of government support. The six cities are mainly used as a test base to gain a better understanding of private consumption patterns and behaviour, but also for the adjustment of framework conditions and infrastructure development. Most analysts state that the technological development of Chinese electric cars is not mature enough to diffuse it to private customers and therefore the support of mainly public cars like taxis and buses seems to be rather reasonable. Car expert Yale Zhang states that the basic assumption behind the 500,000 e-cars by 2015 is that most of them are still bought by governments. In his opinion, this overestimates the local willingness and capacity to buy e-cars (Zhang 2012). Besides, some experts have expressed concerns about subsidizing private consumers, as the development should benefit the society as a whole. So in their opinion, public transport subsidies fulfil this requirement much more than subsidies for private transportation. In contrast it can be argued that government subsidies at this point of technology development could also help to overcome the valley of death of the new technology, yet so far policy makers are still holding back private subsidy schemes on a larger scale.

It can be argued that while US and European car manufacturers, less of course than the Japanese, have for a long time neglected the development of electric cars and instead focused on the optimization of fuel consumption of combustion engines, the Chinese government has seen its chance to promote electric vehicles and thereby avoiding the difficult process of catching-up. It has obviously perceived the Chinese chances in this catching-up process as rather low compared to the chances they saw in the early support of electric drive technology and their own R&D developments. The Chinese government's policies follow the theoretical assumption of Kuhn, Dosi and Utterback and Abernathy, which we outlined above that once a paradigm shift occurs, the chances of new actors coming into play and even winning the game increases.

Not only in China, but also on the global markets, we can see completely new companies being established around new energy cars or single components (e.g. Tesla, Coda, Wheego, Haima) as well as other companies shifting their core business.

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9 http://green.autoblog.com/2009/05/15/chinese-cities-offering-incentives-to-buy-locally-made-hybrid-car/

To summarize the above, one can see that the Chinese government supports electric vehicles at several stages of its development, from basic science to diffusion. However, especially the funding for diffusion might hamper a real diffusion as a dominant design (Abernathy and Utterback 1978; Utterback and Abernathy 1975) might not yet evolve. Therefore one might assume that the Chinese government is taking a wise step in not inflationary providing large scale subsidies for private users at the current stage of development, avoiding to be locked into a certain design that might not end up being the most successful on the market. At the same time, the government is testing some private support and technology diffusion policies in the five model cities in order to get a better understanding on how these policies work and to adjust their policies respectively. The pilot cities are seen as an experimental field which should help to prepare once a dominant design or leading technology is visible.

In contrast to that more careful approach the local diffusion policies of the provinces and cities, especially in the 10 cities 1000 cars program, can be seen rather sceptically as these policies might currently reduce or might have reduced in the past the competition for the best technological path. The variety as stipulated by Nelson (Nelson 2008) is given, but the policies are not technology-neutral so that Dosi's (1982) argumentation against government intervention might come into play here. In the end, the strong financial support on the diffusion side might hinder competition and the well-intended subsidies could create new stumbling blocks for China on its way to this possible new paradigm.

It might be the balance of how much financial support is given at which state of development and how much at the same time the market can freely develop that might decide whether the Chinese policies will have a positive impact on the potential paradigm shift ahead.

4 Indicator Analysis for Patents and Publications

Publications and patents are both indicators of early-stage innovation activities and may offer a perspective on future market strengths, based on current scientific and technological strengths. In an international comparison, the scientific and technological competitiveness can be assessed. Scientific publications are one of the most important outputs of science systems, especially of public research in universities or in non-university institutions. Patents, on the other hand, are a vested right to keep others from using a technology that was invented (filed) for the first time. In exchange for this vested right, a disclosure of the technical items and a complete description of the invention is necessary (Frietsch et al. 2010). The majority of patents are filed by companies or individuals, while only a minority is filed by public research institutions. In Western innovation-oriented countries the share is about 5% of total filings (Dornbusch et al. 2012; Lissoni et al. 2008).

The question in this section is, if China is able to master the technology, to theoretically and especially scientifically base it on solid grounds and gain a national and international technological competitiveness. As the other countries – or to be more precise, the car manufacturers in other countries –, who were and are strong in traditional combustion engines, do not stand still, the crucial point here is to analyze if China is able to really catch-up and make use of the technology and paradigm shift as the theory suggests and some of the spectators expect.

4.1 Publications

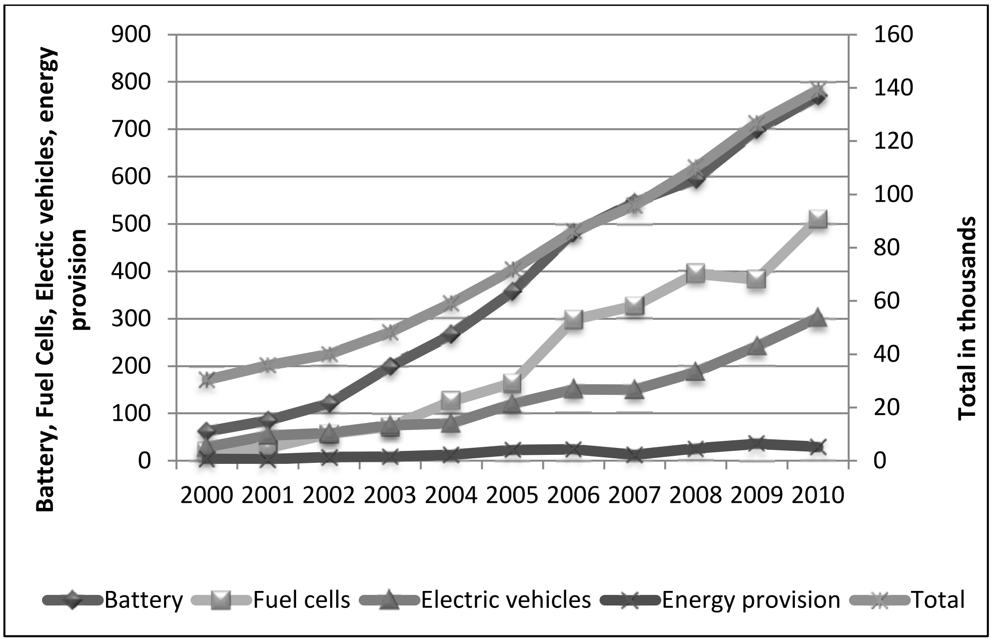
Figure 1 shows the absolute number of Chinese publications and different subfields of electric mobility in the database Web of Science. We differentiate between three basic fields of mobility, namely battery technology, fuel cells, and electric vehicles in general, which includes energy distribution, power electronics, electric engines, but also issues such as brake energy recovery, plug-in hybrids or the layout of electric vehicles in general. Another very important question that needs to be addressed in the era of electric mobility is where the energy comes from. This was already broadly mentioned in the policy section. Therefore, we also include technologies that are relevant for energy provision in the context of electric mobility, like smart grids, bidirectional converters, state of charge control, distributed energy resources etc.

The data shows a steep increase in the total of Chinese scientific publications in general in the database. A similarly steep trend can also be found for publications concerned with batteries for vehicles. A less steep but still steady trend is also visible for fuel cells, while publications in the context of electric vehicles in general only increased after 2006, and reach a much lower level than the number of publications in the other two fields. What becomes very clear from this analysis is that the question of energy provision in the context of electric mobility is almost of no relevance in the Chinese science system.

What is very striking is the strong increase in the share of Chinese electric mobility publications worldwide. It becomes apparent that China (18.4%) has become one of the most important scientific nations in battery research only second to the USA (28.5% in 2010), but also has considerable shares in fuel cells (17.5%) and in energy provision (13.6%), which are all well above the Chinese share in total publications (11.0%). The shares in electric vehicle publications in general reach a lower level, which is similar to the total shares.

Next to the quantity it is the quality of publications that is of interest to our analysis. Quality is usually indicated by citation measures, using the number of citations of each article in the Web of science. The basic idea is that better papers are cited more often (Jin and Rosseau 2004; Moed et al. 2004). The citation index[10] that is depicted in Figure 2 shows values above one (world average) for China in the fields of fuel cells and batteries only recently. This means that Chinese publications in the field are only recently cited on a similar level or slightly above a level like – on average – any other scientific publication in this field. One could also formulate it more positively: given the huge number of scientific publications in the field of electric mobility, they were even cited on a similar level as publications from any other country (on average). So the visibility and from this derived the quality of Chinese publications in these areas is rather high.

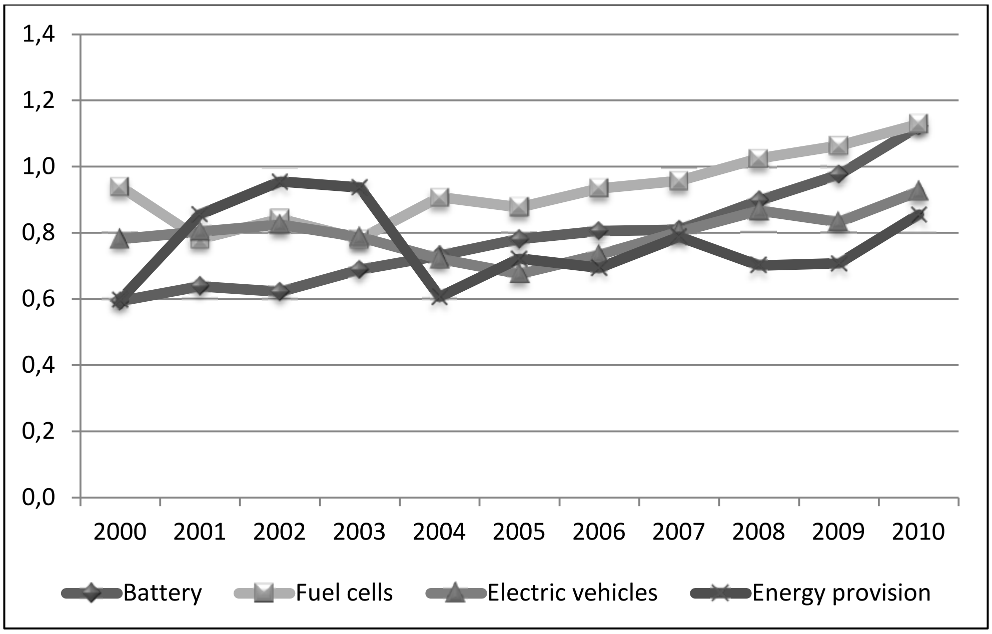
Figure 1: Absolute number of Chinese WoS-Publications in electric mobility fields



Source: Thomson – Web of Science; Fraunhofer ISI calculations.

10 We use a three year citation window for this analysis. In consequence, data for the publication year 2008 is the latest completely available cohort for citation analyses.

Figure 2: Relative citation rate of Chinese WoS-Publications in electric mobility fields



Source: Thomson – Web of Science; Fraunhofer ISI calculations.

4.2 Patents

Patent data analysis allows several perspectives on the technological competitiveness of China in the field of mobility. While scientific publications reflect the activities of the science system and thereby – as a matter of fact – mainly focus on basic research, patents draw a picture of the technological strengths mainly of the industry sector. While this sentence is absolutely true in the majority of innovation-oriented countries, this still might be different in China, where large shares of patent applications are filed by public research institutions. However, patents are more application-oriented than scientific publications. In addition, patents might be filed at different patent offices. This information offers additional information on the markets that are targeted and on the international competitiveness of the technologies. We take the inventor country instead of the applicant country information to define Chinese[11] inventions, as we are interested in the knowledge sources and not in the ownership of the technology. In other words, we want to find out if the knowledge of and capabilities for electric mobility are existent in China and if this knowledge is internationally comparable. We use invention patents only.

11 China is defined as mainland China including Hong Kong, excluding Taiwan.

As Figure 3 shows, the number of patent applications to the State Intellectual Property Office (SIPO) by Chinese inventors has increased enormously since the beginning of the new century. This is a well-known fact. What can be seen in Figure 3 as well is a steep increase also in the number of electric mobility patents, while the dynamics in traditional combustion mobility are rather limited. However, it is also evident that both forms of mobility play a subordinate role in the Chinese patent portfolio at SIPO. In 2009 only about 5,000 patents were filed in electric mobility and just about 1,200 out of more than 200,000[12] patent filings in that year were in traditional combustion mobility.

The strong increase over time leads to high shares of Chinese inventions in the context of electric mobility in recent years. As can be seen in Figure 4, almost 2/3 of all patent applications in China have a Chinese inventor on the list. Another quarter is filed by Japanese inventors and the rest of applications originate in other countries. The largest among them is Germany, followed by the USA and South Korea. This underlines the strong position of Chinese inventors in this field at home (at SIPO).

It is interesting to see in Figure 5 that the shares of Chinese inventors per field are highest for powertrain technologies and biofuels, which are above the average of total filings at SIPO. Electric engine technologies, brake energy regeneration, and batteries still reach a level well above 50%, but are below the average. Obviously, in all of these fields also inventions made in other countries are filed in China as the Chinese market for these technologies might be of some interest to foreign applicants. This is even more so for fuel cells and hybrid technologies as well as for traditional combustion technologies. Another explanation is that Chinese inventors themselves are not yet ready to file invention patents in these areas and might not be able to compete with the international quality of the patented technologies.

This latter argument becomes even more evident when patent applications outside China at the transnational[13] level are analyzed (Figure 6 and Figure 7). The growth of the filings accelerates after 2003 for total filings as well as for electric mobility technologies, while again traditional combustion technologies are not very dynamic. In the recent years under observation another jump in the numbers is visible here. The

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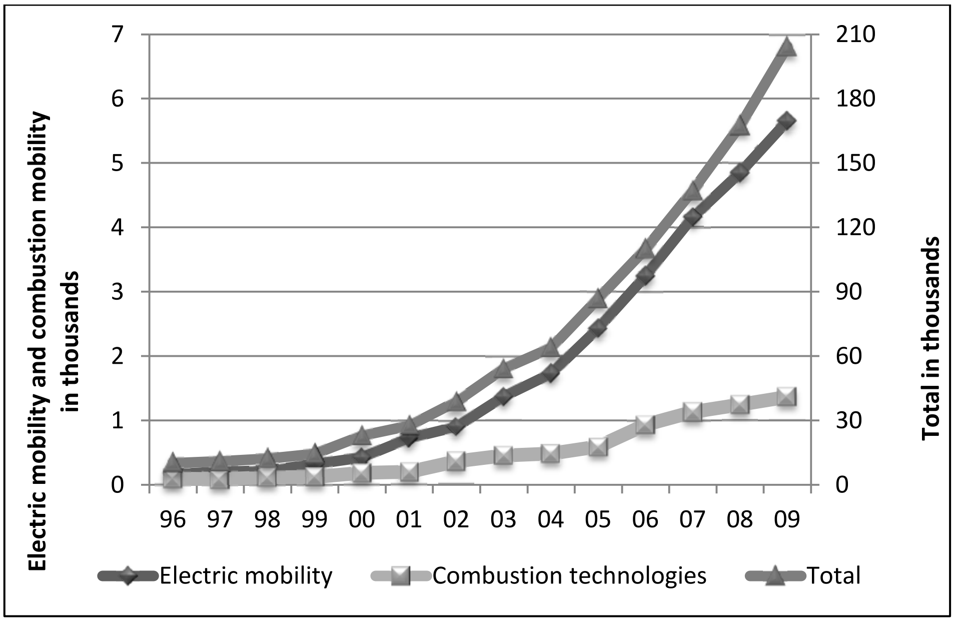
12 We use EPO's PATSTAT database as a source for our analyses. We use priority date – the date or worldwide first filing – to define the year. It takes 18 months before patent applications are published. Some of the applications that were filed to the office might never be published mainly due to the withdrawal of the applicant in the early phase. Next to the use of the priority instead of the filing date, the non-published patents are the reason for the differences between our data and the statistics published by SIPO (or any other office).

13 Transnational Patents are patent families with at least a family member filed at the EPO or under the PCT (Frietsch and Schmoch 2010).

shares in the worldwide patent applications by Chinese inventors reached a level of 6% in 2009 for all patents, 5% in the case of electric mobility, and less than 2% in the case of traditional combustion technologies. What becomes evident again is the fact that the absolute number of patent applications is also rather low compared to the total number of applications. Only about 280 out of almost 12,000 patent applications are in the field of electric mobility. The country with the largest share (see Figure 7) of patents in electric mobility is Japan reaching a level of more than 37%, followed by Germany (21%), the USA (8%), and South Korea (7%). China only plays a minor role with a share of 3.4% in the period 2008-2010.

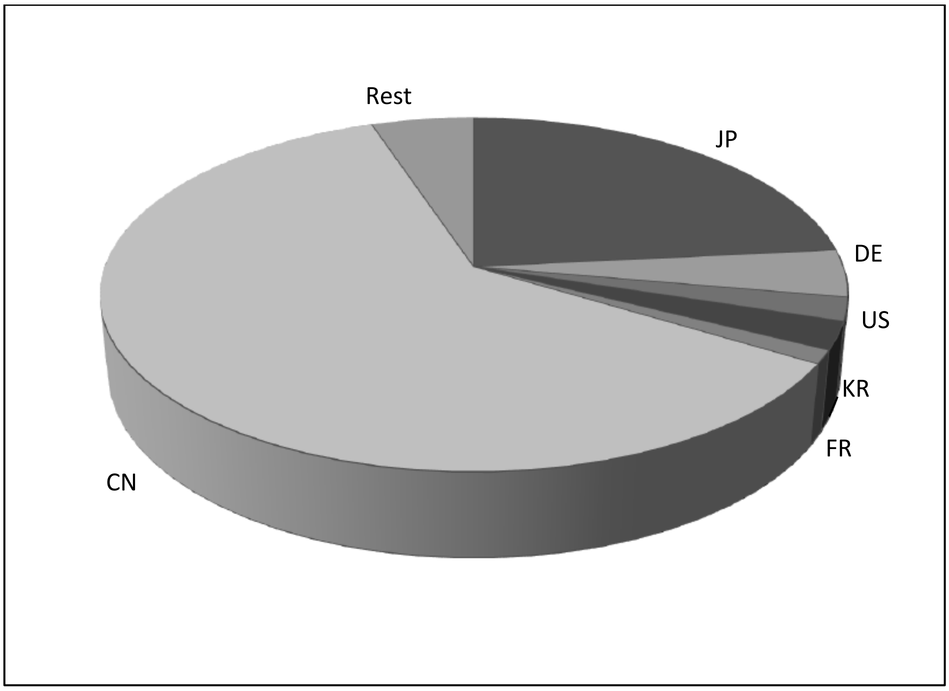
In sum, the application of the scientific findings and the conversion of the scientific strengths into marketable technologies in the area of electric mobility are not yet visible. Especially in the most promising areas of batteries, fuel cells, and – relevant for the bridge to electric mobility – hybrid technologies, Chinese inventors do not yet show broad competences. The results show that it is a long way from science and theory to application and markets. In the coming years, China might be more able to convert scientific results into applicable technologies, but from the current point of view China is still in the catching-up phase. So from our theoretical perspective of paradigm shifts and the opportunity to catch-up or even outperform traditional car making countries or companies, China is not yet able to exploit the full potential. The huge national market, however, might offer good starting conditions and promise economies of scale. This would be in line with both, Dosi's (1982) as well as Utterback and Abernathy's (1978; 1975; 1994) line of argumentation. However, so far it is only a promise or an expectation rather than a real trend, as the policy analysis in the previous section emphasized. What can be seen from our data is that not only Chinese inventors have identified electric mobility as a relevant and interesting area of activity, but also inventors from other countries. So the Chinese technologies need to prove themselves not only on a national level – where they also compete with internationally invented technologies –, but also on an international level. In the end only those might prevail, which are able to offer globally applicable solutions to the challenges of electric mobility. The successes in electric mobility reflected by scientific publications raise the expectations on a positive future development of the Chinese industry and China as a research location also for applications under the new paradigm of mobility.

Figure 3: Absolute number of patent applications in mobility of Chinese inventors at SIPO



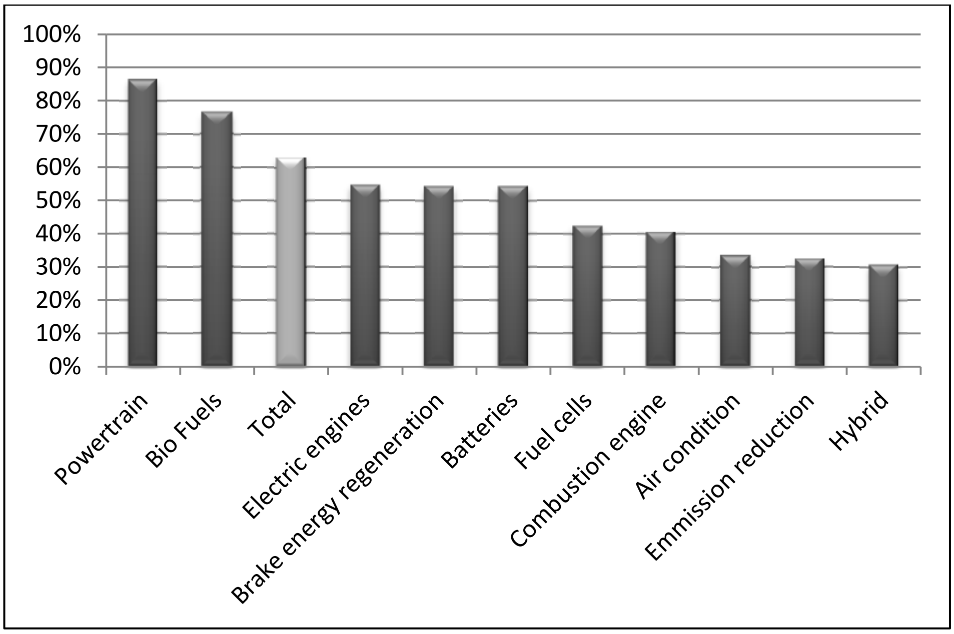
Source: EPO – PATSTAT; Fraunhofer ISI calculations.

Figure 4: Shares of selected countries in SIPO patent applications in electric mobility, 2006-2008



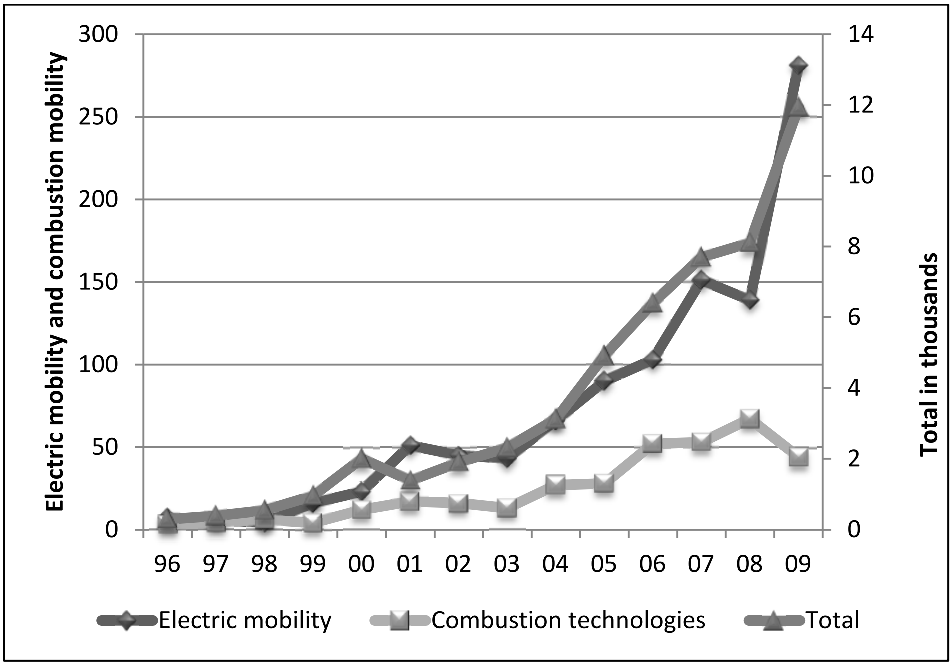
Source: EPO – PATSTAT; Fraunhofer ISI calculations.

Figure 5: Shares of Chinese patent applications in total applications in mobility fields at SIPO, 2007-2009



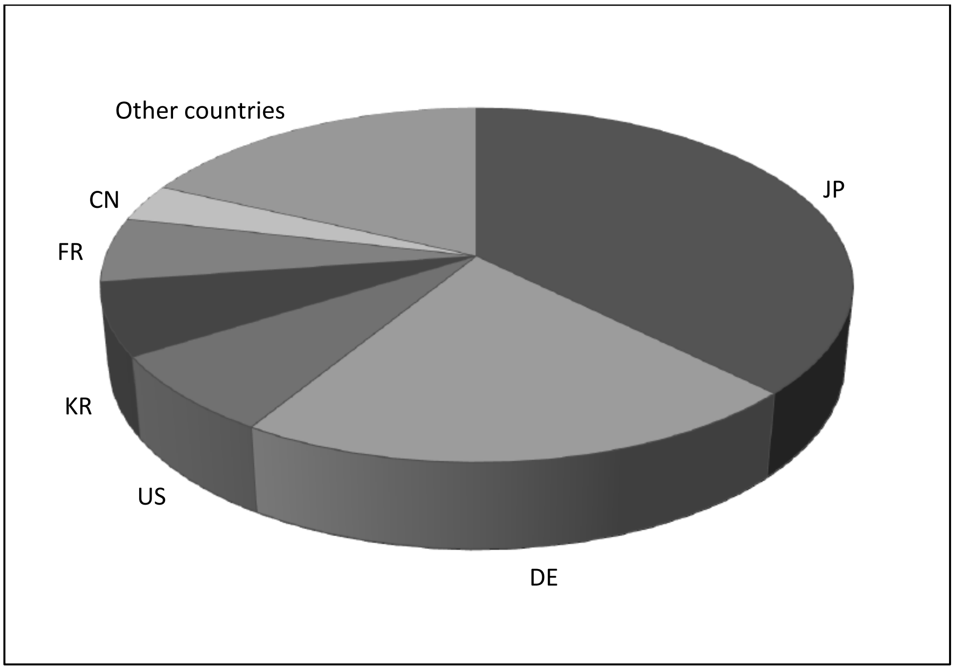
Source: EPO – PATSTAT; Fraunhofer ISI calculations.

Figure 6: Absolute number of Transnational patent applications in mobility areas of Chinese inventors



Source: EPO – PATSTAT; Fraunhofer ISI calculations.

Figure 7: Shares of selected countries in Transnational patent applications in electric mobility, 2006-2008



Source: EPO – PATSTAT; Fraunhofer ISI calculations.

5 Discussion and Conclusions: Opportunities and Challenges

Applying quantitative as well as qualitative empirical analyses, this paper addressed the question, if China is able and has a chance to catch-up in mobility technologies in the medium term. From a theoretical/conceptual perspective, a change in the underlying paradigm might offer new opportunities for new market entrants. It was discussed, if the shift from combustion-based to electric mobility is such a paradigm change. Though we were not able to give a final answer to this question, it seems that the current advantages in innovation policy and R&D performance as well as strong worldwide market positions of the actors in combustion technologies are important factors also for the future positions in electric mobility. There is a clear political and policy hype visible in China – like elsewhere. At least for China it seems that it is not sufficiently backed by market developments. There are clear dynamics and also a large number of scientific publications have originated in China, which might suggest an even higher growth in the future. In addition, the technological position in the home market is considerable, there seems to be no reasonable and considerable trends outside China. Yet mastering electric mobility in China alone will not be crucial enough.

We see that the Chinese government is following the strategy of betting on any horse in the race. Their hope seems to be that this will in the end produce at least one Chinese company that is among the winners. So this strategy might be effective, but surely not efficient. However, the size of the Chinese market seems to allow for such inefficiencies. Furthermore, as our theoretical discussion showed, the technological solution is only one part of the answer to the question of future mobility. The diffusion is another main component in this endeavour. And here again the Chinese governments – national and provincial – play a strategic role especially by setting the regulations, norms and standards that apply to the Chinese market. As the Chinese market is one of the largest markets in the world and currently is for sure the fastest growing market for mobility, the government can influence the diffusion of related technologies in the country. Yet, this does not mean that their companies for sure will take the lead in the global technology development.

Technology diffusion is a science in its own as dimensions like quality, price, and marketing (including sales channels) are crucial for its speed, breadth, and sustainability. And here the diffusion on the Chinese market might be regulated by the Chinese government, but the diffusion outside China might not be influenced sufficiently, especially if the technology and the quality are inferior to the solutions of the non-Chinese actors. Without any question, Chinese car manufacturers will become important players in the field of mobility in general and of electric mobility in particular. But the unanswered question still is, if they will be able to be successful beyond the Chinese market. And here the current visible protectionism of the Chinese government in the Chinese market might hamper or even weaken the position of the Chinese car manufacturers in international markets.

The development of new energy vehicle industry in China – like in many other countries – does need the combined efforts of government and industry. On governmental levels, the coordination of policies among different ministries and agencies and as well as between the national and the local level are of key importance to its success. So far it seems that the most enthusiasm has come from public authorities and the car manufacturers themselves. Yet private consumers and experts seem to be less enthusiastic about the development of new energy vehicles in China.

5.1 Advantages and Opportunities

There are quite a number of advantages for China and the opportunities seem to support its chances to leap-frog into becoming a leader in electric vehicles.

The most important and biggest opportunity is the potentially huge market for electric mobility. As the number of cars per person still remains far below more developed countries and the income of the average Chinese family income is still increasing, a huge growth is anticipated in the automotive market. As the government has clearly stated that it does not intend to let this growth be driven by the internal combustion engine technology, there seems the possibility of a big market share for electric vehicles. As mentioned in the policy analysis, the current plans aim at 500,000 electric cars (pure EV and plug-in hybrids) on Chinese roads by 2015 and more than 5 million vehicles by 2020.

Besides the market potential, the development pace has been quite fast over the last few years. With the 12th FYP and the following policies there is a lot of catching up going on in the companies as well as in the laboratories of research institutes and universities. Since electric vehicles have become one of the strategic emerging industries, the development pace has increased and so has investment. The support through the different national and regional plans and policies goes hand in hand with a huge financial support from the government, even though official investment numbers for this technology are not available. State owned enterprises are also motivated by government investment into this leap-frogging adventure. Driven by the government it has formed a collaboration platform for electric vehicles, called SEVIA (State-owned enterprise electric vehicle industry alliance). Some experts see such measures together with the high investment and the policy support at various levels as a huge advantage for China, because they believe that with such an investment rate into the technology, there will be eventually some success stories and even breakthrough innovations may be possible.

China has already introduced private subsidies for the purchase of cars in the six model regions mentioned before. If the demonstration projects go well, this can easily spread all over the country and analysts have no doubt that the government would be willing to do so. This would then, almost automatically, translate itself into the next comparative advantage, namely economies of scale. In China, the growing middle class, the supporting policies and the size of the market will generate economies of scale, which will result in reduced costs and benefit the users of electric vehicles. This will also give the producers of electric cars in China plenty of opportunity to invest further into this technology and solve those problems that might still exist in the early period of the development. Some experts see advantages for China in the power battery industry: large scale of production and natural resources are said to put China on the forefront of the future development in batteries. Besides, China holds the second largest lithium reserves in the world. As has been discussed in the publication analysis, China has become one of the most important scientific nations in battery research (18.4%) only second to the USA (28.5% in 2010). Very recently, also the citation index shows values above the world average for batteries, indicating a rather high quality of these publications.

5.2 Problems and Challenges

As mentioned in the beginning, the goals of the Chinese government for the penetration of electric cars are still very high. In order to reach these goals, China faces many challenges, some being the same as in other markets, some very unique to China. One of the biggest challenges is the fact that there is still no consensus in industry as to which technological path to follow. Industry still develops in parallel pure electric cars, different hybrid cars and a variety of other technical options (The Climate Group 2010a; 2010b). Also with regards to the battery development, there are still a number of car manufacturers in China using lead acid batteries (Gong et al. 2013: 218), others use the lithium-ion batteries.

Also different marketing and development strategies are chosen by industry, some chose to do independent research and development, others chose to import parts and components to be integrated into their own developments. At the current stage all the above mentioned different pathways might strategically still be the best way to follow, as industry is at such an early stage that the focus on only one technology pathway might be too early and lock-in effects might be too risky (Sun 2010). Yet from the viewpoint of resources, a clear pathway can be very beneficial (The Climate Group 2010a; 2010c) and can accelerate the emergence of a dominant design. At the same time, clear technology policies help industry, including OEM, suppliers and infrastructure development.

Besides the technology path, a number of weaknesses have to be overcome with regard to industry and technology. First of all, the car industry in China is still comparably weak compared to developed countries, especially in the design and development of key components. Large-scale investment in the car industry is still very young and more investment will be needed to develop this industry further. Besides industry, also technology still has some bottlenecks to overcome: in comparison with advanced countries China's battery technology, electrical and electric control and other core technologies are still backward and this will prevent full commercialization of electric cars in the short term.[14]

With regard to battery technology, some experts believe that China has reached already international levels (Sun 2010). Other experts have identified weaknesses also in battery technology. Especially lithium-ion battery production technology is said to still be lagging behind international standards (with regard to materials, cell design, process control and battery management system, energy density, longevity, consistency, safety etc.)

14 http://www.theclimategroup.org.cn/publications/2010-05-Towards_Market_Transformation_Electric_Vehicles

(McKinsey & Company 2012: 3).[15] As our analysis has shown, China has still a rather small absolute number of transnational patents in the field of electric mobility, including battery technology. In other words, our patent analysis shows that China's technological capability in the field of batteries is not at the same level as the leading countries in this field and there is still a long way to go for China. So we do not find any evidence that this paradigm shift can be used by Chinese actors to leap-frog or even outperform actors from other countries. The scientific (Kuhn) and technological (Dosi 1982) revolutions seems to be even more dynamic in other countries.

A major challenge for further development of electric cars in China is the charging infrastructure. Even though infrastructure development is proposed in all the plans and major domestic power and energy companies are committed to it, its implementation is still very weak.

At the current stage, the economical value of the power charging operations and its long payback period reduces companies' investments into infrastructure. Currently operational and proper business models for the charging facilities are still missing, while the existing charging stations are inconvenient for the (Accenture 2011: 60-61; The Climate Group 2010b; 2010c).

Other weak points are the lack of standards for battery charging and the missing interface. Only in 2011 MIIT adopted 4 standards for charging infrastructure and its devices becoming effective on March 1, 2012[16]. These points make it difficult to achieve large scale infrastructure construction (The Climate Group 2010b; 2010c). The lack of standards and regulations is also seen as a risk for investing too many public funds in less successful technologies.

To date the price of electric cars is still too high to reach a significant market penetration. Hybrid cars are already more expensive than traditional ones and pure electric cars are said to be still more expensive than traditional ones.

So far companies as well as researchers have been relying heavily on government support. While in general this is often necessary for the development of new technologies, there is a certain risk that market mechanisms are not coming into force at the right time. But in the context of the global market economy, the competition mechanism will be of great importance for the survival of the industry in the long term. Therefore, a

15 http://www.theclimategroup.org.cn/publications/2010-05-Towards_Market_Transformation_Electric_Vehicles

16 http://theenergycollective.com/lihui-xu/91371/charging-or-changing-question-chinas-electric-vehicle-market

balance between government regulations and market regulations will be needed.[17] Especially the local government support in the 10 cities 1000 cars program has received some criticism for its local protectionism and hindrance of free market competition between the Chinese EV manufacturers (Gong et al. 2013: 225).

Another side effect of government support is seen in the lack of transparency and fairness. Private enterprises and non-key enterprises or research institutes do not have access to policy funds in general. This might harm China's further development in this field instead of nurturing it.

This goes hand in hand with subsidies and financial support for private consumers: at the moment, consumption does not focus on private consumers at all, yet they do not have any incentive to buy new energy cars.[18] Clear standards for private subsidies are required by national and local authorities. On the other hand, China's government seems to believe that due to the immaturity of its technology, private subsidies would benefit from foreign enterprises and this is not in conformity with the national goal of "self-owned brands" (Sun 2010). On the positive side, public fleets like taxis and buses are seen much more useful for the first adoption of electric cars in China than private consumers (McKinsey & Company 2012: 3).

Mainly as a result of the above mentioned issues, investors currently have taken on a "wait and see" attitude, as they do not see the earning potential of an investment. For them, the whole venture of new energy vehicles is still a venture that lacks the necessary infrastructure (Accenture 2011: 60-61).

At the same time, a lack of systematic data collection and monitoring of the existing fleets has been mentioned (Gong et al. 2013: 222). This seems especially due for the ten cities one thousand cars program, where no overall project evaluation is publicly available and from which it seems that not enough lessons learned can be transferred into improving the current technological, organizational and management developments.

17 http://auto.sina.com.cn/news/2010-08-07/0917635965.shtml

18 In the cities of Shenzhen and Hangzhou, where individual consumers can get rebates on their electric car purchases, only 800 and 162 electric cars were sold to private owners by 2011, which is 3,2% of their goals for Shenzhen and 0,8% for Hangzhou (Gong et al. 2013: 221).

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