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The formation of a new technological trajectory of electric propulsion in the French automobile industry

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The Formation of a New Technological Trajectory of Electric Propulsion in the French Automobile Industry

Eike W. Schamp

Joint project with:



Tsinghua University
School of Public Policy and Management



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trajectory of electric propulsion in the
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Abstract

Public debate on climate change mitigation and low-carbon policies has brought the issue of transportation and the choice of propulsion technologies to the fore. A radical shift in drive technologies from the internal combustion engine (ICE) to various forms of electric vehicle drive – hybrid (HEV) and battery electric (BEV) – seems to be emerging. While there are many actors involved in forming this new technological trajectory, they would appear to be embedded in national societies and their institutional settings. Yet, the character of this process and the factors determining it remain fairly unclear. In order to unravel the nature of these early stages of trajectory formation, the paper poses three questions: Firstly, which societal factors have an impact on the early formation of technologies in the field of electric propulsion and how far are they country-specific? Secondly, is a nascent trajectory in electric propulsion that can be defined as being specific to a particular country emerging? And, thirdly, how sustainable do we consider the trajectory, in terms of maturing into a “dominant” design of the technology and competitiveness of the nation’s economy in related green technologies?

France is a good case in point as the country has long-term experience in the development of such technology and is currently Europe’s leader in HEV and BEV production and consumption. Combining an evolutionary perspective and a systemic approach to electromobility, the paper provides an in-depth analysis of the emerging processes of trajectory formation in France and gives some tentative answers to the above questions.

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I would like to thank Julia Hildermeier and Axel Villareal, both associated researchers at the ENS Cachan (France) working on political aspects of e-mobility, for their considerable support particularly in the early phases of the project. I am grateful to the many experts who readily helped to increase my knowledge of various aspects of electromobility in France, particularly to Dr Jérôme Perrin, the Director of Vedecom, the recently founded institute for applied research on electromobility in Versailles. The final version of this paper benefited from comments by Tilman Altenburg and Hubert Schmitz.

Frankfurt, March 2014

Eike W. Schamp

Preface

Mitigating climate change by reducing carbon emissions is one of the biggest and most complex issues the world has ever faced. Technological innovation plays a major role in taking on this challenge. Old and new industrial powers alike are increasingly reforming their policy frameworks to encourage low carbon innovation, and investments are following.

Evolutionary economics has clearly demonstrated how initial choices of technologies and institutional arrangements preclude certain options at later stages; hence, situations evolve in an incremental and cumulative way, resulting in context-specific technological pathways. Such path dependency implies that technologies and institutions do not progressively converge toward a unique best practice, as neoclassical equilibrium models might suggest. The historical and social embeddedness of such evolutionary processes instead results in a variety of very different technologies and institutions across countries.

The starting assumption of our research was that low carbon technologies depend on politically negotiated objectives and policies to a particularly high degree, mainly due to the failure of markets to reflect environmental costs. The way national governments and industries deal with the low carbon challenge varies greatly depending on levels of environmental ambition, technological preferences (such as different attitudes towards nuclear energy, shale gas, carbon capture & storage), the ways markets are regulated, and the importance attached to expected co-benefits (such as exploiting green jobs or energy security). Consequently, low carbon technologies are more likely to evolve along diverging pathways than other technologies whose development is more market-driven.

To test this assumption we conducted the international research project “Technological trajectories for low carbon innovation in China, Europe and India”. The project explored whether, to what extent and why technological pathways differ across countries. Case studies were conducted in two technological fields, electromobility and wind power technologies, in China, India and leading European countries. Whether a diversity of pathways emerges or a small number of designs becomes globally dominant has important implications. From an environmental perspective, diversity may help to mobilize a wide range of talents and resources and deliver more context-specific solutions. Convergence, on the other hand, might help to exploit economies of scale and thereby bring about bigger and faster reductions in the cost of new technologies. From an economic perspective, diversity may provide niches for many firms, whereas a globally dominant design is likely to favour concentration in a small number of global firms – which may or may not be the established ones. Comparing European incumbents with Asian newcomers is particularly interesting, because China and India might well become the gamechangers – responsible for most of the increase of CO₂ emissions but also leading investors in green technology. In addition, the project explored lessons for international technology cooperation, emphasizing ways to navigate the trade-offs between global objectives to mitigate climate change effects and national interests to enhance competitiveness and create green jobs locally.

The project was carried out between 2011 and 2014 as a joint endeavour of four institutions: the German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE), Institute of Development Studies (IDS) Brighton, Indian Institute of Technology (IIT) Delhi and the School of Public Policy at Tsinghua University, with additional collaborators from the Universities of Aalborg, London and Frankfurt. The project was truly collaborative, to the

extent that international teams jointly conducted interviews in China, India and Europe which helped to build common understanding.

Eight reports have been published in, or are currently being finalised for, the DIE Discussion Paper series:

1. Schamp, Eike W. (2014): The formation of a new technological trajectory of electric propulsion in the French automobile industry.
2. Chaudhary, Ankur (2014, forthcoming): Electromobility in India. Attempts at leadership by businesses in a scant policy space.
3. Altenburg, Tilman (2014, forthcoming): From combustion engines to electric vehicles: Implications for technological trajectories. Case study Germany.
4. CHEN Ling, Doris FISCHER, SHEN Qunhong and YANG Wenhui (2014, forthcoming): Electric vehicles in China – Bridging political and market logics.
5. Lema, Rasmus, Johan Nordensvärd, Frauke Urban and Wilfried Lütkenhorst (2014, forthcoming): Innovation paths in wind power: Insights from Denmark and Germany.
6. DAI, Yixin, Yuan ZHOU, Di XIA, Mengyu DING, Lan XUE (2014, forthcoming): Innovation paths in the Chinese wind power industry.
7. Narain, Ankita, Ankur Chaudhary and Chetan Krishna (2014, forthcoming): The wind power industry in India.
8. Bhasin, Shikha (2014, forthcoming): Enhancing international technology cooperation for climate change mitigation. Lessons from an electromobility case study.

On the basis of these case studies, the team is currently working on a series of cross-country comparative analyses to be published in academic journals.

The research team is very grateful for generous funding and a very supportive attitude by the Swedish Riksbankens Jubileumsfond under a joint call with Volkswagen Foundation and Compagnia de San Paolo.

Bonn, April 2014

Tilman Altenburg

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Abbreviations

| | |
|----------|---|
| ABS | Anti-lock braking system |
| ADEME | Agence de l'Environnement et de la Maîtrise de l'Energie |
| ALISTORE | Advanced Lithium Energy Storage System |
| BEV | Battery electric vehicle |
| CCFA | Le Comité des Constructeurs Français d'Automobiles |
| CHAdEMO | Charge de Move |
| EDF | Electricité de France |
| FUI | Fonds unique interministériel |
| GDP | Gross domestic product |
| Gtai | Germany Trade and Investment |
| HEV | Hybrid electric vehicle |
| ICE | Internal combustion engine |
| IMD | Institut de Mobilité Durable |
| LMP | Lithium-Metal-Polymer |
| NiMH | Nickel-Metal-Hydrid |
| OEM | Original equipment manufacturer |
| PHEV | Plug-in hybrid electric vehicle |
| PREDIT | Programme de recherche et d'innovation dans les transports terrestres |
| R&D | Research and development |
| UGAP | Union des Groupements d'Achats Publics |
| VEDECOM | Institut du Véhicule Décarboné et Communicant et de sa Mobilité |

Introduction

Two fundamental processes are currently squeezing the European automobile production system. Firstly, European markets are fading away while Asian markets are booming, both of which result in relocating production to Asia through Asian newcomers and European incumbents. Secondly, a seemingly radical shift in drive technologies from the internal combustion engine (ICE) to various forms of electric drive – hybrid (HEV/PHEV) and battery electric (BEV) – is emerging. Often explained by environmental pressure transferring into “low-carbon” policies, these technological changes seem to mark a technical “revolution” in drive technologies. New technologies rarely emerge from scratch nor do they suddenly appear out of nowhere. They have their own history, starting with a heterogeneous search within creative processes. Innovation theory and empirical evidence point to a substantial heterogeneity of competing ideas at the beginnings of a new technological trajectory, a phase that has been called the “ferment” by Murmann / Frenken (2006). Nonetheless, the formation of such a nascent trajectory is not fully arbitrary but also dependent on earlier paths in technological development. Path creation and path dependence compete with each other in a societal process that is largely “local” in character. We claim in this paper that the nascent technological trajectory to the electrification of vehicles has a strong national connotation, not least due to the importance of national production and R&D systems, national patterns of consumption, and national policies.

Looking at the novelties of the electric propulsion of vehicles, this paper focuses on three research questions:

1. Which societal factors have an impact on the early formation of technologies in the field of electric propulsion and how far are they country-specific?
2. Does a nascent trajectory in electric propulsion emerge that can be termed specific to the country?
3. And, finally, how sustainable do we consider the trajectory, in terms of maturing into a “dominant” design of the technology and competitiveness of the nation’s economy in related green technologies?

Theoretical underpinnings

Understanding a nascent trajectory is a fairly new research field in innovation theory. This paper attempts to combine two theoretical strands, first, evolutionary economics and evolutionary economic geography (Boschma / Martin 2010) for the analysis of time-dependent processes, and, second, an agency-oriented institutional approach for the analysis of the country-specific societal embeddedness of these processes. Basic dimensions of evolutionary theory are the historicity of events, the emergence of a variety of technologies, the selection of one particular technology and its retention through various mechanisms that together cause a “lock-in” of this technology among competing ones. It is common understanding that the life cycle of the ICE technologies has matured, after more than one hundred years of existence. Although the old ICE is not yet dead and well alive, rival new technologies emerge, among them the electric drive of vehicles. Electrification of vehicles can be seen as one possible way of driving vehicles, struggling today against the old ICE drive and other newcomers, be they hydrogen or gas or anything else. Nothing has been decided yet. Whether we are at the beginning of a new life cycle

or a new technological trajectory – that of the electrification of vehicles – and what factors determine it, are still open questions. The issues tackled in this paper deal with the “mechanisms” of selection and retention which may explain an emerging lock-in of the electrified drive. Among them are nation-specific characteristics of path dependency, events that shape the trajectory and, last but not least, policies framing the emergence of the new technology.

At its beginnings, the path is not yet determined and often no “start event” of the trajectory can be identified. This holds particularly true for electrification of the vehicle as the first electric vehicles already came into being at the end of the 19th century (IMD 2011). Since then, the electric vehicle has merely survived in very small and special niches, despite manifold attempts to re-invent the electric vehicle, which have also been taking place in France since the 1950s. Thus, while there is no “historical event” – some kind of revolutionary act by radical innovation or a breakthrough in innovation – that marks the starting point of the trajectory, a host of more or less incremental innovations in various parts of the technical system called “electric drive” took place. Another important point is that, if a new technology is to become an innovation, then users or customers must accept it.

The object of this evolutionary approach, electromobility, is a dynamic, complex system. The system behind the electrification of vehicles can be either defined in technical terms: for instance, competences from different sciences fairly new to the automobile sector come together, such as electrochemistry and electronics; or it can be defined in socio-political terms. The latter is how we understand the term “technological system” here. Agents who push the technology forward form a particular socio-political system. The triple helix concept might be helpful as a metaphor to grasp the diversity of actors and their entanglements (Etzkowitz / Leydesdorff 2000). This combines actions from the economy – enterprises and consumers who finally push forward innovation – with those from academia – from where basically new technologies come from – and politics – where political agents create a regulatory environment that fosters the new technology and promote it by subsidies, etc. A variety of concepts on innovation systems has emerged over the last two or three decades focusing on territories (national and regional innovation systems), sectors and technologies (Lundvall 1992; Malerba 2002; Moulaert / Sekia 2003; Bergek et al. 2008). Here, we understand the nascent trajectory as contingent on each of these perspectives, i.e. on characteristics of the national innovation system, on a sector’s innovation system – the automobile production system – and on a particular technological innovation system – electric and hybrid propulsion technologies.

Path creation in a nascent trajectory can be considered a matter of agency embedded in a particular historical situation and given institutional environment. The nascent trajectory may be conceived as “national” insofar as major agents seem to be bound in their actions to a national territory. This applies to the supply side of the new technology, for instance R&D of large and small companies in the automobile production system or state policies fostering new technologies, and the demand side of a technology, i.e. the market. It is important to note that markets do not yet exist in a nascent trajectory but have to co-evolve or be co-developed (Adams / Brusoni / Malerba 2011). It is the firm belief of this author that economic actors – firms and their staff and also customers – shape the nascent trajectory of electromobility most in capitalist societies.

The case of France

France is Europe's, and one of the world's, early movers in related technologies. France appears to be a good case in point for several reasons. Not only was the electric vehicle invented in France in 1881 (IMD 2011), but the electrification of vehicles was an issue for political action at the time when automobile production systems were still closely bound to a national territory, i.e., from the 1960s onwards, and still are with certain interruptions up to today. Moreover, although France forms part of "continental European capitalism", in the political-economic perspective of the theory of varieties in capitalism, and thus is close to Germany (Amable 2005), it has a particular socio-political system with a strong centralised government. Hence, differences in societal behaviour may be assumed that have an impact on choices in technological trajectories. Finally, French politics have been motivated by a mix of both climate change mitigation policies and economic policies aimed at reducing crude oil dependency and achieving higher competitiveness on world markets. While this can also be claimed for many other countries, the severe experience of considerable deindustrialisation and the decline in the global competitiveness of France may partly explain why the country is a first mover in the trajectory of electromobility.

Methodology

The methodology underlying this report deserves a few words as gaining reliable information on a subject that is both new and complex is always a crucial task. Relevant agents are few in number; they have strategic interests and visions which can be misinterpreted by the author; and information is only partly in the public domain as the topic is of high relevance for the competitiveness of companies and research labs. Hence, it was rather difficult to get into contact with relevant persons. Based on a kind of "snowball procedure", we finally managed to conduct 23 personal semi-structured interviews, mostly through phone calls in accordance with the wishes of the interviewees¹, within a one-year period from May 2012 to July 2013. Triangulation was achieved by studying documents, either from public and public/private organisations steering and/or observing the development of electric vehicles in France² or from the media³. Recent publications from the social sciences have also been used, mostly conference reports and current PhD work.

There is another methodological caveat. Right from the very beginning, we had to be cautious about evaluating past decisions and current events, and, hence, the narratives we arrived at. Firstly, technology is subject to non-coincidental events and this surely holds true for the automobile production system. The development of components and models generally takes several years from the first conceptualisation to serial production. That is why a technological state appearing on the market can never be the actual state-of-the art in technology *per se*. On the other hand, success on the markets is crucial for innovation. This time lag between strategic decisions and the eventual commercial success of a tech-

1 Fortunately, first respondents from companies were often prepared to inform about further possible interviewees at other institutions. Interviews were pursued in the different segments of the triple helix, i.e., 15 in the company sector, 5 with academia, and 3 with central or regional authorities in the field of electro-mobility. Interviews lasted from 30 to over 90 minutes and were generally translated from French into German when being transcribed.

2 Such as Avem, Association for the Future of the Mediterranean Electrical Vehicle, avem.fr.

3 Such as the weekly *L'Usine Nouvelle*, www.usinenouvelle.com

nology brings a high degree of uncertainty not only to agents in the triple helix but also to scholars attempting to evaluate current trajectories. And this holds all the more true because the current shift to “electrifying” the automobile’s drive is very recent in France and elsewhere. It has only been a few years since the “Grenelle 2007” marked the starting point of (re-)electrification in France in the public sphere. Are we currently witnessing a radical shift in the technology of the mode of drive, including a radical shift of competitors in the global market; or a more or less incremental shift of technology that offers opportunities to incumbent players to adopt and adapt and, hence, maintain or even strengthen their position on the markets? The paper will attempt to give some answers in the sense of a “grounded description” that will construct a base for the evaluation.

Structure of the report

This paper will proceed as follows: Section 1 lays the ground by discussing the context of the automobile production system in France in view of the electrification of vehicles. Here we try to bring to the fore the idea of path bondage or embeddedness into a given technological path by describing earlier and more recent developments and policy actions relating to the electrification of vehicles. We do not wish to discuss in detail what “dependency” may mean in the academic notion of path dependency nor recent versions of “path plasticity” (Strambach 2010). However it has to be stated that former decisions and events do have an impact on the current development of the electric drive in France. This paper focuses on passenger cars and light commercial vehicles only; the electrification of trucks and busses, although one of the major challenges in view of environmental policies and energy policies in France and Europe, calls for different technical solutions which will not be tackled here.

Section 2 then describes in detail the technological developments in electrifying vehicles from the perspective of the firm. In the well-known pyramidal order of the automotive production system, companies still face the dominating power of the vehicle assemblers, the so-called Original Equipment Manufacturers (OEM). As firms generally follow mixed strategies and as electrification is a complex system in which firms from several sectors are embedded (Colling / Tuononen / Sao 2010), this section follows an idealised order: Firstly, development of the full battery electric vehicle (BEV) is described using the cases of Renault and Mia electric. Then, the development of hybridisation (hybrid electric vehicle HEV, plug-in hybrid electric vehicle PHEV) is discussed, including the case of PSA Peugeot-Citroen and some suppliers. Thirdly, battery development deserves a special section as batteries are seen as the core technology in electrification. Following our approach based on a variety of actors in the technological system, OEMs, suppliers, and research labs are then analysed.

“It’s the market, stupid” could be the motto of Section 3. A new technology cannot be locked-in – at least in capitalist economies – without being accepted by the markets. Having said that, markets are societal constructs and hence can be “made” – or, at least, their characteristics result from the influence and power of societal partners who sometimes have contradicting interests. This section briefly presents various state policies and joint actions aimed at fostering the consumption of BEVs and HEVs/PHEVs with the intention of creating a market for electric vehicles in France.

Finally Section 4 draws some conclusions on what makes the trajectory in France distinctive, on whether the trajectory in France is a trajectory specific to France, and on how far the trajectory is locked-in or can be easily reversed.

1 France, a particular “place” at a particular point in time

In line with the argument informed by evolutionary economics that actual strategies and decisions of actors are embedded in historically contingent situations, the purpose of this section is to set the French context: the industry, the market and government policies.

1.1 The French automobile industry in crisis

The French automobile production system is the second largest in Europe. Yet it is in crisis as is the entire French economy (Artus / Virard 2011; Gallois 2012). Two large-volume OEMs, i.e. the Renault Group and the PSA/Citroen Group, dominate the domestic market. In 2012, PSA/Citroen accounted for 28% of annual registrations in France, Renault 20%. Both companies suffered from a tremendous reduction of demand on the domestic market, PSA/Citroen by 15% and Renault by 28% in the same year (Ccfa 2012). Both companies have their main sales areas in Europe, with a focus on Southern Europe. Here, they were able to sell their small and medium-sized models successfully – until the financial crisis that hit all Southern European countries. Neither company succeeded in entering the premium segment of the automobile markets in Europe. Moreover, the sector was also affected by the general loss of competitiveness of the French industry (Artus / Virard 2011) and the two OEMs have launched less successful models in recent time. As a result, they have not been able to raise many profits from selling small cars in “ordinary” times, and were unable to shift exports abroad in times of crisis. On 13 February 2013, PSA Peugeot-Citroen announced a net loss of EUR 5 billion in 2012, the largest loss the company had ever experienced. PSA announced it was closing down the old Aulnay factory and laying off 8,000 employees, hence provoking much resistance from the trade unions.

As a result, both OEMs suffer from a severe lack in investment capital at a moment when several state initiatives are fostering low-carbon technologies in the automobile industry. As will be seen in the following, the two OEMs have nevertheless spent much effort in developing a strategy of low-emission vehicles. It should be mentioned, however, that even their ICE-driven product fleet achieves below-European average emission values due to the small size of the cars and – in particular applicable to PSA Peugeot-Citroen – due to the dominance of diesel engines.

The French automobile production system also hosts a number of small niche producers, mostly offering small vehicles for urban transports. In March 2012, eight producers of vehicles for urban mobility were listed, plus four producers of electric busses and one for trucks (invest-in-france.org). Some of these vehicles can be driven without a driver's licence (“sans permis”), mostly in urban transport, and the vehicles have a maximum speed of 45 km/h. Producers have been rather quick in adding electrically driven models to their traditional models generally driven by weak ICEs. Due to a particular demand for small urban vehicles in France as in Southern Europe as a whole, some of these producers serve a small but safe market niche.

Further down the pyramid of the automobile production system, we find some powerful first-tier system suppliers such as Michelin (wheel systems), Valeo or Leroy Somer. There are also a number of second-tier components suppliers. However, the French automotive production system has long suffered from a gap in medium-sized suppliers (Banville / Chanaron 1991) who form a powerful base for technological development in Germany, for

example. Nevertheless, large and small OEMs and suppliers have been able to respond fairly quickly to the recent state initiatives fostering electric vehicles, often due to earlier involvement in the state-initiated projects of the 1990s.

1.2 Do French customers accept vehicle electrification?

Many observers claim that the French automobile market is different from Northern European markets. There is a large segment for small and medium-sized cars offered by the volume-producing OEMs. The still considerable niche for small urban vehicles may be partly explained by the fact that the infrastructure in French and Southern European towns had not suffered from the destruction in World War II as much as in Northern Europe and therefore had not been modernised and reshaped by urban planning to the same degree. It seems, however, that different customer preferences are also prevalent. In the south, the automobile is mostly less of a prestigious good but more a functional means of mobility, according to one of our respondents (I-6)⁴. Hence the “affordability” of electrified vehicles plays a major role in all reflections on technology (numerous interviews). This often translates into the abstinence from extravagant components and the need for reasonable prices. We will find these dimensions again in the statements of car manufacturers explaining the choice of product architecture of a model. In contrast to this, French customers have sometimes been said to be less averse to technological advancement in comparison to other Europeans.

As a matter of fact, France has become the leading market in Europe for the electrification of the automobile, both for BEVs (Tables 1 and 2) and for HEVs. In 2012, France represented 35% of European registrations of electric vehicles, followed by Norway (15%) and Germany (13%, see *L'Usine Nouvelle*, 8 Jan. 2013). Registration of electric vehicles simply doubled in 2012 and 2013. Nonetheless, the BEV segment was still a niche segment of the market for cars in France. This small segment is even divided along two lines: firstly, between passenger cars and light commercial vehicles; and secondly, between models targeting the traditional volume segment of the market, i.e. vehicles for both urban and long-distance range, and the segment of pure urban mobility characterised by short distances but high trip frequency.

BEV models have been mostly produced outside France, however. The PSA/Citroen models, Ion and C-Zero – simply duplicates of the Mitsubishi i-Miev – have been subcontracted to Mitsubishi and imported from Japan. The Renault Fluence ZE has been produced in Renault's Turkish subsidiary at Bursa. Moreover, the Bluecar offered by Bolloré is produced in a Pininfarina factory at Turin in Italy (Knupp 2012). This was partly due to the strategy of both OEMs to enter into the new market segment fairly quickly by learning from and/or subcontracting to their Japanese partners (Nissan in the case of Renault; Mitsubishi in the case of PSA/Citroen). Newcomers in BEV production were rather small companies, such as Mia and Bolloré (see Table 1). Their situation on the market can become tenuous fairly quickly, as is exemplified by the recent takeover of Mia by a financial company due to tremendously declining sales. Even if France is Europe's leading BEV market, it is still too narrow to achieve economies of scale.

4 (I-n) will indicate information from one of the 23 interviewees, in the following. The list of interviewees is available from the author.

| Table 1: Sales of BEV passenger cars in France in 2012 and 2013 | | | | | |
|---|-----------------------|---------------------|-----------------------|---------------------|---|
| Model | 2012 in number | Market share | 2013 in number | Market share | Comment |
| <i>Volume producers</i> | | | | | <i>Volume segments of the market</i> |
| Peugeot Ion, Citroen-C-Zero | 2,744 | 49 | 250 ¹⁾ | 3.0 | Sellout in summer at app. 11,000 € battery included |
| Nissan-Leaf | 552 | 9 | 1,435 | 16.0 | Offer of price reduction in 2013 |
| Renault Fluence ZE | 295 | 5 | 49 | 0.5 | Considered as a commercial failure. Production stop in 2014 |
| Renault Zoe | – | – | 5,500 | 63.0 | Launched in March 2013 |
| | | | | | |
| <i>Niche producers</i> | | | | | <i>Vehicles for urban mobility</i> |
| Bolloré Bluecar | 1,543 | 28 | 658 | 7.5 | For car hire only by Autolib |
| Mia Electric | 384 | 6 | 164 | 2.0 | |
| Smart ED | – | – | 465 | 5.0 | |
| Various others ²⁾ | 64 | 3 | | 3.0 | |
| Total | 5,659 | 100 | 8,751 | 100.0 | Annual doubling of sales |
| ¹⁾ rounded figures; ²⁾ Smart ED included in 2012 | | | | | |
| Source: avem.fr/actualite.. 09.01.2013, accessed 28.01.13; 08.01.2014, accessed 04.02.2014 | | | | | |

| Table 2: Sales of electric light commercial vehicles in France, 2012 and 2013 | | | | | |
|--|-----------------------|---------------------|-----------------------|---------------------|--|
| Model | 2012 in number | Market share | 2013 in number | Market share | Comment |
| Renault Kangoo ZE | 2,863 | 80 | 4,174 | 82 | Price at about 13,000 € battery excluded |
| G3 (Goupil-Industrie) | 335 | | 582 | 11 | Niche producer of municipal utility vehicles |
| Peugeot Ion (utility) | 110 | | – | – | |
| Mia U (utility) | 72 | | – | – | |
| Citroen Berlingo e | 39 | | – | – | next generation in 2013 with Li-Ion battery and rechargeable (ChadeMo) |
| Peugeot Partner e | 33 | | – | – | ibid. |
| Source: avem.fr/actualite 10 Jan. 2013, accessed 28 Jan. 2013; 8 Jan. 2014, accessed 4 Feb. 2014. | | | | | |

In contrast to BEVs, the market for hybrid electric vehicles (HEV) increased considerably in 2012 and 2013, achieving 2.5% of passenger-car registrations in this year (avem.fr/actualité, 15 Jan. 2013 and 20 Jan. 2014). While 27,730 hybrid vehicles were registered in France, in 2012, this figure rose to more than 45,000 in 2013. The Toyota models Yaris hybrid and Auris hybrid figured at the top, together gaining a market share of 49% in 2013, followed by the three PSA/Citroen diesel hybrid models (Peugeot 3008H, 508 RXH and Citroen DS5) with a market share of about 30%. Taking all models together, the Japanese company Toyota is still the market leader in France with about 59%, followed by the French company PSA/Citroen at 29%. Comparing the two years (2012 and 2013), gasoline HEVs gained a market share of 70% among HEVs while diesel HEVs had a share of 30% of hybrid vehicle registrations in France in 2013 (avem.fr/actualité 20 Jan. 2014).

Sales in plug-in hybrid vehicles (PHEVs), by far dominated by the Toyota Prius plug-in hybrid launched recently, did not grow tremendously, either in 2012 or in 2013, probably because of the high price for such vehicles (avem.fr/actualité, 15 Jan. 2013; 19 Jan. 2014). Once again, French customers seem to accept the electrification of vehicles if these are “affordable”. As a result, mild forms in the hybridisation of vehicles are still preferred.

1.3 A short history of policy efforts

French engineers were among the first to construct electric vehicles at the end of the 19th century (IMD 2011). There have been several ups and downs in the history of the electric vehicle in France. Callon (1980), for example, analysed various different attempts in France in the 1960s and '70s to foster innovation in electric vehicle technology, taking a sociologist's perspective on the struggle between different interest groups to steer technology. Although he identified many different ministries and para-public organisations at work, he came to the conclusion that the central state was fairly weak in pushing for new technological trajectories. Also, companies and scientists at universities seemed to be unable to engage in deeper collaboration (Callon 1980, 364). This holds true both for the first period the author analysed: the research on fuel cell technology in the 1960s, and the second period: the project for fully rechargeable electric vehicles. However, the French state power company EDF, which had pushed forward the project, apparently succeeded in convincing the government of the need for demand subsidies. From this we can draw a line to the socio-political conditions of today.

At the turn of the 1960s and into the 70s, there were various different initiatives from power companies in countries such as the United States, United Kingdom (UK) or Germany aimed at the development of low-carbon technologies, motivated by the oil shocks and the apparent availability of economically priced power from nuclear plants, at least in France (Guignard 2010, 9). In France, however, state authorities were divided, interest groups worked against each other, and the link between academia and the private sector had not (yet) developed. Technical development, particularly on battery technology, was hence mainly pushed forward in the defence industry sector only (Dassault Group, Saft) while remaining disappointing as far as electric drive was concerned.

Guignard (2010), in her history of the role of Ademe (Agence de l'Environnement et de la Maîtrise de l'Energie) in low-carbon vehicle development in France, sees the early 1980s as an important pre-phase to a larger turnaround which arrived in the 1990s and which finally

laid the ground for the development of the electric vehicle in various aspects. There was, firstly, a (technical) innovation aspect. Supported by government funds, the Saft company procured the OEM Renault with Ni-Fe batteries for the light commercial vehicle Master (mid-eighties) and then invested into the development of Ni-Cd batteries for the replacement of lead batteries which finally led to serial production in 1995. The second aspect of policies at that time applied to the testing of electric vehicles in practice, mainly on behalf of the state power company EDF. The third aspect related to the reorganisation of state promotion. The former Afme (Agence Française pour la Maîtrise de l'Energie) was to become Ademe (L'Agence de l'Environnement et de la Maîtrise de l'Energie) in 1991, the current organisation responsible for funding applied research and development, granting subsidies to clients (see below) and monitoring the bonus-malus system (see below). Ademe is the government's implementing agency for environmental and low-carbon policies, under the supervision of two ministries, the Ministries of the Environment and of Industry.

With the launch of Ademe in 1991, the state increased efforts in developing low-carbon technologies, responding to initiatives made in California and by the European Commission. During this decade, Ademe funded research in new battery technologies through the PRED-IT-programmes (Programme de recherche et d'innovation dans les transports terrestres, launched by the Ministries of the Environment, Research and Industry in 1990), both in bringing the Ni-Cd battery (replacing the lead battery, Saft company) and the Li-Polymer battery (Bolloré Group) to maturity in serial production. Ademe funded various field trials and organised demonstration projects in cooperation with regional and local authorities to get customers familiar with the technology. In 1995, the state launched an agreement with the two large OEMs and EDF on recharging infrastructure aiming at the use of 100,000 BEVs by the year 2000 through state organisations and local authorities (Guignard 2010, 21). Although this objective was by far exaggerated, as in 2000 only 7,000 electric vehicles were in use, it seems that the 1995 experiment in vehicle electrification later became a major asset of the French automobile production system in developing new hybrid and electric vehicles. In fact, the 1995 experiment aimed at commercialising electric vehicles, hence it simultaneously constituted a technical and commercial challenge. PSA Peugeot-Citroen launched two passenger electric cars, Renault a commercial light vehicle. The experiment failed, however, both for technical and commercial reasons. Companies such as Saft did not manage to develop new battery technologies and OEMs were not able to sell the vehicles successfully. Nevertheless, participants seem to have learned a great deal in this experiment that they could use later in the renewed technical push towards electrification in the 2000s (I-19, see also Section 2.3).

Yet, at the beginning of the new millennium, results were not convincing. New generation batteries still were too expensive – thus giving rise to an early reflection about leasing instead of selling the battery – and had a low performance (maximum reach of 80 km) and charging infrastructure was simply absent. The annual registration of BEVs was considered insufficient reaching only 1,300 BEVs per year by the second half of the 1990s. While France figured first among European nations in the stock of registered BEVs in 2000 (approximately 10,000, versus about 2,000 in Germany), this was far from a being commercial success. As a consequence, further initiatives were launched in the 2000s, such as the plan for a clean and economical vehicle in 2003 (Plan Véhicules Propres et Economes). Research funds were increased and the consumer subsidy doubled to EUR 3,050 per BEV.

Continued state funding resulted in the early launch of new technologies, compared to other European countries, such as a Li-ion battery (through Saft company) which was finally

brought into serial production in 2006 by a joint venture of the French Saft company and the American Johnston Controls. The French system supplier Valeo developed the first stop-start technology in Europe (to be commercialised in a Citroen model); the Bolloré Group became the European leader in supercapacitor technology for HEVs.

To conclude from this abstract on the history of political support and technological development in the “electrification” of the car, many of the political means for pushing the BEVs and PHEVs which later became so prominent with the “Grenelle 2007” had already been thought of and implemented one or two decades before. This holds true for the support of basic research and development (mostly through the Ministry of Research) and of applied research and development, mostly through Ademe (two Ministries), and further added to by investment programmes of the Ministry of Economics (such as Oséo, FUI/Fonds unique interministériel). From the 1990s onwards, this was supplemented by instruments to facilitate commercialisation, either indirectly through agreements with local authorities and large (semi-public) organisations to buy and test BEVs or directly through subsidies to the customers.

1.4 New policy departures in the early 2000s

It is often claimed that an environmental conference in 2007 initiated by the French president – the Grenelle de l’environnement – gave the starting signal to a new phase in electrifying vehicles (Guignard 2010; Hildermeier / Villareal 2011). The conference brought together the state, civil-society representatives and local authorities for sustainable development. However, other initiatives in innovation policy had already been launched as early as 2005. These early initiatives were mainly driven by concerns about eroding international competitiveness; thus what pushed efforts on electrification did not primarily have to do with climate change mitigation – and this also applied to other sectors such as railway transport or the building sector. In fact, related policy initiatives were developed in the context of the financial crisis of 2007/8 when the EU Commission tried to link instruments to re-animate vehicle markets through scrap bonus schemes with environmental issues (Hildermeier / Villareal 2011).

Obviously perceiving a dangerous loss of international competitiveness in the early 2000s, the French government launched new policies to foster technological development. One of the instruments was to establish so-called “pôles de compétitivité”, in the sense of the cluster concept now globally accepted. These are organisations aimed at providing a platform for the exchange of knowledge and for network-building in technologies which are considered essential in improving the nation’s competitiveness (see Hussler / Muller / Ronde 2012) and to contribute to the development of regional employment. The main aim was to stimulate closer cooperation in product development among companies, institutions of applied sciences and even municipalities. Most of these pole organisations have a regional scope as it is assumed that the knowledge to be exchanged is largely of tacit character, requires face-to-face contact, and the building of trust and is therefore facilitated by geographical proximity. Projects are eligible for financial aid from the FUI (fonds unique interministériel) and from regional authorities (Datar / dgcis 2012). Three poles have been launched for improving passenger mobility and a fourth for improving trucks and busses (see Table 3). Later, these became important poles for fostering the innovation in the electrification of vehicles. To what extent this regionalised policy has had the desired effects requires further evaluation (I-13).

| Table 3: Four clusters of (regional) competence in electric vehicles | | | | | |
|---|-------------------------|-------------------------|---|--------------------------|---------------------|
| Denomination | Date of creation | Aspiration level | Headquarters/region | Number of members | Website |
| iDforCAR | End of 2005 | national | Nantes/Bretagne, Poitou-Charentes, Pays de la Loire | 71 | Id4car.org |
| Véhicule du futur | July 2005 | national | Montbéliard/Alsace, Franche Comté | 200 | Vehiculedufutur.com |
| Movèò | March 2006 | global | Rouen/Basse et Haute Normandie, Ile-de-France | 340 | Pole-moveo.org |
| LUTB Lyon Urban Truck&Bus | 2005 | national | Lyon/Rhone-Alpes | 175 | Lutb.fr |
| Sources: Respective websites | | | | | |

Instruments based on the Grenelle came into being in 2008. Officially, the launch of the demonstrator fund for low-carbon vehicles in 2008 by the government (of which Ademe is in charge) represents a new start in the promotion of electrification. The fund agreed upon a R&D budget of EUR 137 million for projects which were near commercialisation, a sum that was considered “whopping” by Guignard (2010, 38). The financial crisis further accelerated the promotion of electrification (Hildermeier / Villareal 2011). In 2009, the French government presented the “low-carbon vehicle plan” aiming at a population of about 2 million low- or zero-carbon vehicles in 2020⁵. This plan encompassed instruments on the supply side as well as the demand side of the market (see Table 4). Hildermeier / Villareal (2011) point to an increased awareness on promoting low-carbon vehicle development through the fact that internal competition arose between two government departments involved, the department of environment and the department of industry.

On the demand side, the earlier bonus/malus system on automobile pollution that rewards customers for buying low-carbon vehicles – the one-off bonus – and penalises customers of other vehicles by a tax – the malus – was tightened. It was, in fact, one of the earliest decisions of President Hollande in 2012 to increase the maximum subsidy from EUR 5,000 to 7,000. Ademe is responsible for the handling of this subsidy/tax system. According to a recent list published by Ademe, (some) French and Japanese BEV and HEV car models benefited from the bonuses while most German car models suffered from the malus. In ecological terms, the instrument seems to work efficiently. Between 2009 and 2011, the share of buyers eligible for a bonus rose from 9.7% to 31.8% while the buyers subject to the malus declined from 17 % to 11.4 % respectively (gtai 1 Nov. 2012). The system favours diesel ICEs because of their comparatively low consumption compared to gasoline engines. Hence, the share of diesel-driven new cars rose to more than 70% in 2012 (gtai 1 Nov. 12).

5 As opposed to 1 million in Germany.

| Table 4: Instruments according to the low-carbon vehicle plan of 2009, as of 2012 | | |
|--|--|---|
| Policy orientation | Instruments | Some details |
| Supply-side policies | (Partly refundable) funds for pre-competitive but near-to-commercialisation products | “Invest in the future” programme |
| | New standards | e.g., for public charging stations |
| | Support of public infrastructure for recharging | e.g., funding |
| Demand-side policies | Further development of the bonus/malus system for customers | Malus: annual tax for cars above 135g CO ₂ /km pollution Bonus: cars below 110g CO ₂ /km pollution eligible for a one-off grant of up to EUR 7,000 per car at 0 g/km (i.e. BEVs). |
| | Promotion of local initiatives in car-sharing and rental of electric vehicles | See Annex 1 |
| | Government-initiated contracts with public and private large-fleet owners to buy electric vehicles | Implemented by the public buyer syndicate UGAP which from time to time announces further purchases such as, for instance, on 20 February 2013, the purchase of another batch of 2,600 electric vehicles that are “economically affordable” offered to state and regional authorities and associations within the next three years, comprising 500 Mia, 2,000 Renault Zoe and 100 Renault Fluence-ZE (Min. Ecol., Dév. Durable et Energie) |
| Sources: gtaï 01.11.2012; ademe.fr; developpement-durable.gouv.fr/ | | |

Another instrument in the promotion of demand for low-carbon vehicles are the various agreements with large public organisations and private companies, such as La Poste, EDF, or car-sharing companies to buy electric vehicles, often combined with a monitoring process. According to the plan that looks like a remake of the plan of 1995, 100,000 BEVs are to be delivered by 2015. A number of regional and local initiatives were organised in order to buy electric vehicles for communal purposes or mobility services (renting and car-sharing systems). With the rising perception of a structural crisis in the French industry, pinpointed by the “Rapport Gallois” in 2012 (Gallois 2012) and academic publications such as Artus / Virard (2011), these policies have become even more prominent. A new “plan automobile” was launched by the minister Montebourg in July 2012 aimed at increasing the number of purchases of “ecological” vehicles. Critics point out, however, that France has seen many plans in the past which never have been implemented.

2 Firms as major agents in pathways to electric drive technologies

2.1 Car makers: technological choices of incumbents and newcomers

The most visible agents who embark on the technical development of electric vehicles are the original equipment manufacturers (OEMs). While the sector producing ICE-driven vehicles in Europe has been subject to consolidation for a considerable time now, BEVs are also being produced by some newcomers. While incumbent OEMs benefit from economies of scale, experience in engineering, and well-known brands among other things, newcomers may benefit from radical new ideas. Who will finally hold the sway in the technological trajectory of the electrification of vehicles is likely to depend on the speed and depth of technological change. This section will demonstrate that the two large incumbent OEMs in France – although following different approaches to the electric vehicle – still determine the trajectory, leaving only a niche segment to the newcomers. We argue that the slow pace in technological developments and cautious investment based on realistic strategies work in favour of incumbent OEMs. Bergek et al. (2013) have added a further argument for path dependence in the nascent trajectory of electric vehicles. These authors found that incumbent OEMs from Japan, the United States and Europe were able to combine accumulated technological knowledge with the creation and acquisition of new knowledge, for instance on the electrification design of passenger cars. They coined the term “creative accumulation” of knowledge which seems to fit perfectly to the automobile production systems in old industrialised countries.

One must remember that technology is a means but not an end in the current strategies of OEMs for gaining global competitiveness. Along with that, the current benchmark for strategic options in the electrification of vehicles is the Japanese company Toyota. Toyota launched the first HEV, the Prius, in 1997, and was also the first to bring a PHEV (Prius new generation) onto the market in 2012. By now, Toyota has sold more than 6 million HEVs all over the world (as of 2013). French volume OEMs drew contrasting conclusions from this: while Renault focused on the fairly quick development of BEVs, PSA/Citroen decided to embark on HEVs – after the initial launch of two BEV models copied from Mitsubishi. Last but not least, we have to bear in mind that car producers’ knowledge base is principally on how to integrate various different components in order to create a complete car; their competence is in designing the architecture of a complete vehicle and mastering the integration of all components into it, based on long “industrial” experience in volume-production processes.

Essentially, the major technical challenge lies in the design, that is, the conceptualisation of the product architecture of a vehicle. Ulrich (1995, 420) defines product architecture as “(1) the arrangement of ‘functional elements’ [of the product]; (2) the mapping from ‘functional elements to physical components’ [of the product]; (3) the specification of the ‘interfaces’ among interacting physical components” (single inverted commas designate italics in the original; brackets from the author). Much of this is tacit knowledge based on trajectories in vehicle architecture and, hence, cannot be protected *per se* by patents (although parts of it are). Moreover, it seems that the product architecture of the passenger car has long been strongly oriented to integrating the ICE into the vehicle. This has had consequences for two basically different technical approaches to the electric vehicle: either electrification of the car is thought of as an incremental process that changes the architecture of the car gradually – something that has been true for early generations of elec-

tric cars and all kinds of hybridisation – or it is conceived of as a radical new perspective of what an electric vehicle could be. In the latter case, almost everything in the architecture of the vehicle can be new. Producers of a BEV, such as the Mia electric company, claim to follow this radical shift in thinking. Renault has followed both paths, first adapting an ICE-driven model, the Fluence, to electric drive, launched in 2010, and then designing a completely new electric vehicle, the Zoe, which was launched in early 2013. The first was due to the strategy of entering the new market as quickly as possible which seemed to materialise with the Grenelle 2007. Here, there was simply no time available for a completely new conceptualisation as new concepts generally require three to four years of R&D. However, the decision in favour of one of these architectures is not necessarily synonymous with a choice between new “high technology” and well-known technical solutions, as will be shown with the case of Mia.

Basically, we can differentiate between two strategies of carmakers. The first was to immediately leap into the production of a fully electric car, the BEV. As we will see in the next part of this section, creating the architecture of a BEV represents a real challenge. Moreover it seems that such a strategy is more risky as it calls for a considerable shift in the consumer’s preferences and behaviour. The second strategy is more cautious, shifting the product architecture step-by-step from an ICE-driven car to a HEV one by introducing emission-reducing technologies. This anticipates a slower learning process on the part of the customer. This is what PSA/Citroen did. However, differentiating along these lines of reasoning follows a more ideal path of technology than empirical evidence suggests. While Renault obviously is not involved in hybrid technologies at present, PSA Peugeot-Citroen was not limited to them. In fact, PSA/Citroen was the first OEM to launch series BEVs in Europe with the PSA-Ion and the Citroen C-Zero models in 2010, building on the 1995-experimentation when PSA Peugeot-Citroen was the first OEM in Europe to offer electric vehicles to the public, albeit in very small numbers. Cooperation with Mitsubishi in re-branding the Mitsubishi I-Miev model with its modern product architecture into the PSA/Citroen BEV models Ion and C-Zero – which were then imported from Japan – enabled PSA to be quick on the market after the Grenelle 2007 came into being while avoiding high development costs. Renault’s partner Nissan was another OEM bringing BEVs onto the market in the form of their Nissan Leaf model. After having sold more than 50,000 vehicles assembled in Japan, Nissan started production of the Leaf in the United States (at Smyrna/Tennessee) and the United Kingdom (at Sunderland) in 2013. Moreover, PSA Peugeot-Citroen is involved in the two-wheeler market of electric scooters and the conceptualisation of BEV urban models. Nevertheless, in the following sections, we make a differentiation between OEMs following BEV strategies and OEMs following HEV strategies (see also Hildermeier / Villareal 2011). However, whichever differences appear in the strategies of French OEMs, they share a common understanding of the market, namely of a clientele that is looking for an “affordable” vehicle with high functionality, as OEMs had found until today in Southern Europe. It is clearly a strategy oriented towards the low and middle-priced volume segment of the market.

2.1.1 The development of battery electric vehicles (BEVs)

The design of electric vehicles and the management of serial production entail considerable learning processes and causes car manufacturers high costs from the very start. During the various different phases in the history of electric vehicles, both volume producers in

France developed electric vehicles several times but they never ultimately attained commercial success. According to the philosophy of a volume producer, both OEMs took care to electrify a broader range of models. Both experimented with the electrification of small passenger vehicles such as the Renault Clio model or the PSA/Citroen 106, AX and Saxo models and light commercial vehicles such as the Renault Master and Express and the PSA/Citroen Berlingo in the 1990s. All these experiments were characterised by sticking to the architecture of the respective ICE model and “simply” replacing the traditional drive by an electric drive. The two volume producers chose different organisational methods to produce these niche products: PSA Peugeot-Citroen outsourced production to the niche producer of special cars Heuliez to whom PSA Peugeot-Citroen had been outsourcing niche products for a long time. PSA Peugeot-Citroen thus unconsciously laid the ground for the later emergence of a newcomer in BEVs, Mia electric (see below). Renault assembled the electric models in-house.

When electrification of vehicles became a renewed issue with the Grenelle de l’environnement in 2007, Renault chose a direct path to full electrification of the vehicles. Company sources maintain that the basic principles of this strategy refer to

- attaining and retaining full knowledge of electric drive – based on the alliance with Nissan and the proximity to the battery producer AESC, a Nissan/Nec joint venture,
- benefitting from strong competence in the management of serial production – based on its history as a volume producer,
- benefitting from the capability to construct models at an “affordable” price for the clients (that is, from the classical capabilities of a volume producer).

Entering the market in a timely manner is a “must” for a volume producer. In contrast to PSA/Citroen, Renault decided to temporarily stick to the traditional model architecture in order to cope with time restrictions. The passenger car Fluence-ZE and the light commercial vehicle Kangoo-ZE, which were both launched at the end of 2011, were conformed to electric drive modalities by replacing the ICE, but without undertaking major architectural changes. This required some efforts in engineering, in particular for the Fluence-ZE model, as the battery requires a great deal of space. However, as the battery was located in a standing position behind the rear seats, this caused inconveniences in the road performance of the car, due to the heavy weight of the battery, a problem which required to be overcome. Renault also joined up with the Israeli company Better Place to undertake an interesting experiment in Israel and Denmark: with the “quick drop” technology developed by Renault, Better Place intended to quickly exchange batteries for recharging – in just the same time as refuelling would require. The vision was to sell 100,000 Fluence-ZE models to Better Place by 2016, but in fact only one thousand models had been delivered by May 2012, when Better Place went bankrupt (*L’Usine Nouvelle*, 27 May 2013). The Fluence model is still being produced at the plant in Bursa/Turkey but has obviously never become a success. Renault subsequently started designing radically new car architectures designed specifically for BEVs. In March 2012, the company was able to launch the “quadricycle” Twizy, a 4-wheel-vehicle for one person, without side windows and many other fittings. The Twizy targets the segment of urban mobility and was a response to electric vehicles for urban transport which was launched by several small companies fairly

quickly after 2009. Most of these vehicles do not need full automobile certification (“homologation”).

Simultaneously, Renault developed a new small passenger car, the Zoe, which was the first BEV model in Europe for the volume market that had been totally newly designed (Renault slogan: “100% produced in France”). Pre-series models were launched in February 2012, sales started in March 2013 and reached about 10,000 units in 2013, mostly delivered to France (5,500), Germany (1,000) and the Netherlands (500, avem.fr/actualite 29 Jan. 2014). Table 5 lists challenges that had to be mastered in design, mostly with assistance from large system suppliers.

| Table 5: Some technological challenges for the design of the Zoe model | |
|--|--|
| Challenge | Solution |
| Allocation of the heavy battery into the body without affecting the driving characteristics of the vehicle | Positioning beneath the floor between both axles |
| Although only a small series at the beginning, the need for reduced production costs | Uses same platform as ICE-driven Clio 4; assembly on the same production line |
| Battery with a range of up to 250 km (optimal conditions) | Li-ion battery imported from Korea (LG) but planned to be assembled in France, see Section 2.2 |
| Reducing and recuperating energy consumption | Heating pump that avoids using the battery for heating (TSE) Brake energy recuperation system (Bosch, Continental) Power saving wheels, new generation (Michelin ENERGY TM E-V) |
| Definition of the car/grid interface for battery recharging | Chameleon charger (Renault) for recharging at different intensities of current |
| Sources: <i>L'Usine Nouvelle</i> , 13 Nov. 2012, 23 Feb. 2012, 29 Mar. 2013. | |

Looking at the three strategic principles of Renault in detail reveals some interesting traits of how the company combines innovations in technology with innovations in business practices. First, with reference to the full knowledge of the electric drive, Renault seems to maintain a balance between full control of the value chain, in particular of battery design and production, and the well-known double-sourcing strategy – the choice of two suppliers for a given part in order to avoid dependence. Renault has always been considered to be in an advantageous position through its alliance with the Japanese Nissan as AESC (Automotive Energy Supply Corp.), a joint venture of Nissan and NEC, was able to provide Renault with batteries. In fact, the Fluence-ZE model and the Kangoo-ZE light commercial vehicle were equipped with AESC batteries. These are Li-Mn₂O₄ batteries (see Table 8), fully imported from Japan (*L'Usine Nouvelle*, 3 Nov. 2009). Earlier, Renault had announced that it was going to co-produce Li-ion batteries for the new Zoe model at the car's assembly location Flins near Paris with AESC. But in 2012, Renault withdrew from this proposition and made a contract with the Korean LG Chemicals company (more precisely, a joint venture of LG and Cea, the public, formerly nuclear power authority in France) for providing the Zoe and the Twizy models with Li-ion batteries. The Twizy is in fact currently equipped with a LG battery which comes from Korea.

Second, with reference to serial production capacities, different decisions have been taken, such as developing the Zoe model on a common platform with the Clio and assembling both on the same assembly line, regardless of the type of drive. The same principle applies to the light commercial vehicle Kangoo (ICE drive) and Kangoo Z.E. (electric drive), assembled at the Maubeuge site. This allows for similarity in production cycles of up to 90% for the Kangoo models at Maubeuge and 80% for the Zoe/Clio models at Flins (*L'Usine Nouvelle*, 23 Feb. 2012). The workforce of both lines was trained for months at the Renault Technocentre in Guyancourt. One must imagine, for example, that the battery of the Zoe model has a weight of 290 kg and requires to be installed very carefully into the body of the car. Renault – and the Mia electric company (see below) – are said to be currently the only producers in France who have been able to master the serial production of electric vehicles. It comes without saying that such capabilities allow for considerable cost reductions.

Thus, Renault's third strategic principle, achieving the "affordability" of electric vehicles, has partly been attained by Renault's competence in the manufacture of series (I-3, 10). However, the bulk of costs were caused by the battery that is estimated at several thousand euros. This is where the commercial innovation of Renault comes in: the OEM sells the vehicle *without* a battery at a reasonable price (e.g., Fluence-ZE at about Euro 27,000; Zoe from about Euro 13,700 onwards; Twizy at about Euro 7,500; Kangoo-ZE at about Euro 25,000) and then rents the battery out at monthly fees (Euro 79 for the Zoe). This idea was definitely not new, as it had already been talked about in the 1980s, but it had never been realised before (Guignard 2010, 22). When sales of the Zoe model decreased by the end of 2013, Renault added a low-rent model at Euro 49 per month for customers who do not drive many kilometres each year (5,000 km/year).

To sum up: Renault managed to become the first volume OEM in Europe to bring a newly designed volume BEV onto the market and to, simultaneously, offer a variety of four models of BEV with different architecture to its clients. In a technical sense, these novelties cannot be considered "disruptive" though: as mentioned in Section 1.3, the company had already experimented with electric propulsion technologies during the 1990s; the early BEV models in the 2000s stuck to the design of an ICE-driven vehicle. Finally, Renault had preferential access to knowledge about electric drive, including battery technologies, through its alliance with the Japanese Nissan. It is therefore fair to say that BEV development within the Renault company is largely path-dependent.

Newcomers in BEV production have recently appeared in the market segment for urban transport. We will not be considering the segment of "no permit" vehicles here: small (and slow) vehicles for urban transport that have not acquired homologation but are familiar to customers in Southern Europe. Instead, we focus on fully homologised electric vehicles, that is, those that can be used by customers in a way similar to most ICE-driven cars. Mia electric and Bolloré are currently the most important producers in France (see Table 1) but differ considerably from each other in origin, business model, resources and, finally, technology. While Mia originates from the automobile sector benefitting from competences in automobile design and production, Bolloré is the only "true" newcomer benefitting from know-how in battery production and a new business model. In the following, we will focus firstly on the technological concept of Mia and then on the business model of Bolloré. Bolloré's technical competence in batteries will be discussed in more detail in Section 2.2.

The Mia is currently the only model that the Mia electric company has. Although the concept is consistently oriented towards low costs – in other words at reaching an “affordable” price for the vehicle – similar to Renault, technical solutions are very different. The Mia electric vehicle is not a high-tech product nor is it composed of high-tech components, according to some representatives of the Mia company (I-6, 11). The idea of the carmakers was to build a small, light and manageable vehicle, to be handled simply and capable of being used on the narrow roads of Southern European towns (I-11), at an affordable price. In developing its product architecture some years ago, the designers chose the (ICE) Smart model as a technical benchmark, as it had earlier been developed by the Swiss Hayek.

The Mia is a car for 3 to 4 persons, achieving a maximum speed of 100 km/h and a range of 125 km (www.mia-electric.com). There are both passenger and utility versions of the car. It has current state-of-the-art safety assets such as ABS, a driver’s airbag, and a brake-assist system. The differing product architecture of the Mia is based on a clear product philosophy which focuses on three targets: simplicity, low weight, and uncomplicated daily use. Achieving these targets is expected to result in a relatively low price for the car. These targets translate into a number of technical solutions which are not necessarily new but which, taken together, form a particular new concept for a car. These solutions are based on the absence of equipment that is considered a “luxury”; of high-performance in drive technology; of model variety; of high-cost production equipment (such as a paint shop); of large costs in R&D (through co-development, adaptation of well-known technologies); and, finally, of a sophisticated business model for sales. For example, the steel tube body frame draped with coloured plastic parts results in a production line that does not need the most expensive equipment usually required in traditional car making, namely a press working line and a paint shop. Both initial investments for equipment and time laps in building-up the equipment were considerably reduced allowing for a quick move into the new market. Where important components were concerned, designers added well-known and low-cost technology, abstaining from the current best state-of-the art, as for example with the asynchronous electric motor bought from a large French supplier or the Li-FePO₄ battery. All of this contributed to reducing the price of the car. Moreover, incremental innovation is widely existent in the design of components. The low-energy heating system has been co-developed together with a German supplier, and currently also the cooling system. However simple technical solutions to reduce energy consumption in the heating and cooling systems, such as electronic devices that allow the use of electricity from the grid to heat or cool the vehicle before starting, create new technical challenges for other components of the vehicle, such as the quality of body production. For example, joints must be closed as far as possible in order to provide for good isolation.

Although the Mia company may appear to be a newcomer founded in 2010, the concept of the Mia model is path-dependent as it is based on the long-term experience of leading designers and the production workforce in automobile production. Box 1 describes the entangled history of the company’s foundation in more detail, supporting the argument for a path-dependent development. The design concept of the Mia can be seen as resulting from a combination of earlier experiences in the light-weight construction of sports cars, the failure to launch an electric vehicle with a large reach at high costs, and the incumbent engineering know-how in electric cars.

Box 1: A short history of Mia's origin

The story begins with the failure of an engineering company in Switzerland which had focused on the machinery for producing optical fibre cables and went bankrupt during the dotcom crisis of 2000. The company was sold to a Swiss financial investor who recreated the company under the name "*Mindset AG*" in 2007 aiming at developing a "*fundamentally new electric vehicle*" (according to the annual report of the Mindset Holding 2011, 7). Ideas about building BEVs were everywhere in the early 2000s, and Mindset latched on to the idea of a fast sports electric car as demonstrated by the American Tesla electric vehicle that was one of the solutions most discussed at that time. The new company appointed a former chief designer from the classical automobile sector who is still well-known in Germany, Murat Günak. He had gained much experience in and had certainly brought many contacts from car companies such as Peugeot, Daimler and Volkswagen (Geiger 2011, Bibendum 2012, No name 2011).

In November 2008, the first Mindset prototype came into being. The Mindset was conceptualised as a long-distance sports vehicle. In the sports vehicle design sector, reducing weight is one of the major construction principles. It would seem that the company had some relevant competences. Furthermore, batteries of the Li-ion type were conceptualised to deliver the power necessary for a wide-reach sports car. The company announced a contract with a firm newly created by a German inventor in 2011. In January 2012, it then announced the development of a "*path-breaking step in battery development*", arriving at 52 kWh with a 200kg battery, and, hence, an energy density of 0.26 kW/kg (Mindset press release 25 Jan. 2012). The company claimed that this was a major competitive advantage and made many promises both as regards a reach of more than 400 km with fully electric drive and more than 1,200 km with a hybrid drive. However, some observers found these promises relating to reach implausible and claimed that they were mainly targeted at finding new investors. In August 2012, the company went bankrupt.

Meanwhile, as early as in 2010, the German designer had already left the company. We do not know his motives but these may be to do with challenges and opportunities arising from the insolvency of an old French car assembler, Heuliez, in early 2009. This family-based company had been created in the early 20th century at Cerizay as a producer of carts. It then turned to full automobile assembly in 1925 as a specialist for estates, mainly as a subcontractor to Peugeot and Citroen, two of the large OEMs in France at that time. The company became a specialist in niche models, particularly cabriolets, and, during the 1990s, took part in many research projects on the electric vehicle. It was in these capacities that Heuliez became involved in the development of the Mindset model. The company also started to develop an electric vehicle of its own, the concept car Friendly. When the automobile markets ran into difficulties, the company had to close down and the knowledge of about 80 engineers in the technology of the electric car was in danger of becoming lost. At this moment, the company Mia electric was created (in 2010), with the investment of a German trader in pharmaceuticals, in the legal form of a German company with headquarters in the Federal State of Saarland. Appointing Murat Günak implied acquiring both his experience and his personal network in electric-vehicle design. Moreover, part of the engineering team was taken over, with its experience in technologies of the electric car; the model Friendly became the basis of the development of a new car concept, the Mia; and a small part of the old factory was also taken over for the production of the Mia electric vehicle.

Recently, the company has wished to co-develop a small and light hydrogen motor as a range extender, together with another German engineering service supplier, in order to enlarge the market. This latter company, however, went bankrupt revealing a major weakness of the business model of Mia electric company: it is a small company which has no bargaining power vis-à-vis the large incumbent system suppliers in the automobile sector. Although the company may buy standardised components from large suppliers, such as the airbag or the ABS, it as a result prefers to cooperate with equal-size partners in the adaption and development of other components – but this implies the big risk that they are not able to undertake the necessary investments in new technologies.

Founded in 2010, the Mia electric company was able to launch its new BEV model, the Mia, quite quickly in late 2011. In February 2012, the company proudly announced the

1,000th Mia car rolling off the production lines and presented another version of its model at the recent Geneva Motor Show (2012) (mia-electric 2012). The Mia is sold at the price of a middle-segment ICE car of Euro 22,000 to 25,000 in Germany, battery included. In France, where the state offers a EUR 7,000 subsidy to the customer, the price is reduced respectively. France is Mia's main market, although some cars are sold in various European countries including Denmark, Germany and the United Kingdom (see Table 1). Yet the company has not achieved its ambitious goals. Plans for an annual production of 10,000 vehicles were reduced to 5,000 in 2012 but a look at Table 1 reveals that less than 400 vehicles were sold in its main market in 2012. A total of 842 models were sold by mid-2013. As a consequence, the main owners of the Mia electric company sold their shares to a German financial group in June 2013 (*L'Usine Nouvelle*, 14 Jun. 2013, *Saarbrücker Zeitung* 16 Jun. 2013). In March 2014, the company went bankrupt. An ambiguous market situation had emerged in France: while Mia managers had hoped to benefit from Renault's efforts to launch the Zoe model and thereby increase the customer's awareness and interest in BEVs, they may have suffered also from Zoe's apparent success since its launch in March 2013 (see Table 1). Actually, the management seems to be imitating the successful Bolloré system (see below) in launching a national car rental system based on the Mia electric vehicle (avem.fr/actualité16 Jan. 2014).

The other newcomer, Bolloré, may have a better chance of survival due to the owner's exceptional vision and business model and due to higher resources from the production of polymer membranes and secondary products, the LMP battery (see Section 2.2) and supercapacitors. The entrepreneur Vincent Bolloré developed a full value chain. This ranges from the production of the battery – through the company Batscap, founded in 2001 – to the electric vehicle called Bluecar – produced in a limited series at a factory leased from the well-known automobile design company Pininfarina, near Turin in Italy; and, finally, its use in the car-renting company Autolib created in 2011 in Paris (see Section 3). Bolloré's vision does not target the technical issues of the Bluecar electric vehicle *per se*, but the commercial viability of the LMP (lithium-metal-polymer) battery (see also Section 2.2 and Section 3).

There is still a lively scene in BEV-development for market niches in France by small teams. Some newcomers originate from the racing-car sector, such as Exagon Engineering who recently announced a luxurious sedan model Exagon Furtive eGT based on a lithium battery and a carbon-fibre body. Others diversified from the existing light urban transport sector, such as the small company Lumeneo which announced it was opening an assembly line for the Neoma model, a model to be sold at EUR 14,700 and a battery rent (1 Mar. 2013). Hence, it seems that the race for electric vehicles to be used in urban transport has just started in France. Most companies emulate Renault's business model: Buy the vehicle, but rent the battery. While this business model might accelerate the introduction of electromobility in France, it is not very likely that niche producers and newcomers will be able to revolutionise the incumbent automobile production system.

2.1.2 Hybridisation of the ICE – another path to the electric vehicle

Adding electric components to an ICE in order to reduce fuel consumption – the currently major form of so-called hybridisation of vehicles – clearly adheres to the traditional trajectory of automobile technology, but only at first sight. To various degrees, hybrid drive technologies combine the combustion engine with an electric engine within one vehicle. In

contrast to the direct technological path towards the BEV, there are no newcomers in hybrid-drive technologies in France. From an evolutionary perspective, hybridisation is tied to established knowledge in ICE-drive technologies, and is, hence, “dependent” on it. In France, the volume producer PSA/Citroen was previously a forerunner and is currently the only OEM pitching on hybrid technologies. As Section 1.2 has shown, this strategy seemed to meet current market requirements better than the BEV. Hybridisation can take the shape of several intermediate technologies, from the “micro” HEV (where the main ICE is supported by a small electric motor) to “full” HEV and “plug-in” HEV, with powerful batteries and electric motors and a small supporting ICE. In terms of the final aim to directly avoid CO₂ emissions through full electrification of a vehicle, all hybrid technologies are transitory. However, from the engineer’s perspective, there are no transitory technologies in the proper meaning of the word apart from tremendously increasing demand on the battery. Each step in the electrification of the vehicle requires innovative technologies of its own. Furthermore, hybrid technologies seem more challenging than pure electric technologies insofar as the combination of two engines requires more efforts in weight reduction and particularly in the electronic management devices of the drive – at least in markets where the demand for such products is high.⁶ On the other hand, hybridisation does not require the vehicle to have a completely new product architecture.

Although PSA/Citroen claims to have similar targets as Renault in electrifying the automobile (I-13) the company follows a step-by-step approach via hybridisation, and, hence, a different strategy towards electrification (Hildermeier / Villareal 2011). The benchmark for this strategy was Toyota with its first HEV worldwide, the Prius, and the next step to the PHEV, the Prius III, recently taken in 2012. These models, however, have a gasoline ICE. In recent decades, PSA Peugeot-Citroen had become a well-known producer of diesel engines who has benefitted from the shifting demand to diesel-driven ICE automobiles in Europe. So PSA/Citroen has emerged as an innovative European OEM in all kinds of diesel engine-based hybrid technologies. PSA/Citroen was also a technological forerunner in other hybrid technologies on several occasions (see Box 2).

Box 2: “Micro” hybridisation through stop/start and brake energy recuperation

As early as in 2005, PSA/Citroen brought the first stop-start mechanism to the European market in a Citroen model, in co-development with the French system supplier Valeo. The first generation of “micro-hybridisation” did not change the architecture of the automobile very much, in particular no change in battery technology was needed as the system even worked with traditional lead batteries. Nevertheless the model failed on the market. When the second generation stop-start system was re-introduced into PSA/Citroen models later in 2010 (also developed by Valeo), the company no longer stood alone in Europe. Other OEMs had followed, partly using other technological solutions. Since then, the stop-start system has been a mass product enjoying economies of scale as all models of PSA/Citroen except the largest ones now use the system.

In addition, braking energy is recuperated via the alternator and transferred to the battery. Technically, there are several ways to store recuperated energy: mechanically through a balance wheel (as in Toyota and Audi models, see *L’Usine Nouvelle*, 18 Jun. 2012); hydraulically (as now tested by PSA Peugeot-Citroen with the hybrid air technology); electrically through a supercapacitor; and chemically through the battery. PSA took the latter path (I-1, 15, 16).

6 According to Tilman Altenburg, there is much less demand for sophisticated technical solutions for HEVs in China. I am grateful for this information.

With its knowledge of diesel ICEs, the company was able to combine a low fuel-consuming and low CO₂-exhausting ICE with the electric drive, as the diesel engine consumes less than an ordinary gasoline engine. In 2011 and 2012, PSA/Citroen was the first European OEM to launch serial production of diesel HEVs with three models (PSA 3008H4 and 508H4, Citroen DS5 H4). PSA/Citroen was ranked No. 1 in average fleet CO₂ emission in Europe in 2008; No. 2 (behind Toyota) in 2009; No. 3 (behind Toyota and Fiat) in 2010; faced a comeback as No. 2 in 2011, and probably again as No. 1 in 2012, according to a close observer (I-13). Yet, this does not necessarily translate into commercial success as a diesel ICE is more expensive than a gasoline ICE; adding an electric engine raises further production costs considerably; and the costs of the battery still are very high. Hence, HEV vehicles are generally launched in the higher-priced segment of large cars where the series produced are small. Secondly, the market is largely restricted to Europe as European customers often prefer diesel ICEs while customers in China and the United States still prefer gasoline engines. Having said that, European markets have been stagnating – if not shrinking – for a long time.

Compared to a gasoline HEV, the diesel HEV requires considerable new development of the drive, particularly in the management of the electronics. The design of a HEV brings several major technical challenges to the OEM (see Box 3).

Box 3: Some technical challenges in the concept of a diesel HEV

Battery: Usually battery performance does not form part of the technical competence of an OEM. The benchmark Toyota Prius achieves 3 to 5 km pure electric drive in its HEV version and 25 to 30 km in its PHEV generation. Toyota, as well as PSA/Citroen, both use a Ni-MH battery in the HEV models while clearly more performance is needed in PHEV models. That can only be delivered by Li-ion batteries. PSA/Citroen buy Ni-MH batteries for the Peugeot 3008 H4, 508H4 and DS5H4 models from the Japanese Sanyo Electric that already supplies Ford and Honda models (*L'Usine Nouvelle*, 3 Nov. 2009). These are imported from Japan.

Tuning the two drives in different modes of traction: Management of the drive chain is the decisive issue to master as it largely affects consumer's comfort in driving (I-7). In the DS5H4 model, for instance, the ICE and the related drive train sits on the front axle while the electric motor and electric drive train is at the rear axis, each axis having a different gearbox. They are related through an electronic control unit. Setting the interplay of both axles, either in the mode of driving only by diesel ICE or electric engine or in the combined mode is a major challenge. While electronic control systems come from suppliers such as Bosch, the OEM's main competence is in software development. This is not new to the sector as, for a long time, ICE adjustment setting has been based on the OEM's software know-how, mostly in simulation. As a consequence, there is close cooperation between the component supplier and the OEM in the design of the management of the drive chain. Many research units, public and private, currently deal with this technical adjustment problem between the two drives (I-7, 17).

Weight management: Battery weight in the DS5H4 model is 55 kg; batteries of PHEV are considerably heavier, and the battery for the BEV Renault Zoe has a weight of 290 kg (see above). A challenge is not only the total weight, that affects the range of driving electrically, but also the positioning of the weight in the car body that matters for road performance of the vehicle.

Cleaning exhaust gases: The diesel ICE produces less heat but more particles compared to a gasoline ICE, particularly at reduced power (as in the combined mode of drive). This calls for another electronic exhaust system control.

Technical challenges are generally overcome by close cooperation between the OEM and some system suppliers, at least in Europe (see Sturgeon / van Biesenbroeck / Gereffi 2008 for other forms of coordination between OEMs and suppliers in the United States and Ja-

pan). Such was the case with co-development of the stop/start system with Valeo or the electronic control system with Bosch. The competence of an OEM in general and of PSA/Citroen in particular is clearly seen in its capacity to integrate the various different components into the design of a car. As an interviewee put it:

“What’s the knowledge of an OEM? This is not how to produce an alternator. OEMs buy many components, as we do for example from Valeo or Bosch. We know how to make a car, that is, to get all elements of a drive chain running” (I-13).

Again, PSA/Citroen seems to be among the first in Europe to have invested in a PHEV concept for several years. The technology has been moved forward to the stage of prototyping and even field demonstration in a project called “Hydole”. In this three-year-project, which ended in 2013, PSA/Citroen made a reality test of a new configuration in PHEV technology, in cooperation with research labs and system suppliers, and co-funded by Ademe. For the first time, PSA Peugeot-Citroen developed its own batteries from lithium cells delivered by the French company Saft, designed a high-performance battery that only needs cooling by air and can be recharged during movement with the hybrid drive. The reach by electric drive only is over 80 km. The model would need a “downsized” ICE such as the newly developed 3-cylinder gasoline engine of PSA (Gazeau 2013, I-23) which might open up the Chinese market. Thus, the PHEV model of PSA/Citroen would have a considerably higher performance than the competing Toyota PHEV Prius and the diesel PHEV Volvo V60 D6 Hybrid launched in 2012 by the now Chinese-Swedish company Volvo. The concept of the demonstration vehicle differed considerably from concepts of competitors as the fundamental goal was to develop an “affordable” PHEV for European customers. This can be translated into values below EUR 30,000 while current and future competitors demand higher prices on the market (currently: Toyota Prius EUR 36,000, Opel Ampera EUR 44,000, Volvo V60 D6 H EUR 60,000; the BMWi3 launched end of 2013 is above EUR 38,000). Recently, serial production has been postponed by PSA/Citroen from 2012 to 2016 or 2017, however. This provides opportunities to early followers such as the German premium OEMs who announced that they would be bringing PHEV models to serial production soon (see Altenburg forthcoming).

HEV technology obviously tries to cope with a dilemma which arises between decreasing fuel consumption along with increasing “cleanness” of the vehicle through increasing electrification on the one hand, and tremendously rising costs on the other. *“The larger the electrical capacity of a vehicle, the higher the costs”* says one observer (I-13). One of the major “musts” of a volume producer is, as mentioned above, to launch vehicles that clients can afford. Hence, “affordability” is a guiding principle in the OEM’s and PSA’s strategy. As a result, a step-by-step strategy evolved which enabled PSA Peugeot-Citroen to enter various different segments of the market. One of the consequences is to stick to low tension in battery technologies (at a maximum of 48 to 60 volts). Accordingly, demands on batteries are less challenging and batteries are less expensive. The cost barrier is also obvious to system suppliers such as Valeo who likewise prefers to remain with low-tension systems so that it can offer “affordable”, lower-priced components (I-16).

Currently PSA/Citroen offers a range of models that include various degrees of hybridisation, including micro- or mild hybrid vehicles, in order to cover several geographical markets and market segments. A particular focus at the moment seems to be on low-cost hybrid vehicle technologies such as, for example, proven in the “Hybride eco” model. In order to achieve the objectives of reduced fuel consumption at low costs, its hybrid tech-

nology will be limited to brake energy recuperation and a small battery which is able to move the vehicle for about 100m only (I-17). There is, however, another technology available to PSA/Citroen which allows for brake energy recuperation by air compression, not battery, hence in a non-electric way. With the recently presented “Hybrid Air” technology, the company is striving to get a foothold in the Chinese market (avem.fr/actualite 2 Jan. 2014). For the moment, PSA/Citroen is pursuing heterogeneous technologies that promise to be affordable, both for the customers and the company. Although competitors are closing the technological gap rather quickly, PSA/Citroen is hesitant to go ahead to the next generation of hybrid electric vehicles, the PHEV. It is self-evident that hybridisation of propulsion is, to a large degree, based on a strong competence in ICE propulsion and, therefore, can be considered a path-dependent process.

2.2 Agents in the development of battery technologies

Energy storage under particular conditions of mobility is still at the core of the technological challenges of the electric vehicle (I-4, 7, 13). Although recent innovations in battery technology have been achieved predominantly in Asia (Japan, Korea, China) and the United States, it is often claimed that France has retained some experience in battery development and production over many decades, in contrast to other European countries and, in particular, to Germany. The long and continuous history of battery development and production in France is one of the major and unique characteristics of the French trajectory to electromobility (see Section 1.4). Nevertheless, by far the majority of batteries for electric vehicles stem from Asian and US-American companies (*L'Usine Nouvelle*, 1 Nov. 2009). Even so, much effort on battery technology has been reported recently in France, both in the private sector and in government-funded R&D labs. It is still the case that the serial production of batteries for HEVs and BEVs is fairly limited, not least due to other strategic options of French producers. The leading French battery company, Saft, is strongly involved in battery development for the defence, space and aircraft, and for the railway and power industries. All these sectors require highly customised electricity storage facilities and offer a market that promises far higher profits than the electric vehicle market.

The new generations of vehicle batteries have a very different architecture to small consumer batteries (such as for laptops, mobile phones, etc.), due to higher performance requirements, higher demands on safety, durability, space and, not least, shock robustness (I-19). Also different, vehicle batteries for use in HEVs, PHEVs and BEVs (other than the classical lead batteries) are more or less customised products as general standards such as in the consumer electronics industry are missing. The product architecture of a vehicle battery has to be adapted to the architecture of the vehicle, both in performance and size. On the other hand, although based on a customised design, the battery concept simultaneously needs to be suitable for serial production. Battery technology is complex as it combines knowledge of electrochemistry, material sciences, electrical engineering, electronics and software development, and not least the know-how of serial production. The battery is a system requiring a number of production processes and the input of knowledge from very different fields of competence. In addition to the electrochemistry of the cells, major challenges arise with regard to measuring, controlling and balancing the tension between the cells, processes that determine the performance, the durability and the safety of a battery. Electronics, both in hardware and software, fulfil these tasks in the battery management system. As these are more proximate to the end product, the customisation of batter-

ies is largely based on this technological field. This would, in general, call for a location of battery assembly near to customers, the OEMs. In terms of the capacity of the French innovation system on batteries, some observers bemoan the loss of the electronic industry in France (in particular of printed circuit production) but emphasise the capacity for software development in battery management systems (I-20, 23). However, a battery assembler will only start serial production when both battery concept and battery integration into the vehicle have been agreed upon with the OEM (I-19) and a minimum threshold of production can be achieved. It is a matter of fact that the small serial production of BEVs is still not sufficient to justify the development of an industry for electric batteries.

2.2.1 The trajectory of battery technologies in France

From a technological perspective, there is a long experience in electrochemistry and basic battery research in France, both on the part of companies (especially Saft) and research labs such as, in particular, some departments of CNRS (Centre national de la recherche scientifique/National Center for Scientific Research) and Cea (Commissariat à l'énergie atomique et aux énergies alternatives). Insofar, French battery know-how is at least adopting, if not creating, new technologies in Europe at an early stage. This may not hold true for production, though.

From an evolutionary perspective, it seems important to note that new battery technologies were developed with the emergence of new applications and, hence, markets. Until the end of the 1980s, leading technologies had been the lead battery and the nickel-cadmium battery. The lead battery suffered from weight, fragility and corrosive materials; the Ni-Cd battery had more capacity but less power. Nickel-metal-hydride (NiMH) and the lithium batteries emerged with the rise of the portable computer in the early 1990s (Cea 2010, 8). Japanese, then Korean and recently Chinese companies specialising in battery technology have benefitted from the emergence of the world-leading electronic industries producing games controls, laptops, mobile phones, digital cameras, and so on, all of which require the storage of electrical energy. Although technical characteristics and requirements are considerably different in the automobile sector, this nevertheless also laid the base for battery development for the electrification of vehicles. During the 1990s, NiMH-type batteries began to be used in hybrid vehicles, first by Toyota and Honda. They have the advantages of lower pollution, the ability to stock more energy, and have a reduced memory effect⁷, compared to former battery technologies (Cea 2010, 8). The recent HEV models of PSA/Citroen still use NiMH batteries that are imported from Japan (Sanyo). At the beginning of the 2000s, the Japanese began to develop Lithium-nickel-cobalt and lithium-manganese batteries – technologies which, however, caused serious problems in risks as regards the thermal stability of the battery and its durability (I-19).

France – and the United States – are seen as early proponents in the “*global battle for batteries*”, at least in commercial terms (Dupin 2009). Two lines of technological development can be traced within the French battery-production system, firstly knowledge and research on the electrochemistry of the battery, and, secondly, the knowledge on how to design and integrate a battery into an electrified vehicle. The first line relates to the very

7 The “memory effect” of a battery refers to the capacitance loss through frequent partial discharge. It has been observed in the past but seems to have been overcome in recent battery development.

sophisticated requirements expected of battery characteristics in the defence, space and aircraft industries. Going back to the 1980s and 1990s, companies that were involved in the space and aircraft industries had amassed profound knowledge of electrochemistry and battery development, mainly Saft and the Dassault Group. Saft is still the leading industrial company in France which has competences in the core areas of battery production at its disposal, i.e. particularly an understanding of electrochemistry and the production of battery cells. With promotion by the government via Ademe and fostered by research labs such as Cea-Liten, the lithium-ion technologies were further developed in France as of the 1990s, nearly simultaneously to development in Japan (I-20). In 2007, the Saft company was the first French company to bring a Li-ion battery into serial production, through its joint venture with the American Johnson Controls company. However, employing only about 3,000 persons, Saft is a medium-sized company, in global terms, and apparently lacks size for the mass production of battery components and assembly.

During the 1990s, a quick takeover of nickel-cadmium and nickel-metal-hydrid technologies and the emerging development of Li-ion batteries took place. Very recently, the li-iron-phosphate line of chemistry has been particularly pushed forward in France (I-19, 20). The public research lab Cea-Liten has commercialised know-how via the recently founded start-up Prollion; Saft has recently successfully commenced serial production (2007); while li-iron-phosphate batteries are also assembled by another start-up, E4V. Li-iron-phosphate batteries are considered sufficiently stable in their behaviour, provide sufficient energy (although less than other types of Li-ion batteries which in turn suffer from higher instability), have more durability, and are less expensive (I-19). For industrial purposes, they are packed either in small batteries of 48 Volt as for the Mia electric vehicle or in high-tension batteries for sports cars, such as the recently launched sports car Exagon.

Table 6: Short history of development in battery technologies in France, 1990 to 2010

| Type of battery | Wh/kg | Charging time (minutes)* | Start of applied R&D** | Start of series production | Producer |
|---|---------|--------------------------|------------------------|----------------------------|-------------|
| Lead | 30 | 300–600 | | | |
| Nickel-cadmium (Ni-Cd) | 50–55 | 180–300 | 1980s | 1995 | Saft |
| Nickel-metal-hydrid (NiMH) | 70–80 | 180–300 | 1990s | 1997 | Saft |
| Lithium-ion | 160–200 | 90–120 | mid-1990s | 2006 | Saft |
| (a) Lithium-manganese (LiMn ₂ O ₄) | | | since about 1995 | | Saft |
| (b) Lithium-iron-phosphate (LiFePO ₄) | | | | 2007 | Saft E4V |
| Lithium-metal-polymer | | | 1990s | 2005 | Batscap |

Wh/kg: watt hour/kilogramme

* CEA 2010, 9; I-19; ** It is always difficult to identify the “real” beginning of R&D. Cea (2010, 8), for instance, says that research on the chemistry of lithium had already started in the late 1970s. It is fair to say that applied research on the lithium battery as a combined system mainly started during the 1990s.

Sources: Guignard 2010, 21

A different technology, the lithium-metal-polymer battery (LMP), was developed by what may be considered an outsider. “*We are the only one in this technology in the world*”, said Vincent Bolloré with pride in 2011 (*L’Usine Nouvelle*, 17 Jan. 2011). Based on long experience in the development and production of thin gel-type membranes (films) in polymer, the entrepreneur Vincent Bolloré bought patents from Canada (and later took over the Canadian patent-holder) and further developed the lithium-metal-polymer battery type in the 1990s (from an iron-phosphate type). He brought this into serial production in 2005. LMP batteries offer the advantage of solid chemistry instead of the fluid electrolyte in Li-ion batteries. While they have a relatively large size, their energy density is lower which results in less tension on the electrodes, higher stability, less heating, and, hence, more safety (I-18, 19). Due to its size, the battery has a larger range, but a lower performance due to low-energy density, compared to Li-ion batteries (I-19). Thus, the battery differs considerably from the general lithium-based technology in design. It seems that the experience in producing very thin membranes in polymer allows for a very thin cell design and a higher flexibility in the design of the LMP battery (Akku-abc.de). Although the LMP technology was developed with financial assistance from Ademe during the 1990s (Guignard 2010, 22), it seems no longer to be researched by French public research labs. Further research on the chemistry of the cells has been done in Canada (I-19), and that may be the reason why LMP cells are produced in Canada by a subsidiary of Bolloré and imported to France for battery assembly at Batscap. According to some observers, the battery is more costly, however, and reduced competitiveness on the market may explain why Bolloré only used these batteries for his own electric vehicle Bluecar (see Section. 2.1.1).

Li-ion batteries in their line of Li-manganese or Li-Ni-cobalt technology now have a better performance which is necessary for quickly rechargeable energy-stock systems. They have been commercialised in BEVs such as the Nissan Leaf (LiMn₂O₄ battery type) and the Mitsubishi I-Miev (on a Li-cobalt type battery). The Nissan Leaf model was introduced to the French market by the Renault Nissan Alliance while the I-Miev model was copied by PSA/Citroen as C-Zero or P-Ion. Lithium batteries have also been commercialised by premium OEMs in Germany, such as the Mercedes S-class hybrid (in 2009) and the BMW 7 series ActiveHybrid (in 2010, both batteries from a then joint venture of Johnson Controls Saft/Continental).

This brief history of the development of battery technology in France reveals the three dimensions of strength of the French innovation system: First, there is a strong research base along with competent enterprises (although rather few) which are able to participate successfully in the global race for new battery technologies. Second, France is in the fortunate position of having two different battery technologies available: the Li-ion technology and the LMP technology (I-7). This has resulted in recent investments in new factories that have strengthened battery production in France (see Table 7). Third, France benefits from software and electronic companies experienced in developing Li-ion battery technology for ships, railways, stationary purposes, etc. (I-23). Again, they have the disadvantage of being too small for serial production in the automobile sector. However knowledge of serial production is the main driver of the companies’ competitiveness.

To be precise, French battery-producers have invested considerably into new assembly lines very recently, mainly for French BEV production (see Table 7). They purchase cells from abroad, either Asian countries (China, Korea) with regard to Li-ion batteries or Canada with regard to the LMP battery. This gives rise to a complex division of labour between

| Table 7: Recent investments in battery production facilities for electric 4-wheel vehicles in France | | | | | |
|---|------------------------|---------------------------|------------------------|---|-----------------------|
| Year | Location | Company | Type of battery | Production Capacity (units of batteries) | Main client |
| <i>Batteries</i> | | | | | |
| 2008 | Ergué-Gabéric Bretagne | Batscap | LMP | 2,500 | BEV Bluecar (Autolib) |
| 2008 | Nersac | Johnson Controls/Saft* | Li-Ion | | HEV Mercedes, BMW |
| 2010 | Le Bouchet 2 Essone | Dow Kokam | Li-Ion 7 kWh | 15,000 | BEV Neoma |
| 2011 | Le Mans | E4V | LiFePO ₄ | 10,000 | BEV Mia |
| 2012 | Ergué-Gabéric | Batscap | LMP | 12,500 | BEV Bluecar |
| 2015 | Flins, Ile de France | LG Chemical (for Renault) | Li-Ion | planned | BEV Renault Zoe |
| <i>Supercapacitors</i> | | | | | |
| 2008 | Ergué-Gabéric Bretagne | Batscap | | | |
| * taken over by Saft only in 2013 | | | | | |
| Sources: <i>L'Usine Nouvelle</i> , different issues | | | | | |

enterprises from different sectors. For instance, cell manufacturers may buy cathodes, anodes etc. from suppliers. Battery producers may pack purchased cells to become a battery, and add electronics, software and electrical subsystems bought from other of its suppliers. Thus, battery pack producers are system assemblers, somewhat similar to OEMs. As a consequence, innovation and technological development may sometimes be allocated more to the suppliers of battery manufacturers than to battery assembly.

Knowledge in the packaging of batteries is based on how to define battery requirements for the purposes of electric drive and how to integrate the battery into the vehicle. Various attempts to foster the development of the electric vehicle, in particular the 1995 agreement between the French government and the two large OEMs pertaining to the development of electric vehicles, seem to have safeguarded this competence of the customers of battery producers (see Section 1.3). Engineers in a few battery-producing companies have learned a great deal about the special requirements of vehicle batteries in cooperation with engineers of vehicle producers (I-19), particularly how to assemble a battery from purchased cells and other components (I-20). This knowledge became the base of the rejuvenated efforts in French battery development during the 2000s. It seems evident that a new technology is being driven forward by only a few key persons who have the experience and creativity at their disposal, i.e. “tacit” knowledge. This tacit knowledge can move across sectors and national boundaries as is witnessed by the career paths of key persons. It can be argued that crossing boundaries is almost a “must” for creativity and innovativeness. As anecdotal evidence, Box 4 provides an example in the form of Denys Gounot, the founder of E4V.

Box 4: The career path of Denys Gounot, founder of the E4V company

At the time when French automobile producers were experimenting with electric vehicles, in the mid- of the 1990s, Denys Gounot was a leading manager at Saft company. He later moved to a US-based telecommunications equipment company but returned to France in the early 2000s. Further interested in battery development, he decided to research lithium-iron-phosphate battery technology as he was sceptical about the lithium-nickel-cobalt and lithium-manganese technologies. Although the batteries had less energy density, they were safer, had larger durability and were less costly (I-19). Denys Gounot finally created his own battery assembling enterprise, E4V, in 2008, whose technological competence was mainly based on mastering the electronics of the battery.

This anecdote is not yet complete, however, without looking at the other side of a partnership: the automobile producer (see Section 2.1). During the 1995 experimentation, the car producer Heuliez who had long been in partnership with Peugeot for assembling special models since 1925, was responsible for all three electric vehicles offered by PSA/Citroen. This 1995 experimentation turned out to be a failure, however, in particular due to unsolvable problems in battery technology. Public support for R&D on batteries turned from nickel-cadmium technology in the early 1990s to lithium-ion and even lithium-metal-polymer technologies in the late 1990s. These were far from being applicable to serial production at that time, however (Guignard 2010, 22f.). Nonetheless, Heuliez engineers retained their knowledge and developed a new electric vehicle in the 2000s, together with Denys Gounot. It was shortly after the foundation of E4V that Heuliez went bankrupt and had to close down. With the creation of Mia electric in 2010, cooperation still continued and Mia electric became an important partner for battery development and production.

2.2.2 Partnerships in battery technologies

Automobile battery production in France is embedded in various partnerships: downstream because of the need for close contact to customers (OEMs) in customised production; and upstream to profit from the international division of labour. The explanation for downstream partnerships is worth repeating again: the pace of development in battery technology depends on the state of demand for their power. Factors determining battery technology are: performances (at different, sometimes contradicting dimensions), risks (concerning safety, durability) and costs. Requirements increase at all levels with the degree of electrification of the vehicle, i.e. from mild hybrid to PHEVs and, finally, BEVs. The more end customers are prepared to change the drive technology of the car – from pure thermal drive to hybrid or electric drive – but *not* their driving behaviour, the more demands are laid on the performance of the battery. Customers facing the limited range of electric vehicles available through current battery technology are said to prefer rapid charging at special stations. If their driving behaviour remains the same as before, namely conditioned by thermal drive, this results in the need for special charging stations and also in increased demands on the battery. In general, Li-ion batteries seem to respond better to these requirements, but neither battery researchers nor battery producers have fully mastered the chemistry of the Li-ion battery yet, as several accidents in the recent past have shown (traffic accident in China; accident involving the Dreamliner plane). Problems of overheating and durability still remain to be solved (I-18, 19). If the customers were to change their behaviour, for instance by showing patience as regards charging time and by carefully looking for frequent recharges wherever possible, then batteries of lower capacity would be sufficient, that is, ones producing less heat and which were safer. This is the case with the Mia model and its li-iron-phosphate battery as described above. However most BEVs, such as the recent Zoe (Renault) and PHEVs (PSA/Citroen plans) require more efficient batteries and will thus be equipped with other types of Li-ion battery. In contrast to the debate among technicians and politicians, recent practical tests have demonstrated, however, that many

French customers prefer to recharge their batteries at home and are thus indeed patient as regards recharge time (avem.fr/actualité, 14 Apr. 2013).

As mentioned above, challenges to the battery development for electric vehicles do not only arise in respect to electrochemistry but also in how to design a customised battery and, finally, how to integrate it into the structure of the vehicle. These necessarily lead to close partnerships between automobile assembling companies and battery producers. For various reasons, both of the two large OEMs in France prefer to either source (PSA/Citroen) or co-develop battery technology (Renault) from/with Japanese suppliers (see Table 8). Although there has been much debate about the Renault-Nissan Alliance and the preferential relationships to the Japanese battery producer NEC leading to plans for a battery factory in France for the supply of the new Zoe model, Renault finally decided to outsource battery production to the Korean LG company. The setting up of the factory – which will be an assembly plant using cells imported from Korea – has been postponed to 2015, however, probably due to the risks of overcapacities in Li-ion battery production and to the insecure market success of the Zoe model. As a consequence, the large OEMs still import finished batteries from Japan and Korea.

Table 8: Type of battery in Citroen and Renault models

| Year | PSA model | Type of battery | Producer | Year | Renault model | Type of battery | Producer |
|------|------------------------------------|----------------------------------|----------------|-----------|--------------------|----------------------------------|----------|
| 2010 | C-Zero (electric) | LiMn ₂ O ₄ | LEJ* | Oct. 2011 | Renault Kangoo ZE | LiMn ₂ O ₄ | AESC |
| 2010 | Berlingo-e Light commercial | NiCl ₂ | | Nov. 2011 | Renault Fluence ZE | LiMn ₂ O ₄ | AESC** |
| 2012 | DS5 H4 (hybrid) | NiMH | Sanyo Electric | Mar. 2012 | Twizy | Li-ion | LG |
| 2013 | Berlingo electric Light commercial | Li-ion | LEJ | Mar. 2013 | Renault Zoe | Li-ion | LG |

* Lithium Energy Japan is a joint venture of Mitsubishi and Yuasa companies;

** Automotive Energy Supply Corp., joint venture of Nissan and NEC

Sources: I-1, 15, company news

Obviously, companies in France do not play a role as serial producers for the large French OEMs although their competence and capacities have increased substantially in recent times. It is not possible here to give a presentation of the four battery-producers in France currently at work mainly for niche vehicles in the automobile sector in detail. In brief, the sector is fragmented, along various different dimensions. Two of the incumbent battery producers in France, Saft and Dow Kokam, do not seem very interested as they have strong roots and are still focused on the defence, space and aviation, and the railway industries. The newcomers in battery assembly, Batscap and E4V, have a focus on BEV “newcomers” among the OEMs and thus on small series production only (see Table 7). As a result, French battery-producers may currently have appropriate knowledge of battery technology at their disposal but lack the industrial capacities for battery mass production (also I-23).

Nonetheless, this small industry is fairly global in ownership, upstream procurement and market orientation. With the (partial) exception of Saft which is vertically integrated up to the stage of cell production, all companies import cell technology from abroad, either from China (Saft, E4V), Korea (Dow Kokam) or Canada (Batscap). Dow Kokam is a foreign, US- and Korea-based company. Among the French companies, only Saft is a multinational, albeit a small one. These multinationals have recently preferred to set up their main production facilities in larger markets than France. Saft S.A., traditionally oriented towards Europe, the United States and Australia, invested in China (2007) and India (2007, 2013) both for reasons of market access (India) and procurement (predominantly China). In response to the American Recovery and Reinvestment Act launched by the US Government in 2009, Saft and Dow Kokam established Li-Ion battery production plants in the United States, as did competing American, Korean and Japanese companies. These so-called “Obama factories”, however, seem to have resulted in current overcapacities for Li-ion batteries (*L’Usine Nouvelle*, 28 Feb. 2013). The prices for vehicle batteries have declined tremendously, from EUR 500 per KWh in 2010 to EUR 200 in 2013 (according to the German journal *Wirtschaftswoche* 25, 17 Jun. 2013, p. 9). As a consequence, competitors may squeeze each other out. In the United States, one producer went bankrupt; in Germany the OEM Daimler recently looked for new partners in the recently founded joint venture Li-Tec; and Renault shifted partnership from the Japanese AESC to the Korean LG who then postponed investment in France.

2.2.3 A renewed research base for electric drive technologies: major public players in battery R&D

As can be seen from the previous sections, battery technologies are currently a contested field in knowledge development and global competitiveness. A lot of basic research is still needed to overcome technological barriers in battery development for powerful HEVs and BEVs. Here, public research has an important role to play and this holds particularly true for the French national innovation system as it has long been said to be mainly based on research in public research labs (Chesnais 1993). Far from being able to deliver an exhaustive picture of the research landscape in France on all aspects of battery development, this section will present a brief overview of the very recent reconstruction of public research in France in favour of basic, and even applied, research in battery technologies. Two complementary trends have emerged in this restructuring process, firstly, the strengthening of basic research at universities, and, secondly, the strengthening of research cooperation between public R&D labs or universities and large companies in various fields of technology. Underlying these trends is the general restructuring of the French science system which commenced with the law on the research programme of 2006 (Boelke 2007).

Although basic public research on battery technologies has a long history in France (see Section 1.3), the French government substantially reorganised and increased investments in public research during the first decade of the 2000s. Basic research efforts seem to mainly focus on primary stages of the battery, in particular cathode development. The main problem in cell technology is related to the choice of materials for cathodes and anodes (here replacement of expensive graphite by other metals), the separator technology, and the search for fire-proof electrolytes (I-20). At present, the major object of battery research in France is Li-ion technology which is also confirmed by institutes of both basic and applied research. In actual fact, none of the technologies can be seen as mature, according to a voice from a public research institute (I-5). While plenty of research on the

subject takes place and this results in the quick expansion of technological knowledge, there is no security to allow considerable breakthroughs to be made. This engenders considerable problems for company-based applied research and product-development as development projects generally require a certain amount of time, mostly three or more years: if considerable shifts in (basic) knowledge take place several times within this development period, projects are often interrupted and subsequently closed prematurely (I-5).

Cea-Liten, IFpen and Ifsttar are three large public research labs, to name only the most important public research labs collaborating with the private sector. Although these labs (respectively their predecessors before a recent reorganisation) have been incumbent for a long time, they have played an increasing role in energy research and battery development in recent times. They are located either in the Paris or Grenoble region.

Box 5: The Cea-Liten research lab

The most focal institute is the former “Commissariat à l’énergie atomique et aux énergies alternatives” relabelled simply “Cea” in 2010, indicating a turn to renewable energies. Cea-Liten (Laboratoire d’Innovation pour les Technologies des Energies Nouvelles et les nanomatériaux) was created in 2007 as one of the Carnot institutes in France, a label which had been introduced just previously, in 2006. Carnot institutes aim at playing a major role in technology transfer from research to private companies. In fact, their function is similar to the German Fraunhofer Societies, although some respondents claimed that no similar organisation existed in France (see also Böhlke 2007, 23). Since 2006, Carnot institutes have established manifold instances of cooperation with the industry. Liten claims to be “*one of the main European research centres on new energy technologies*” (www-liten.cea.fr), with about 150 own patents at its disposal and managing 600 others in 2010 (www-liten.cea.fr). In 2009, Cea created a start-up, the Prollion company, as a joint venture with Alcen for the development and commercialisation of Li-ion battery technologies, based on its own technology on Li-iron-phosphate batteries.

Box 6: The IFpen research lab

IFpen (IFP energies nouvelles) emerged in 2005 from the former Institut Français de Pétrole (IFP) created in 1944, again aiming at research, knowledge transfer, and training on sustainable technologies for the industry, and once again IFpen is labelled a Carnot institute. Electrification of vehicles is one of the five research fields at IFpen. In this area, the institute focuses on energy storage systems, in particular on mastering the performance of the battery. Just as Cea-Liten, IFpen collaborates with large battery-producers in France such as Saft and Dow Kokam, for instance, as regards research on the influence of temperature on the state of charge, on the battery cycle and on energy losses for different exploitation methods, etc. (I-7). Where battery management is concerned, control of the state of charge and temperature are important tasks for collaborative work at IFpen.

Box 7: The Ifsttar research lab

Ifsttar (Institut français des sciences et technologies des transports, de l’aménagement et des réseaux) emerged in 2011 as the result of a recent reorganisation of research institutes (Inrets, on transport and safety research, and LCPC, the Central Lab on Roads and Bridges) and is oriented towards research on transport, infrastructure, natural hazards and the urban environment “*in order to improve living conditions of our citizens and – in a wider sense – forward the sustainable development of our societies*” (ifsttar.fr/presentation/). Forming part of CNRS, Ifsttar is dedicated to basic research both on the technologies of electric vehicles (for example optimisation of energy management of the vehicle, based on test equipment for motors and batteries) and social acceptance of electric vehicles. The institute attempts to optimise technologies based on a deeper understanding of the mobility behaviour of consumers.

University research has become increasingly important in fostering the knowledge base in different areas of electromobility. Basic research at universities is largely funded and directed by CNRS, the state research organisation. Several universities such as the Grenoble Institute of Technology (INP) at Grenoble, the University of Montpellier and the University of Bordeaux are often mentioned in the fields of electrochemistry for batteries (I-5, 18, 19). Again, little is known about the restructuring of the French university system in terms of the decentralisation of research capacities. Amongst others, university research has been strengthened through politics to attract experts from abroad, or more precisely from the United States – as exemplified by Professor Tarascon from Amiens University, a widely known expert in lithium battery technologies (see Box 8).

As can be seen from Boxes 5 to 8, more than ever before, the central government is trying to improve the links between pure research and commercialisation through various forms of support in applied research, testing and demonstration, and, finally, initiating science-industry networks. A host of further institutes have been founded in recent years, often together with universities. Some focus on all kind of social research on sustainability and mobility (such as the Institut de Mobilité Durable, IMD) recently created by Renault and the university ParisTech), others are joint efforts from the industry, supported by university research and state funds, to push the electrification of vehicles forward (such as Vedecom founded in 2012: Institut du Véhicule Décarboné et Communicant et de sa Mobilité). Furthermore, the state fosters cooperation between the private sector and public research labs by only granting funds for pre-competitive research to private-public consortia of private companies, public research labs, and universities (I-5, see also Ademe.fr).

To sum up, the French trajectory to electromobility seems to benefit from uninterrupted basic research that has, however, until recently been unconnected to the private sector, and from the very recent efforts to close this gap by trying to improve linkages to companies through various forms of networking. Little is known about its effectivity, though. For instance, the personal network of French researchers at universities, public research labs and large companies would deserve a closer analysis in order to better understand French assets in battery R&D.

Box 8: A brief view on the career path of Professor Tarascon

Professor Jean Marie Tarascon is an expert in Lithium-ion battery technology, having worked for 15 years in the United States, at Cornell University, the Bell Laboratories and the Bellcore Labs. Back in 1994 he was given a Chair at the University of Picardie in Amiens and established working groups on the chemistry of lithium and novel electrodes design based on nano-electrodes/electrolyte components.

As one of France's leading experts in battery development, Jean Marie Tarascon later became a most influential promoter of science-industry networks. He was one of the initiators of the European network on lithium battery research ALISTORE (Advanced Lithium Energy Storage System based on the use of nano-powders and nano-composite electrodes/electrolytes, www.alistore.eu), founded in 2004, which is formed from 20 research labs, among them five French universities, and 18 European companies, mainly OEM and battery producers. He was also one of the initiators of the RS2E network (Réseau sur le Stockage Electrochimique de l'Energie), launched by the French Minister for Higher Education and Research in July 2010 (avem.fr/actualite, 3 Aug. 2010, *L'Usine Nouvelle*, 20 Jan. 2011). Compared to ALISTORE, this network of 8 French research labs and 9 French companies has a national but broader orientation in technologies and their application, and, additionally, aims at the training of engineers in battery technology at Bordeaux (energie-rs2e.com, 2 Sep. 2013).

2.3 The indispensable role of other (than battery) suppliers in innovation and electrification

Since what has been called the second industrial revolution in the automobile industry in the 1990s, many facets of Toyotism and “lean production” have been introduced into the management of the automobile production system. One of the major results was that OEMs have largely outsourced the production and product development of major components to so-called first-tier or system suppliers. Technical innovations have often been developed by large companies of this sub-system, such as the ABS system by Bosch, while the OEMs have considerably increased their own R&D departments for the technical integration of increasingly sophisticated components and the control of technologies “made by others”. As we know, many OEMs have meanwhile outsourced up to 75% of value creation to suppliers while safeguarding strong control on the value chain. Value chain governance in the sector is still mainly “captive”, according to the terminology of Gereffi / Humphrey / Sturgeon (2005).

All this also applies to the French automobile industry, and there is nothing to challenge the expectation that this will not change considerably with the shift from the ICE to the electric engine. One reason is that incumbent system suppliers are often at the front of the technological shift to the electrification of vehicles, another that newcomers may principally appear only in the battery sector.

Again, it is useful to make a differentiation between a trajectory aimed at the immediate full electrification of the vehicle – i.e. the BEV – and another approaching electrification step-by-step – i.e. the HEV and in future, at least in France, the PHEV. This differentiation applies to the kind of innovation required, not to the way in which innovation emerges. For instance, few new suppliers will appear in the production system with the shift to BEV electrification. Rather, incumbent suppliers will invest in cooperative research and development to meet the technical requirements of the large incumbent OEMs PSA/Citroen and Renault. They may add new products to their portfolio but this is normal business to stay in their market. While much innovation towards electrifying vehicles comes from the suppliers, the current automobile production system is unlikely to change significantly in terms of the way it is run: the large OEMs will as always cooperate with large system suppliers who are part of the global competition, whether French or foreign firms. Here one should mention two recent projects: PSA Peugeot-Citroen recently announced the VeLV project, the concept of a light urban electric vehicle in the class of the Renault model Twizy that will be developed together with the French suppliers Leroy-Somer, Michelin, Valeo and Saft, the British supplier GKN, and the German supplier Leoni (avem.fr/ 26 Jan. 2013). One day earlier, PSA Peugeot-Citroen said it was cooperating with the French supplier Valeo and the two German suppliers Bosch and Continental in a project relating to a small HEV “Hybride eco” (avem.fr/ 25 Jan. 2013). The small niche producers also collaborate with small (niche) suppliers, sometimes in cross-border cooperation. They are in greater risk of losing a supplier who goes bankrupt, as was recently the case for Mia with the development of a fuel cell for small cars.

Although most innovation from the suppliers is incremental, it is very relevant if HEVs or BEVs are to be made at an affordable price. Many large system suppliers have developed new components for the electrified vehicle, such as energy-saving tires (Michelin),

a new generation of the electric motor (Leroy-Somer), a stop/start system in several generations for HEVs (Valeo, see Box 2) or new technologies in heating and air conditioning for BEVs (see Box 9). Co-development of French OEMs does not stop at the borders. In fact, the German system suppliers Bosch and Continental – both present in France – are often mentioned in co-development, among others.

Box 9: New heating and cooling technologies for BEVs

As long as the capacity of the battery is a bottleneck for the range of the car, each innovation that reduces energy requirements from other uses, such as heating or air conditioning, is welcome. This applies particularly to the BEV. As has been shown for the case of the Mia, one solution is to stick to an incumbent technology of air conditioning but to shift the high energy consuming moments of power output to the recharging time of the (parked) vehicle. Nonetheless, this kind of preconditioning can only be a partial solution to the thermal problem (I-6, 16).

Due to EU regulations, OEMs had to replace the cooling agent R134a which is said to cause severe damage to the climate by the beginning of 2013. Daimler refused to use the new cooling agent arguing that its environmental harmfulness is similar to the previous one. This OEM suggested using CO₂ as a cooling agent, claiming a much better climate change-mitigating effect. Small and medium-sized suppliers, however, do not seem to be able to invest in the use of such a new cooling agent as long as the large OEMs are not prepared to co-invest in this innovation (I-14).

Simultaneously, further technologies come to the fore, replacing the chemical method of air conditioning. Magnetic cooling promises the advantages of not being based on chemical agents and of consuming less energy. Apart from the problem of the rising costs of magnets due to the high costs of rare earths, magnetic cooling is still at the stage of a research project that is quite a number of years from serial production (I-16). Another technology has been used in the Renault Zoe model where a heating pump uses external temperature for heating.

Moreover, heating and air conditioning may be supported by several other approaches which tackle the thermal problem of the interior of the car, for example through improved isolation of the body, new types of reflecting windows, or even new types of painting (I-16).

As long as the markets accept the hybrid technologies more easily than the BEVs, incumbent OEMs will not be afraid of losing their competences in the serial production of thermal engines although large system suppliers such as Bosch or Leroy Somer may gain by producing electric engines (or Michelin and Continental with their project for engines at the wheels). Know-how in the serial production of thermal engines will still be in demand for a long time. Moreover, OEMs have specialised on certain engine competences and have for a long time now exchanged agreements among each other on the subject of thermal engines. To conclude, the notion of a complete reorganisation of the automobile production system which was already discussed with the emergence of Toyotism at the beginning of the 1990s, seems to be wrong. OEMs still have many areas under control: their product architecture, particularly their capabilities to integrate new and different components to the car; their handling of all kinds of software to manage internal processes within the car; their know-how in serial production; and, last but not least, their brands and market access.

3 Framing an emerging market for electric vehicles

The crucial step through which a technical novelty becomes an innovation is the transfer from concept to practice. Section 2 has demonstrated that the existence of competence in serial production is a major challenge to the trajectory towards the electrification of vehicles. However, serial production needs a market. Consequently, another necessity is to shape a market for innovative products. Markets are not simple given, in particular not for “disruptive” novelties; they have to be “framed” within a societal process, according to a theoretical perspective which has recently gained influence (Callon 1998). These frames determine the calculative behaviour of economic agents, among them in particular the customers. While firms develop strategies to create a market for their novelties (Santos / Eisenhardt 2009), a new market requires a host of supporting “framing” conditions, if it is to emerge. Some authors have pointed to a strong unwillingness on the part of customers to alter their practices with regard to mobility (Marechal / Lazaric 2010; Ozaki / Shaw / Dodgson 2012). Consumption patterns are fairly path-dependent in this field, although the emergence of a young urban middle class preferring car-sharing to the private ownership of vehicles has been acknowledged.

Here, it is useful to concentrate on two instruments “framing” the markets, in particular for BEVs in France. Procurement of publicly available infrastructure for the access to power is one way of indirectly stimulating possible demand. This applies to charging stations in countries where batteries in BEVs are sold or leased (not swapped) – as in France. State policies to promote private and public demand for BEVs is another, direct way of stimulating the emerging market. Although the Government is the dominant agent in both instruments, implementing them requires collaboration with partners. Government agencies at different territorial levels – local, regional, national and beyond (EU) – and large companies are expected to work together in setting the frames for the emergent market (see also Villareal 2011).

Public access to battery charging stations is generally seen as a major challenge for policy-makers and agents across Europe. In technical terms, communication between the vehicle and the grid particularly becomes a problem when quick recharging is required and both alternating and continuous current in recharging is to be available. However, the problem seems less one of technical feasibility and more one of agreements on a common standard for plugs. A consensus would be necessary between large industrial players such as the state power company EDF, providers of recharging technologies such as Schneider-Electric, the domestic OEMs and, finally, international competitors – and also to avoid competing standards from hampering cross-border mobility thus reducing access to export markets for electric vehicles. For example, the type 3 plug favoured by a Southern European alliance of EDF and GAMI (Italy) and supported by 19 European manufacturers (EV Plug Alliance) did not correspond to the type 2 plug favoured by the Germans, or to the Japanese standard CHAdeMO favoured by Nissan. In France also, there was initially dissent about using continuous current (PSA, together with Volkswagen!) and alternating current (Renault).

In actual fact, charging stations have been rather reluctantly established in recent years by a mix of private and public agents, i.e. some OEMs such as Nissan and local administrations. There has clearly been a “battle for standards” between the Japanese-based CHAdeMO and the American-based J1772 standard. While Nissan looked for allies such as Siemens, the Americans had won all large German OEMs as allies (BMW, Daimler,

Volkswagen; *L'Usine Nouvelle*, 22 May 2012). The situation seemed to have reached a stalemate although the state had launched a programme assisting selected cities (labelled “Eco Cities”) in the establishment of charging stations (developpement-durable.gouv.fr). With the opening of the first European CHAdeMO charging station in Haguenau/Alsace in May 2012 (financed by the region), Nissan announced a programme of up to 400 CHAdeMO charging stations in Alsace and the Netherlands (*L'Usine Nouvelle*, 22 May 12). In fact, 107 quick-charging stations were set up in France by January 2014 (avem.fr/actualite 31 Jan. 2014). This type of station is also suitable for recharging the Mitsubishi-based models of PSA/Citroen but not (yet) Renault models. Toyota had launched a three-year test to try out its new Prius plug-in generation in 2010 in Alsace, based on a 110 charging station investment from EDF with the type 3 standard plug (avem.fr/actualite, 14 Apr. 2013). Curiously enough, Renault had decided to equip its BEV model Zoe with recharging technology that requires a special investment of car owners at their homes. Very recently, the European Commission suggested that the type 2 plug should be the new European standard and set as an objective 800,000 recharging stations in the EU countries by 2020 ([avem](http://avem.fr), 24 Jan. 2013). It seems, however, that the debate is still open, as the majority of existing charging stations in Europe up to now are located in France (hence of type 3) while the majority of European countries, on the other hand, have accepted the type 2 standard (*L'Usine Nouvelle*, 30 Jan. 2013). Not surprisingly, local authorities in France hesitate to invest further in charging stations until standards are agreed upon and the numbers of BEVs sold are relatively low (*L'Usine Nouvelle*, 9 Mar. 2012). This means that the European standard for charging stations has not yet “locked-in”, even in France where the government had planned to install up to 15,000 public charging stations in 2009 although, in 2012, less than 3,000 actually existed.

Recently the French Government tried to overcome this stalemate by launching the “mission Hirtzman”, an initiative to speedily expand the number of public recharging stations (developpement-durable.gouv.fr/, 4 Oct. 2012). Customer behaviour may render these debates fairly unnecessary, however: in general, alternating current needs long recharging times of several hours while continuous current allows for a quick recharging. Several regional tests conducted by Renault and Toyota have revealed that customers (often commuters) prefer (slow) recharging that takes place at home. Furthermore, if customers were to continuously look out for slow (and even short-time) recharging whenever they stopped to do something, there would be no need for sophisticated public charging stations. This applies particularly to urban mobility where short distances and frequent halts dominate.

The direct way of framing the emerging market is to stimulate possible customers to buy and use the novelty of electric propulsion. Direct promotion through the bonus-malus tax and subsidy systems for private customers has been discussed in Section. 1.4. Although this system has produced certain outcomes – France is still Europe’s largest market for BEVs – it has not been sufficient to overcome the barriers of a small market niche. Hence, creating a sustainable market requires further effort. Three instruments are significant here: firstly, early purchases of electric vehicles by public bodies in order to start up a “market” for BEVs; secondly, the promotion of regional networks to “test” BEVs in practice and to demonstrate their viability; and, thirdly, the launch of mobility services based on BEV, such as Autolib.

This is all about raising sufficient interest among customers to use and buy BEVs or PHEVs so that a mass movement towards low-carbon mobility may emerge. In fact, reaching a minimum threshold of users which would render the novelty economically via-

ble is a major challenge. Part of this challenge lies in convincing producers to offer related products before the markets are well defined. This was the aim of the “low-carbon vehicle plan” of 2009 (Section 1.4) that envisaged a programme for large semi-public companies to buy 100,000 electric vehicles by 2015. OEMs responded fairly quickly to this demand by electrifying light commercial vehicles based on a traditional car architecture (see Section 2.1), either produced in their own factories (Renault) or subcontracted to one of the incumbent assembly subcontractors in France (Venturi company for PSA/Citroen). Collective procurement through UGAP (Union des Groupements d’Achats Publics) and large fleet owners still form the backbone of demand for light commercial BEVs from a variety of large and small French OEMs.

The initiative overlaps with another more recent political instrument to foster the use of BEVs. Based on regional agreements between one or two OEMs, local authorities and urban transport service providers (such as car sharing, car rental or public transport companies), local and regional associations were created to develop certain fields of urban electro-mobility. Basically, the main players in these initiatives are the state power company EDF, a regional authority (mostly offering financial assistance), and Ademe (financial assistance in the “fonds démonstrateur” programme), added to by regional not-for-profit organisations and, sometimes, particular enterprises. These regional initiatives generally “test” an electric vehicle model produced by an OEM at local production facilities such as Renault in the west of Paris or Smart in the eastern Moselle region. Generally, only a few numbers of vehicles are involved. Moreover, initiatives sometimes serve as an experiment with a limited time schedule (see Annex 1).

The Autolib “experiment” is different from this for several reasons. It was launched and financed by a newcomer to the automobile and urban mobility sectors, covers different services around passenger transport, forms a major part of a broader vision of the use of batteries for electric vehicles, and seems to have become successful – in other words, it promises to become sustainable.

Box 10: The car rental Autolib, a brief history

In 2011, the City of Paris wished to launch a particular mobility service in the Ile-de-France region (Hildermeier / Villareal forthcoming). Vincent Bolloré, the entrepreneur who developed the LMP battery technology (see Section 2.2.1), implemented the service with his Autolib concept. Based on the Bluecar electric vehicle model using the LMP battery (see Sections 2.1.1 and 2.2.1), Autolib is a rental car system for registered customers with its own system of charging stations. Autolib’s car rental business model is supplemented by a special internet-based information system in the Bluecar vehicles which was developed by another subsidiary of the Bolloré group (*L’Usine Nouvelle*, 19 Jan. 2013). The system facilitates the permanent localisation of rented vehicles and the continuous control of the availability of such vehicles, the current state of each battery, and the range of the car (*L’Usine Nouvelle*, 19 Jan. 2013).

Autolib envisages maintaining up to 3,000 Bluecars and 400 charging stations in the Ile-de-France region. In early 2013, Autolib said it had more than 60,000 subscribers and 50,000 weekly uses (*L’Usine Nouvelle*, 22 Feb. 2013) and expected to break even in 2014. Autolib has meanwhile extended its services to the second urban metropolis in France, Lyon, and very recently to Bordeaux. It is present in Indianapolis (United States) and plans to move to Asia as well.

For a long time said to be isolated in France, Bolloré finally succeeded in building new alliances, among them with Renault in car-sharing in Lyon, Bordeaux and soon London (*L’Usine Nouvelle*, 19 Sep. 2013; 12 Dec. 2013). It seems that Renault is extremely interested in Bolloré’s GPS system monitoring the use of Bluecars and connecting the vehicles to the internet.

Bolloré's business model has been deemed exceptional and path-breaking by some observers (among them I-6) while others are more critical from the point of view of urban eco-mobility (Hildermeier / Villareal forthcoming). The business model is based on Bolloré's vision of a wide value chain around the LMP battery. Only few LMP batteries have been sold to other customers so far, including some that are used in the small electric buses of Gruau (under the brand "Bluebus"). Hence, the entrepreneur was looking for a demonstration field for the mobile use of the batteries in Bluecar vehicles and the Autolib services. From this, Bolloré fostered market extension by extending the car rental system to other large French urban agglomerations, offering long-term leases to private and commercial customers (france-mobilite-electrique.org/ 11 Jul. 2012). He even envisaged selling the Bluecar to private customers in 12 French cities, at a competitive price of EUR 12,000 and a battery for rent for EUR 80 per month (france-mobilite-electrique.org/ 26 Feb. 2013) – thus mimicking the Renault business model. Additionally, Bolloré looked for secondary use in (stationary) energy storage at homes when the battery power fades to 80% and under. In total, Bolloré has followed a life-cycle perspective and systemic approach to launch his own new technology, the LMP battery.

The framing of electric vehicle technology extends further to many other sectors in the economy. We are not able to include these in our systemic approach to the electric vehicle. But it is important to mention the basics of electromobility: the availability of power at an affordable price. Some observers claim that nuclear power enables the French state-owned power company EDF to maintain comparatively low energy prices. EDF is still interested in developing new energy uses and in increasing demand. In fact, as mentioned in Section 1.3, EDF has been promoting BEV development for a long time. Even today, the company is involved in various projects to foster the electrification of vehicles. For instance, an approach is currently taken by EDF (through its distribution subsidiary ERDF) and La Poste, the largest user of electric vehicles, to conceptualise an algorithm (with support from the ParisTech university) for optimising the matching of local demand and local provision for current for the recharging of electric vehicles (*L'Usine Nouvelle*, 21 Jun. 2012). Grid management in general may need new impulses if BEVs become a larger segment of the car market.

At the end of the value chain in a "cradle-to-grave perspective", new challenges arise when the electric vehicle, and particularly its battery, becomes "waste". A major challenge faced by technologies which are suitable for climate change mitigation lies in their capacity to damage other dimensions of the environment (soil, water). Moreover, as has been discussed time and again in the public, one of the major challenges limiting the mass use of the electric vehicle is the threatening scarcity in some raw materials, among them predominantly the rare earths used for the production of batteries and magnets (in electric engines). Hence, recycling technologies and services come to the fore for two reasons, namely environmental protection, and economies in raw material. This is where there is still a gap. In France, the Belgian chemical company Solvay has just started to test new recycling methods, for instance of NiMH batteries which are used in hybrid vehicles (*L'Usine Nouvelle*, 6 Feb. 2013).

Further systemic links could be discussed. Much of the technology of electrification also applies to other transport systems, such as railways, trucks and busses, boats and aircraft. Hence, there are many overlaps both from the perspective of research laboratories and from that of companies. Policy instruments in various fields such as building legislation

(external power outlets at the car parks of new office and residential buildings as a “must” for battery recharging) or urban planning add to the framing of the market. As a result, knowledge about ways to frame the market for electromobility is still limited. On the one hand, the effectiveness of some measures such as the standardisation of plug technology for recharging batteries is unclear. On the other, we are far from fully understanding all fields of societal framing, given the systemic character of the technological trajectory to electromobility.

4 Conclusions

In taking an evolutionary perspective on the “greening” of vehicle drive in France, the paper has analysed the emerging paradigm of the electrification of vehicles which is still at its very beginnings. The old technological paradigm – the ICE-driven vehicle – is still alive and kicking; the emergent one is widely based on knowledge related to incumbent fields of technology (Boschma / Martin 2010) and on the previous strategies and policies of agents, i.e. influenced by previous attempts at the electrification of vehicles, by acquired knowledge gained in these attempts, and on incumbent organisational (concerning both companies and state organisations) and even incumbent geographical structures. It is hence “path contingent”. However, in the field of propulsion technologies there is considerable heterogeneity in the experimentation with competing technologies, and, as a consequence, no technological trajectory has yet been fixed. To express it in evolutionary terms, the trajectory has not yet “locked-in”. While there is undeniably a greening of the drive technology in France, and French companies – incumbent and new OEMs as well as suppliers – have more radically focused on early innovation in the greening of drive technologies than other companies in Europe in particular in Germany, neither BEV nor PHEV technologies have become fully accepted.

4.1 The traits of a “French” trajectory in the electrification of vehicles

This paper has argued that the trajectory of electrification of vehicles has a strong national connotation. This national trajectory – as renewed as it has been – reveals several traits that make the French method of “greening the automobile” country-specific.

Firstly, previous efforts to electrify vehicles in France created **opportunities for responding quickly to changes in the political environment**. Earlier initiatives in the electrification of vehicles from the 1980s until the 2000s – even if they had resulted in manifold failure – laid the ground for learning processes in companies from the automobile production system, the state-owned electrical power company, the electrical sector, research labs and probably also political actors. Many actors were thus well prepared to quickly respond to the Grenelle de l’environnement in 2007. There was more or less continuous, uninterrupted research on technologies for the electrification of vehicles at public research labs and universities. Competence in R&D had recently been reinforced with the promoted re-migration of academics/scientists from the United States and the creation of new research labs, both for fundamental and applied research (Section 2.2.3). Obviously, a further reserve of experience also mattered, that is, the know-how relating to the serial production of electric vehicles that had been accumulated by both large and small OEMs. Herein, France at least partially exhibits one of the strengths which is generally accredited to the

Japanese production system: one of the major advantages of Japanese OEMs such as Toyota and Nissan lies in their long-term experience in the serial production of electric vehicles, be they BEVs or HEVs.

Secondly, choices made by economic agents in the technological trajectory followed the **basic principle of “affordability”**, namely the availability of vehicles for low and middle-income customers. Those interviewees from the triple helix (that is, from firms – both OEMs and suppliers, research labs, and the political administration) pointed to this principle (I- 6, 9, 11, 13, 16, 17, 19; see also Hildermeier / Villareal 2011). “Affordability” governed the choice of technical solutions whose technical traits were known and where experience in serial production had been made before; in other words, they were more or less incremental in character. This did not prevent producers from developing basically new product architectures such as the BEVs made by Renault or Mia and the HEVs made by PSA/Citroen. For example, several times the decision was taken to stay with electrical solutions below the 48 to 60 Volt barrier, a barrier between so-called low and high tension in the automobile sector. Agents know that although this results in a lower performance it safeguards product safety and experience in serial production, thus resulting in lower costs. Several times respondents pointed to the difference between this and choices made in the Japanese and German automobile sectors where high-tension solutions, riskier choices and, as a result, more costly solutions seem to prevail. Again, this is an idealised statement as, for instance, the French battery producer Saft is engaged in sophisticated high tension Li-ion battery development for sports cars (I-16, Saft press release 40-12, exagon-motors.com). “Affordability” is also applicable to the step-by-step strategy in the hybridisation of vehicles (such as PSA/Citroen) and commercial innovation such as the battery lease of Renault.

Thirdly, the emerging trajectory of electrification brought a **variety of technologies** to the fore but probably not so much new agents. The paper identified the emergence of two seemingly separated “subsystems in technology” at various dimensions. There is, firstly, the separation of the markets between a market for urban mobility and a market for an “allround” mobility which is traditionally targeted by the ICE-driven automobile. The niche of urban mobility in its strict sense is larger in France than in Northern Europe. As a consequence, a variety of small urban electric vehicles have been developed in recent times. A particular product architecture has been designed for the urban electric vehicle, as was exemplified in the cases of Mia or Bolloré. Simultaneously, the electrification of the vehicle was also pushed forward into the traditional volume segment of the automobile market. This segment is determined by the two large OEMs in France, PSA/Citroen and Renault. Here, another duality has emerged. Each of these companies was the first in Europe to bring the new technology into serial production on the market, either with the technology of HEVs (diesel HEVs by PSA/Citroen) or BEVs (Zoe model by Renault). Related to this is the recent growth in the battery industries which, once again, takes two directions. On the one hand, the technology of lithium-ion-based batteries is pushed forward by many agents such as large public research labs and a large number of companies in the battery sector. On the other, we witness the emergence of an alternative technology in lithium-based battery development, namely the LMP battery. However, capabilities in battery assembly predominantly apply to the production of small series only. No French battery producer has mastered the production of large series yet which would achieve low costs per unit (I-23).

Fourthly, the French trajectory in vehicle electrification is characterised by various efforts to create a **market**, mainly **due to state initiatives**. These are directed both to the supply side of technological development, mainly through the promotion of R&D, and to the demand side, through a diversity of demand-creating or initiating instruments. State activities have certainly had a mixed motivation. When many observers take the Grenelle de l'environnement in 2007 as a starting point for the recent emergence of the electric vehicle in France, they implicitly suggest that a major impact of it was the wish to strengthen environmental policies. However, promoting the international competitiveness of the French industry in general, and the automobile sector in particular, was another extremely important driver of government actions: long before 2008 it was realised that the French industries had lost their share of global markets. The public debate about losing competitiveness has increased tremendously in recent years (see Gallois 2012; Artus / Virard 2011). Finally, there is also the balance of payments argument on rising crude oil prices.

4.2 Is this “French” trajectory sustainable?

Thus, at first sight the French automobile production system seems to benefit from first-mover advantages, in the launch of BEVs and diesel-HEVs and in battery development, at least in European markets. However, all these initiatives and efforts have not (yet) resulted in a lock-in of the technological trajectory. In fact, the trajectory even seems endangered in various aspects.

Firstly, in this “*very political phase*” [of the emergent trajectory], to quote Jullien (2011), government policies are obviously not sustainable as the state is still suffering not only from the financial crisis but also from long-term economic deficiencies (Gallois 2012). It is doubtful whether the government can stick to the very costly demand-pushing subsidies in the long run. In fact, there is even an exit option, as the subsidy for the purchase of electric vehicles is prolonged on a yearly basis: In October 2013, the government reduced the maximum subsidy from Euro 7,000 to 6,300.

Furthermore, regulations on technical standards in the field of electrification of vehicles are no longer set by the national state in Europe but by the European Commission. This is an aspect that would certainly deserve further analysis. Suffice it to point to one of the recent struggles for environmental goals to further reduce the average fleet CO₂ emission. The proposition of the EU Commission to reduce average CO₂ fleet emission rates to 95 g/km by 2020 was softened upon pressure from the German Government in favour of the German premium OEMs – thus undermining the competitive advantage of the low(er) emission vehicles of French OEMs.

Secondly, France has suffered from a decline in its industrial capacity, in particular during the recent decade. Its manufacturing industry is less research-oriented, has invested less, is less export-oriented and is more dominated by micro- and small-sized enterprises than its German counterparts (Brenke 2013). Overall, the private sector is also weak in the financial power required for a breakthrough in new technologies. For more than 15 years, annual expenditures for R&D have remained at a rate of little more than 2 % of GDP (gtai 7 Dec. 2012).

Thirdly, France suffers from a fragmented vertical production system. Interview respondents claimed that France no longer had a comprehensive “*filière industrielle*” at its disposal.

Fragmentation had occurred at all different levels and in many different ways. Value chains upstream were not complete as France had lost much of its industrial competence during industrial decline, particularly in the electronics sector (I-16) and, probably, also in the electrochemical industry (I-19). The classical pyramidal system in automobile production was characterised by a few OEMs – as we have seen, suffering from declining markets – and a small number of first-tier system suppliers. It was weak in its second- and third-tier component suppliers because the size distribution of enterprises in France was unbalanced (Banville / Chanaron 1991; Brenke 2013). As a consequence, suppliers of electric vehicle development and assembly in France are often foreign firms, as exemplified by Renault's Zoe model where important components such as the electric drive, motor and batteries are bought from Germany and Korea, respectively (I-19, see Section 2.1.1).

In addition to fragmentation in the production system, there is also fragmentation in the French innovation system because of a large gap between substantial basic research in France and the possible implementation of this knowledge in the industry. In contrast to recent changes in the public R&D system (see Section 2.2.3), it was almost common understanding among our respondents that weaknesses in innovation capacities were due to a lack of cooperation between R&D labs and enterprises. It is apt to say that an organisational bridge to overcome distances in knowledge (according to Nooteboom 2000) – basic understanding of principles in science versus experience and application within industrial processes – hardly exists or, if it does, functions inadequately. In fact, many respondents cited a competitive advantage of Germany because of the existence of and well-functioning of the Fraunhofer Society (I-11, 12, 13, 19). It is often claimed that the Carnot institutes established recently in France do not completely fill the gap.

Cooperation among companies is also considered weak. Some respondents even claimed that a cultural gap exists as the French are less prepared to engage in cooperation than others (I-11, 12, 13). It has been demonstrated long ago in another context that it was possible but difficult to establish trusting networks among enterprises in France (Lorenz 1999, citing the case of engineering industries in Lyon). This weakness is all the more important in the early stages of a new technological trajectory when industrial standards have to be settled such as standards for recharging stations. Finally, this translates into difficulties in achieving economies of scale in industrial production.

Fourthly, French OEMs are more or less weak in global exports. This holds true in particular for PSA/Citroen because of the strategy which gives preference to diesel ICEs. The strong competence in diesel engine technology that PSA/Citroen has proven in the near past through various innovations and one that had fostered exports to European countries may turn into a disadvantage on markets outside Europe. Large markets in emerging countries such as Brazil, China or India prefer gasoline-based hybrid vehicles. This is why PSA/Citroen recently prioritised the development of gasoline-based HEVs against the plug-in diesel hybrid – a technology they are nevertheless still promoting. As for Renault which has good competences in low-cost vehicles mainly through its Dacia brand, it remains to be seen whether it can successfully launch the BEV model Zoe on foreign markets. Although recently published cost calculations comparing similar ICE and electric vehicles (Renault Zoe versus Renault Clio IV; Renault Kangoo ZE versus Kangoo dCi) revealed that costs per kilometre are lower for the electric than for ICE vehicles, including capital depreciation (Aschard 2012), this is only applicable to France where the publically financed ecological bonus on vehicles substantially affects private cost calculations.

There are many visions for an era of the electric vehicle in the 2020s, either as a hybrid or fully electric. The question arises as to whether the advantages that the French car-manufacturers achieved because of early introduction of the technology to the market and the advancement of battery technology in France will safeguard their market position in this electric-oriented future. However there seems to be nothing new about the logic which has been dominating the automobile sector for a long time: it is the willingness of the consumers, in the home markets first and then in export countries, that will finally decide upon the fate of innovations in the sector. Currently, HEVs and BEVs are still only available in market niches in France.

4.3 French players embedded in global linkages

Let us finally return to the geography of the automobile production system as it has emerged during times of globalisation. While it is true that Japanese companies have managed to safeguard their national production system at several layers of the vertical production chain, and China is currently striving to follow a similar pattern, most OEMs are global in production and market orientation, in supplier systems, and even in the model development of the ICE vehicles. This also applies to French volume producers whose traditional core market is Southern Europe. It has become clear in many sections of this paper that HEV and BEV development, production and sales also cross borders, at least in Europe. The battery sector, as comparatively strong as it seems to be in France, has proven to be globalised in ownership, upstream procurement, and innovation processes (see Section 2.2). One may put a question mark, therefore, after the assumption with which this study started, relating to the particular “nationality” of technological trajectories in relation to the electric vehicle.

On the contrary, many observers would claim that the company strategies of the mighty OEMs matter more in explaining technological trajectories, as has long been suggested by the literature on automobile production systems. First, OEMs chose different technological solutions in accordance with available resources in their production and knowledge systems as has been revealed in France by the heterogeneity of strategic orientation of the HEV line (PSA/Citroen) and the BEV line (Renault, Mia, Bolloré and others). Gersch / Rüsike (2013) recently analysed the differences in resource use and strategies for risk and specific investments in the BEV development of two large OEMs, Volkswagen (VW) and Renault-Nissan. They found a much larger commitment of Renault-Nissan to BEV development, and hence a greater dependence on it, than in the case of Volkswagen. In other words, OEM strategies differ both within and across countries. Second, OEMs have specific production systems which often cross borders to proximate neighbours, as revealed in so many examples of the French OEMs, be they as large as PSA/Citroen and Renault or small such as Mia electric. The German companies Bosch, Conti and others have been mentioned time and time again as suppliers of components to electric drive construction in France, both for HEVs and BEVs. Conversely, French first-tier suppliers such as Valeo see foreign OEMs as their main clients. Third, BEVs such as the Mia electric or the Renault Zoe and HEVs have been conceptualised right from the very beginning for an international (European) market. The only “national” market seems to exist for small electric vehicles for urban use, ones which are not homologised. Fourth, despite the fact that Southern Europe is considered the core market of PSA/Citroen and Renault, both are global companies with increasingly global strategies, in particular in view of large Asian markets.

Last but not least, knowledge systems in new technologies in general and research on the electrification of vehicles in particular have been globalised. While incumbent OEMs mostly prefer national, if not local, cooperation with suppliers and engineering services in the model development of vehicles (Schamp / Rentmeister / Lo 2004), the development of battery technologies is strongly based on interrelationships with foreign R&D labs. Anecdotal evidence even shows that some modern “Argonauts” have an enormous impact on technological development in France. Saxenian (2006) had coined this term in her prominent study on the re-migration of highly qualified electronic engineers from California to China as a major base for the rise of Chinese electronic industries. Take Professor Jean Marie Tarrascon (*L’Usine Nouvelle*, 27 Nov. 2012, and other articles) or Denys Gounot, the founder of the battery producer E4V (*L’Usine Nouvelle*, 27 Sep. 2012, and other articles) as examples who have both re-migrated from the United States where they had accumulated much knowledge in their field (Sections 2.2.1 and 2.2.3).

Finally, the markets of neighbouring countries and the market strategies of OEMs are seriously entangled with other. Early French BEV producers tensely waited for the launch of further BEVs by other OEMs claiming that a variety of models would create a network effect fostering demand growth. For the moment, however, German OEMs play a role in different segment of automobile markets – in the premium segment: they can afford to design very expensive technological solutions, such as BMW’s carbon-fibre car body (Altenburg forthcoming) but do not (yet) offer HEVs or BEVs at “affordable” prices.

These arguments notwithstanding, we find the national perspective still justified at various dimensions. Technical solutions in the early trajectory clearly show a country-specific path contingency as shown in various sections above. Furthermore, the co-evolution of emerging markets for HEVs and BEVs is also a “local” process, in particular if the “local” government is strongly involved in market creation. Likewise market success relies on new customer services and demand-side support which are basically local and, therefore, subject to policies tied to national territories. While geographers may have a different understanding of what “local” means, much of what has been discussed in this paper underscores our perspective on the nation as the principal “local” territory in this nascent trajectory.

Two conclusions emerge from this report regarding the questions of whether there is a new technological trajectory in the electric drive of vehicles and whether it is “locally embedded” and specific, at least in the case of France. For the time being, the answers must remain undetermined. Firstly, from an evolutionary theory perspective, the trajectory to the electric vehicle has not yet locked-in, either in France or elsewhere in Europe: we are still at the very beginning of a possible trajectory, in a phase characterised by a variety of competing technological options for low-carbon vehicles, such as the still alive and mature ICE technology (where there has been much progress in reducing the CO₂ emission of the ICE) and some new technologies such as, for example, the fuel cell or gas-based drives, and, more recently, hydraulic (air hybrid) drive technologies. It is certainly not a new strategy by the OEMs to research a variety of “low-carbon” drive technologies (such as has been shown to apply to German OEMs by Hurtig et al. 2010), shifting the focus from time to time and looking for new alliances. Take as an example the recently announced alliance of Renault with Daimler and Ford in order to develop the fuel cell by 2017 (*L’Usine Nouvelle*, 28 Jan. 2013). There is a constant state of flux in the more or less “greening” technologies of vehicles which currently results in an “adhocracy” of technological trajectories.

Secondly, although the paper has analysed the distinctive features of a national trajectory of electric drive technologies in France at different dimensions, their future will be decided not only in France. How far will the French OEMs and large suppliers benefit from being first movers in electric vehicle technologies in Europe in recent years? Are the hybridisation technologies related to the diesel HEV by PSA/Citroen competitive in the long run? PSA/Citroen has experienced a quick follower in diesel technology and even a precursor with the Volvo diesel plug-in in 2012. Will the concept of a new product architecture, such as Mia's, be accepted by customers? And does Mia electric have sufficient financial means to establish a brand and gain a considerable niche in European markets? In addition, will the concept of a new product, the Zoe, combined with a new commercialisation strategy – the leasing of the battery – be accepted by European customers? Can strengths in battery R&D be transformed into the competitive serial production of sophisticated batteries for electric vehicles? For the time being we are not able to give any clear-cut answers to these questions. As mentioned in Section 4.2, some doubts on the sustainability of the French production system in electric vehicles may be justified, though. However, these questions also make clear that the future of electric vehicles technologies is also largely subject to commercial issues such as available finance, the establishment and maintenance of a brand, or the offer of services to customers. Given the single market in the European Union, the permanent cross-border cooperation in the automobile production systems and the European research networks and policies, this is likely to flow into an amalgamation of technological trajectories in Europe.

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Annex

| Annex 1: Some recent regional projects testing the application of electric vehicles | | | | | |
|---|-------------------------|---|-------------------------|----------------------------------|--------------------------|
| Location | Start / Duration | Car model | Number of models | Number of users | Type of usage |
| La Rochelle | since 1999 | Mia, C-Zéro | 50 | Private households | Car sharing “Yelomobile” |
| Moselle Electronique | 2011– | e-Smart | | 45 enterprises | |
| Rouen Crea’Venir | 2011– | Renault | | Municipal car pool | |
| Besancon | 2012– | Peugeot Ion | 2 | | Car sharing “Autocité” |
| Grenoble Green Car-e | 2011–2012 | Renault | 16 | Corporations | |
| Strasbourg projet Kleber | 2010–2013 | Toyota Prius plug-in | 80 | Corporations | |
| St. Quentin en Yvelines | 2012– | Renault Twizy | 50 | Private households | Car sharing |
| Save (Yveline, Ile de France) | 2011–2012 | Nissan-Leaf, Renault Kangoo Z.E. and Fluence Z.E. | 65 | 40 companies and private persons | |
| Nice | 2012– | Peugeot Ion, Peugeot Partner, Citroen Berlingo, Mia | 126 | | Car sharing “Autobleu” |
| Sources: Avem (france-mobilite-electrique.com); Renault; La Rochelle Agglomeration; enviscope.com; enerzine.com | | | | | |

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