Exploring the automotive transition: A technological and business model perspective

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1. Introduction

"I believe that water will one day be employed as fuel,
that hydrogen and oxygen which constitute it, used singly or together, will
furnish an inexhaustible source of heat and light, of an intensity of which
coal is not capable."

(Jules Verne, The Mysterious Island, 1874)

When Jules Verne spoke of hydrogen as the energy source of the future, automobility was in its infancy. Since then, several automotive engine technologies (powered by steam, electricity, and gasoline) have been developed. Due to its technical and economic performance, the internal combustion engine (ICE) has prevailed for many decades. In the 1970s, scientists began to better understand the long-term effects of fossil fuel use (Jones and Henderson-Sellers 1990). Increased awareness of the devastating consequences of burning fossil fuels on the world's climate has led to increased efforts to develop and deploy climate-friendly technologies (Balint et al. 2017), such as battery and fuel cell technology.

The transition of the automotive system began many years ago. The automotive system consists of actors and stakeholders such as automotive producers, suppliers, government, and customers. Because it affects many actors simultaneously, the technological transition in the automotive industry is said to induce a systemic change (Abdelkafi and Hansen 2018). "Technological transitions are defined as major technological transformation in the way societal functions such as transportation, communication, housing, feeding, are fulfilled" (Geels 2002, p. 1257). To be part of the future automotive system, automotive producers and suppliers must adapt by developing new technologies and business models (Sarasini and Linder 2018). While technologies are the result of research and development (Mitcham and Schatzberg 2009) and constitute the set of solutions required to serve the market, business models represent the way companies commercialize these technologies and bring them to the customer (Abdelkafi et al. 2013). Hence, business models support the diffusion of technologies (Sarasini and Linder 2018). For example, the value proposition of a business model constitutes the specific way in which a certain technology is brought to market with the aim of achieving commercial success (Khan and Bohnsack 2020). Business models can help even an average-performing technology achieve a market breakthrough (Chesbrough 2006). Nevertheless, business models can be an iterative and challenging process with many trials and errors until the most promising business model for a given technology is identified (Johnson et al. 2008). In this context, Bidmon and Knab (2018) emphasize the importance of considering transitions from a technological and non-technological perspective. Therefore, in order to study the automotive transition and its outcomes, it is important to understand which technologies and business models will prevail in the future.

Regarding powertrain technologies, there are currently at least three candidates that may or may not be present in the mobility system of the future: (i) Internal Combustion Engine Vehicles (ICEVs), (ii) Battery Electric Vehicles (BEVs), and (iii) Fuel Cell Electric Vehicles (FCEVs). BEVs and FCEVs are more sustainable powertrain technologies due to their zero local CO_2 emissions (Abdelkafi and Hansen 2018). In addition, the electricity used in BEVs can be generated from renewable energy sources such as solar and wind power. Some types of charging infrastructure for BEVs even use solar energy to convert it to electricity, which is then fed into electric vehicle batteries, reducing grid dependency (Chandra Mouli et al. 2016). FCEVs also represent another sustainable solution as long as hydrogen can be produced without relying on fossil resources (Dash et al. 2022). Following the European Commission's announcement that only electric cars will be commercialized in the European market by 2035 (European Parliament 2022), it can be said that the ICEV will be replaced by alternative, more sustainable technologies. This will lead to the use of electric mobility for all road transport vehicles that use an electric motor as power unit, regardless of the electric drive concept and its energy storage. As a result, BEVs and/or FCEVs will be more widespread in the future. The theory of dominant design (Anderson and Tushman 1990) predicts that one of these technologies will dominate (van de Kaa et al. 2017). Thus, the two technologies—although similar in some respects, notably in their reliance on electric motors—are in competition. What is remarkable, however, is that carmakers are taking different approaches. While Toyota and Hyundai are investing heavily in hydrogen and fuel cell technologies (Ball and Weeda 2015), other companies such as Volkswagen and Daimler (now Mercedes-Benz) do not seem to see hydrogen-powered vehicles as the dominant technology of the future, but rather BEVs (Trencher and Edianto 2021). Frank Weber, CTO at BMW, expects that "hydrogen will not be a solution for the masses" (Andreas Floemer 2021). Despite some development activities up to pre-series models, these car manufacturers do not currently have any FCEV series models in sight. As powertrain technology is a major determinant of the automotive transition, the question is which technology will dominate in the future?

The second relevant element in technological transitions is business models (Bidmon and Knab 2018), because the choice of the business model can facilitate or hinder the diffusion of the technology. The widely diffused technology, which represents the dominant industry standard, can be considered the winner of the transition phase (van de Kaa et al. 2017). While a large body of research acknowledges the need to develop new business models for new powertrain technologies, recent research questions this aspect and asserts that powertrain technologies may not be the driver of future automotive business models. In contrast to many contributions in the literature (e.g., Kley et al. 2011), Athanasopoulou et al. (2019, p. 80), based on an expert-based study, found that none of the expert groups involved in the study believe that electric driving will have an impact on business models. Thus, existing research on whether powertrain technologies will have an impact on business models, is rather inconclusive as there is research that acknowledges that powertrain technologies can drive new business models (Tongur and Engwall 2014), while other research does not (Athanasopoulou et al. 2019). Therefore, a better understanding of the drivers of automotive business models in the future is needed.

Servitization business models are thought to be at the core of the automotive transition. For example, it is assumed that automakers will increasingly develop mobility-based services and transform into service-oriented companies (Hanelt et al. 2015). However, the recent announcement by BMW and Mercedes is quite remarkable. Both car producers discontinued their carsharing business *Share Now,* which was founded in 2019, and the venture was sold to a competitor (electrive.net 2022). Both car producers justify their move to abandon carsharing by saying that they want to focus on their core business, which is the production of vehicles. This strategic move of both car producers is surprising, not because OEMs are focusing on their core business again, but because it seems to go against the mainstream research that emphasizes that car ownership will rather be replaced by mobility services in the future and also the rapid growth of carsharing services (Mindur et al. 2018). Moreover, by abandoning the carsharing model, the OEMs are giving up a direct link to better understand customers' behavior and their mobility needs. This is reflected in the statement of one of the CEOs that they are not the airline, but the aircraft manufacturer (Spiegel 2022). Thus, car manufacturers are following different paths: some manufacturers are expanding their mobility services, while others are discontinuing them.

In light of the above observations, the following research questions are formulated:

1. Which powertrain technologies (BEV or FCEV) will be dominant in the future?
2. What are the key drivers of new automotive business models?
3. Are mobility service-based models the winning business models in the automotive industry?

The first research question is positioned in the area of technological innovation, while the second and third questions are positioned in the area of business models. To answer the research questions, the following procedure will be used. The next section provides a literature background consisting of selected insights into the automotive transition in general, a comparison between the powertrain technologies BEVs and FCEVs, and a brief introduction to business model drivers in the automotive industry as well as service-based business models. Section 3 presents the research methodology, which is based on two interview studies, is presented. The first interview study deals with the first research question, while the second study aims to propose answers to the second and third questions. Section 4 focuses on the results of the interview studies and derives four scenarios for the automotive industry, using expert judgement to assess their likelihood of occurrence. Section 5 discusses the findings against the background of existing research. Finally, section 6 concludes and suggests directions for future research.

2. Literature Background

2.1 Automotive transition: General Overview

Drawing on technology lifecycle considerations, the ICE as today's dominant engine technology (Olabi et al. 2021) seems to be at the end of maturity, or even at the decline stage, whereas BEVs and FCEVs are rather in the emerging/growth stage. As noted by van de Kaa et al. (2017, p. 3), "there is no doubt that the transition to a sustainable transportation sector is expected to move from internal combustion engines to hybrids, plug-in hybrids, and biofuels in the mid-term, to all-electric vehicles (battery or fuel cell) in the long term."

Transition theory, which is often applied to the automotive industry (Wesseling et al. 2020), is useful for understanding industry changes at the system level, taking into account different areas such as infrastructure, mobility, the global automotive market, energy prices, climate policy and electricity (Dijk et al. 2013). It provides the foundation for studying technological transformations, in connection to socio-technical and societal transitions, which denote broad and long-term changes in the societal functions such as mobility and energy consumption (Bidmon and Knab 2018). Geels (2002) defines technological transitions as major technological transformations for the fulfillment of societal functions such as transportation and communication. Thus, a transition is not an incremental but a radical change with far-reaching implications for the development of a system, involving different actors such as firms, consumers, policy makers, and researchers (Svennevik et al. 2021). Transitions are also influenced by factors such as markets, consumer behavior, policies, and infrastructure. For this reason, a single theory may not be able to comprehensively address all perspectives of transitions comprehensively (Köhler et al. 2019).

From a technological perspective, the dominant design approach became a cornerstone concept of transition theory. Anderson and Tushman (1990) introduced the concept of cyclical technological change, in which technological discontinuities lead to a period of ferment, followed by the emergence of a dominant design, which, in turn, is followed by a period of incremental technological change. The phase of technological discontinuity can be either competence enhancing (exploiting existing knowledge) or competence destroying (using new knowledge and skills). Subsequently, the emergence of a dominant design marks the end of the period of ferment and the key point in the formation of an industry, but "dominant designs do not emerge from inexorable technical logic […] since a single technological order rarely dominates all other technologies on important dimensions of merit, social or political processes adjudicate among multiple technological possibilities" (Anderson and Tushman 1990, p. 616). The cycle of technological discontinuity is characterized by an increasing number of competing firms at the beginning of each cycle until a dominant design emerges, leading to a decline in competing firms and a small number of firms dominating the industry (Todorovic et al. 2017). Thus, a dominant design that wins the race among competing technologies becomes a de facto standard. As a standard, the technology will be the first choice for customers, and this will drive the companies' market shares. Competitors, therefore, shift their efforts to this technology, initiating a phase driven by price rather than design competition. Dominant design theory thus predicts that after a period where designs are fluid, only one technology can win. "Given the fact that the automotive industry has strong indirect network effects, it is likely that a dominant design will eventually emerge" (van de Kaa et al. 2017, p. 1). Network effects occur when the value of a technology increases as the number of users adopting the technology increases. For example, direct network effects occur when the number of subscribers to a service increases. The more users, the more valuable is the service. Indirect network effects result from the value that people derive from complementary goods. For example, a video game console benefits from the high availability of games specific to the console (e.g., van der Kaa et al. 2017). In the automotive industry, the main indirect network effects exist between ICEVs and gas stations. However, BEVs will require an expansion of the electricity charging infrastructure, while FCEVs will require the development of a network of hydrogen refueling stations. Therefore, the availability of infrastructure will have a major impact on whether BEVs or FCEVs will dominate in the future. If the electricity-based charging infrastructure is widely available in the future, this will favor the diffusion of BEV technology and its establishment as the dominant design.

Companies can monetize their technologies by using different business models. The business model can be the main reason why a technology becomes dominant. Business models can support the commercialization of a new technology, even if it is a more expensive option than other alternative technologies (Sarasini and Linder 2018). Business models "can contribute significantly to systemic societal change, such as the one needed for achieving sustainable development" (Bidmon and Knab 2018, p. 913). The interactions between technology and business models are underscored by Chesbrough's (2006) statement that an excellent business model combined with an average technology is more successful than a sophisticated technology supported by a mediocre business model. According to Amit and Zott (2020), the business model is related to the firm's activity system, which is the set of activities a firm engages in to create the customer's value proposition. Business model changes occur at four levels: (i) content (what are the activities to be included in the system?), (ii) structure (how are the activities sequenced?), (iii) governance (who does what activities?) and (iv) value appropriation logic (Zott and Amit 2010). This perspective is based on the activity-based view, which conceptualizes a business model as an activity system (Lanzolla and Markides 2021). In this view, firms make a deliberate decision about which activities to include within the boundaries of the firm. This view complements the resource-based (Barney 1991) and transaction-based (Williamson et al. 1975) views of the firm. Since firms require resources to carry out activities, they can decide, depending on the availability and accessibility of resources, whether to integrate these activities within the firm or to outsource them to external actors. The transaction-based view considers the specificity of assets and opportunity costs as important aspects in deciding whether or not to integrate activities. This research adopts an activity-based understanding of business models. Accordingly, a technological change will not be achieved without adjusting and reconfiguring essential activities within the firm's value network. The automotive transition due to technological change is therefore expected to lead to a reconfiguration of the entire system of activities, resulting in changes in the content of activities performed by individual firms (e.g. OEMs entering into car sharing activities), the sequence of activities (e.g., data analytics and Artificial Intelligence (AI), or software in general, are at the core of autonomous driving rather than the vehicle itself, or the hardware), and redistribution of activities among organizational units within the individual firm or among different actors (e.g., OEMs such as Tesla accommodating the charging activity through an extensive network of charging stations, instead of utilities or third-party providers).

2.2 Powertrain Technologies: BEV vs. FCEV

The debate on whether and to what extent hydrogen will be used as an energy source for road transport is still ongoing (Asif and Schmidt 2021). For FCEVs, it is necessary to distinguish between different applications: private cars, public transport, buses, and trains (Olabi et al. 2021), and different types of trucks. According to the current state of technological development, FCEVs can be refueled more quickly. They offer a longer driving range and have a lower vehicle weight, which is highly relevant for commercial vehicles (Ball and Weeda 2015). In contrast, "the window of opportunity for hydrogen to play a significant role in the electrification of passenger vehicles is rapidly shrinking" (Trencher and Edianto 2021, p. 2). A major challenge is to build a hydrogen infrastructure. This makes battery electric vehicles an option that can take the lead over fuel cells. A recent commentary in the journal "Nature" does not give hydrogen a role in the car and truck sector, but emphasizes its use in areas such as aviation, shipping and steelmaking (Plötz 2022).

Worldwide, the number of electric vehicles has increased significantly in recent years, although there are significant differences between countries. In 2021, China, the United States, Germany, the United Kingdom, France, Norway, the Netherlands, and Japan are leading in the total number of plug-in electric vehicles: BEVs and Plug-in Hybrid Electric Vehicles (PHEV) (IEA 2022a). Worldwide, there are more than 16.5 million BEVs and PHEVs on the road. In addition, there are 66,000 electric heavy-duty trucks (with a gross weight of at least 26,001 pounds according to the U.S. gross vehicle weight rating (U.S. Department of Energy 2012)) and 670,000 electric buses on the road worldwide in 2021, representing respectively 0.1% of heavy-duty trucks and 4% of the global bus fleet, respectively (IEA 2022b). Fuel cell technology, however, has only a marginal share. In 2021, there are 51,600 FCEVs in use around the globe, distributed among Korea, the United States, China, and Japan, and only 730 hydrogen refueling stations (IEA 2022b).

In addition to the growing environmental awareness of societies in many countries and regions, political pressure is leading to a gradual shift towards electric vehicles. For example, conventional cars and vans based on internal combustion engines will be banned from sale in the European Union by 2035 (European Parliament 2022). BEVs can be an "intermediate technology" that introduces electric mobility, but later either shares the mobility market with FCEVs due to complementary vehicle characteristics (Ball and Weeda 2015) or even gradually disappears in favor of FCEVs, which can dominate the market as a stand-alone solution. In the long term, the diffusion of hydrogen as an energy source will depend on infrastructure availability, public awareness and acceptance, and policy support (Ball and Weeda 2015). This research is an attempt to answer the question of which technology (BEV or FCEV) will be dominant, and whether they will integrate the automotive industry sequentially or in parallel.

2.3 Business model drivers in the automotive industry

In the existing literature (Sarasini and Linder 2018), it is argued that business models can support the market adoption of electric vehicles and thus the realization of their economic potential. Applications related to social media, mobile data, big data, and cloud computing are increasingly becoming part of business models in the automotive industry (Hanelt et al. 2015). Thus, digitalization is also enabling the development of more versatile products and services, while giving rise to more complex and novel business models (Bohnsack et al. 2021). For example, Teece (2018) identified at least four sources of change: electric vehicles, autonomous vehicles, connected vehicles, and personal mobility services. Each individual source may lead to significant business model innovation, while in combination these sources of change may lead to even more diverse and innovative business models. From a general perspective—not necessarily in the realm of the automotive industry—digitalization has been found to have many impacts on business models. A recent systematic literature review by Ancillai et al. (2023) on digital technology and Business Model Innovation (BMI) analyzed 106 publications and identified four main research themes: (i) digital technology-driven BMI archetypes, (ii) digital technology's effects on BMI, (iii) digital technology-driven BMI process, and (iv) digital servitization. For our study, themes (ii) and (iv) are particularly relevant. Indeed, digital technologies can change the value proposition because digital technologies can provide insights into customer behavior and market needs that can be used by manufacturers and service providers to create new products and services. Technologies such as Industry 4.0 and real-time data exchange can have a profound impact on value creation, e.g., with regard to maintenance processes or collaboration with external actors. In terms of value appropriation, the data-driven nature of digital technologies leads to new revenue generation models and cost structures, for example through cost savings resulting from higher productivity. In addition, digital servitization, which denotes "the transition toward smart product-service-software systems" (Kohtamäki et al. 2019, p. 390), has been identified as a relevant business model innovation that has developed over time as a branch of servitization research. This aspect will be discussed in more detail in the next section. The findings in the general literature on the impact of digital technologies can also hold true for the automotive industry. In a comprehensive review, Sterk et al. (2022) examined the impact of digital technologies on the value proposition, value architecture, value network, and value finance in the automotive sector. In particular, the authors show that digital technologies can affect the value proposition along five dimensions: safety, convenience, cost reduction, traffic efficiency, and infotainment. Athanasopoulou et al. (2019) found that electric driving does not necessarily lead to new business models in the automotive industry, but identified four groups of services that have a significant impact on automotive business models: personalized services, generic mobility services, shared mobility and connected cars. Thus, the implementation of digital technologies is leading to a change in the typical automotive business models. In this context, Bohnsack et al. (2021) distinguish between three business model types: (i) physically-oriented business models, (ii) digitally-oriented business models, and (iii) hybrid business models. For example, connected cars lead to hybrid business models, because they combine physical and digital elements.

It should be noted, however, that while digital and data-driven technologies have often been discussed in the context of business models, other factors may trigger the development of new business models in the automotive industry. For example, sustainability (e.g., Wells 2013), regulation and policymaking (e.g., Yun et al. 2020), and customer behavior (e.g., Moons and Pelsmacker 2015) are all relevant factors that can push automotive companies to innovate their business models.

All of the business model drivers identified are not independent and therefore interrelated. For example, as policymakers become aware of the negative environmental impacts of transportation emissions, they may change regulations to promote more sustainable mobility, e.g., by subsidizing electric vehicles and infrastructure. The higher the availability of the charging infrastructure and the lower the price of the vehicle due to government support, the more likely it is that customers will switch to e-mobility and, consequently, the higher the diffusion of electric cars. As more electric cars are produced, higher economies of scale (Ali and Naushad 2022) can be achieved in vehicle production and distribution, leading to even lower vehicle prices. At the same time, the business of installing and operating charging infrastructure will become more attractive, leading to more widespread use of charging stations. Overall, customers will face lower barriers to switching to electric vehicles, moving the market toward more sustainable mobility. These positive feedback loops between the business model drivers are necessary to overcome the chicken-and-egg problem and thus to achieve market uptake (Ziegler and Abdelkafi 2022). In practice, however, this has not happened on a large scale, in part because, despite public subsidies, the initial price of electric vehicles has been higher than that of equivalent vehicle models with combustion engines, in addition to technical limitations of the technology such as driving range and charging time (Liu et al. 2021).

2.4 Service-based business models in the automotive industry

Companies in the automotive industry "need to consider changing their business models from a product to a service-oriented model" (Athanasopoulou et al. 2019, p. 73). Service-oriented business models can be supported by digital technologies, as digitalization can significantly improve the design options for business models (Hanelt et al. 2015a). The integration of digital technologies can help companies reduce path dependencies and avoid lock-ins (Bohnsack et al. 2021). The digitalization of physical products and the interconnection of digitized products (Lanzolla et al. 2021) have largely contributed to the development of more complex business models in the automotive sector (Llopis-Albert et al. 2021), where business models have traditionally been based on the sale of new vehicles (Wells 2013). For example, shared mobility has been made much easier for users through the apps of mobility providers. Digital offerings and services can create additional value, for example, by using charging stations for advertising purposes (Madina et al. 2016), and can improve the user experience, for example, to meet the user's desire for increased connectivity (Hanelt et al. 2015). This latter aspect is highly relevant, as the relative importance of the user experience as compared to vehicle quality is expected to increase in the future (Teece 2018). In particular, connected cars, which are vehicles with internet connection and associated applications (Bohnsack et al. 2021), offer increased potential for the development of innovative business models and new services (Teece 2018).

2.5 Summary

The mobility transition will trigger a systemic change involving many actors in the mobility system. While several theoretical frameworks, such as transition theory and dominant design perspective, address technological shifts in general, their application to the context of the automotive industry does not provide a clear answer to the question of which powertrain technologies will be dominant in the future. Observations from the field also show that automotive companies are currently following different technological paths, confirming the difficulty of answering this question. Hence, the first research question: which powertrain technology will dominate? As technologies and business models are linked, new technologies may require new business models to support commercialization and market take-up. A fair amount of research has focused on the impact of electric vehicle technologies on automotive business models. However, some recent literature has shifted the focus from powertrain technologies to digital technologies as the main driver of future automotive business models. The literature identifies many other business model drivers such as sustainability and customer behavior. It also identifies service-oriented models and digital servitization as a consequence of digital technologies, as they enable companies to collect data during the product use to support the development of solutions that are better adapted to customer needs. Given these gaps in the literature, this article aims to answer two further questions: are new powertrain technologies for BEVs and FCEVs not business model drivers as previously assumed? If so, what are the real drivers of new business models in the automotive industry?

3. Methodology

This research follows a two-stage methodology based on semi-structured interviews with experts from the German automotive industry and electric mobility (Figure 1). Therefore, the geographical scope of this research is Germany. Semi-structured interviews reduce the risk of not eliciting the desired information and allow for more in-depth exploration of certain topics (Rabionet 2011). While quantitative methods require large samples, a smaller sample is often sufficient for semi-structured interviews (Qu and Dumay 2011). Researchers can stop conducting further interviews after reaching information saturation. This saturation is reached when the incremental increase in information with each additional interview is minimal. That is, if it is observed that experts' views are converging, leading to the expectation that additional interviews will not yield substantial new insights, then no more interviews are conducted.

The first study of this research aims to capture the relative dominance of BEVs and FCEVs. As it will be detailed in the results section, more than 80% of the experts agree on one specific option, which is the coexistence of both technologies, thus showing clear convergence of expert opinion. In the second study, the main objective is to capture the business model drivers. During this study, it has been noticed that the last 2-3 interviews (out of 14) did not provide any new insights regarding business model drivers, indicating that a state of information saturation had been reached. The number of 14 experts may seem low at first glance, but in a literature review on sample sizes for saturation in qualitative research, Hennink and Kaiser (2022) found that information saturation can be reached with a relatively small number of interviews, varying between 9 and 17. All interviews were conducted in German, then recorded and transcribed in German, while the analysis and coding process, which will be explained later, were conducted in English.

The experts were selected primarily on the basis of their years of experience in the automotive industry. In addition, the expertise of the interviewees was ensured by the following measures: (1) prior involvement of the experts in previous projects in which the authors have participated; (2) snowballing technique, as participants were asked at the end of the interviews to recommend other experts who could participate in the study (Stratton 2021). The underlying assumption is that people with a certain level of expertise will tend to know people with at least the same level of expertise; and (3) the use of social media such as LinkedIn, where years of experience are explicitly mentioned. Potential participants were sent the main topics and, if they wished, the interview questions. While some experts did not accept the invitation due to availability constraints, all other experts contacted felt knowledgeable enough to contribute to this study.

The first interview study addresses RQ1, which deals with the future technological transition from conventional to alternative powertrain technologies by exploring whether one powertrain technology will dominate (either BEV or FCEV) or whether both technologies (FCEV and BEV) will coexist. The study involved 11 experts from various fields: German OEMs, suppliers, consulting, start-ups, and research institutions (Table 1). The interviews were conducted from April to May 2020 and lasted between 30 and 58 minutes with an average of 51 minutes.

Table 1: Categorization of the interviewees of the first interview study

Interviewee	Position	Company/Institution	Interview duration [in minutes]
1.1	Staff member	Automobile manufacturer/OEM	54
1.2	Technical specialist	Automobile manufacturer/OEM	55
1.3	Technical specialist	Automobile manufacturer/OEM	58
1.4	Strategy specialist	Supplier	57
1.5	Senior consultant	Consulting	47
1.6	Consultant	Consulting	55
1.7	CEO	Start-up	49
1.8	Department manager	Research institution	50
1.9	Press officer	Federal association	30
1.10	Consultant	Speaker, content creator	58

1.11	Consultant	Speaker, content creator	48

The second interview study explored questions about the drivers of new automotive business models (RQ2) and whether mobility service-based models are the winning models in the future (RQ3). It involved 15 experts in the field of electric mobility, many of whom had expertise in digitalization and infrastructure (Table 2). A total of 14 interviews were conducted, as one interview involved the participation of two experts. The interviews lasted between 23 and 60 minutes, an average of 40 minutes. An overview of the research questions and the corresponding interview studies can be found in the appendix.

Table 2: Categorization of the interviewees of the second interview study

Interview	Company/ Institution	Position	Interview duration [in minutes]
2.1	Consulting	Consultant	40
2.2	Automobile manufacturer/OEM	Department Manager	25
2.3	Federal association	Country Office Representative	36
2.4	Federal association	Country Office Representative	47
2.5	Federal association	Country Office Representative	42
2.6	Automobile manufacturer/OEM	Founder & CEO	39
2.7	Federal association	Board member	35
2.8	Research institution	Scientist	55
2.9	Research institution	Senior Scientist	39
2.10	State association	Advisor	60
	State association	Advisor	
2.11	NGO	Advisor	45
2.12	Federal association	Project Manager	44
2.13	Consulting	Consultant	48
2.14	NGO	Advisor	54

The interview transcripts were analyzed using qualitative content analysis (Gläser and Laudel 2010). The coding process was supported by the software tool MAXQDA® (MAXQDA 2023).

The main categories were created deductively, as they were derived directly from the research questions. The subcategories were created inductively based on the interview data and then assigned to the main categories. Table 3 provides examples of quotes from the interviews. The selection of quotes from the interviews is only meant to illustrate the coding procedure from interview statements to subcategories and then from subcategories to main categories.

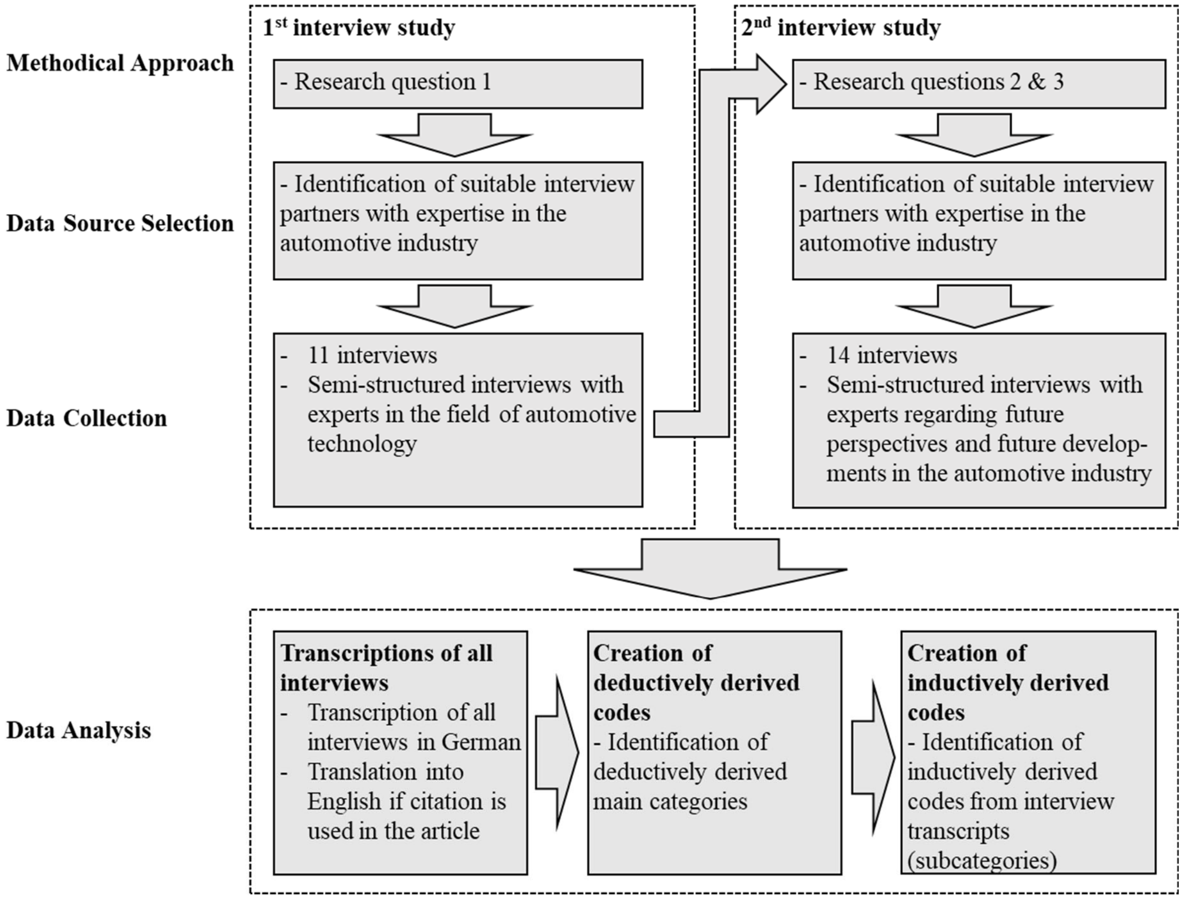

Figure 1: Overview of research methodology

Table 3: Exemplary main categories and subcategories of the interview studies

	Main category	Subcategory	Exemplary quotes
Interview Study 1	Powertrain technologies	Only BEV	"From the gut, I would say without [FCEVs]." (Interviewee 1.7)
		Co-existence BEV and FCEV	"Definitely with. I've been doing this for 33 years ... . For me it's clear that the goal is fuel cell vehicles. But there won't be an either or, as many people always think. What is better: battery or fuel cell car. What technology will prevail? Here is my answer: Both." (Interviewee 1.2)
		Advantage BEV	"And charging also has just big advantages. You never have to go to a gas station again if you have a charging station at home." (Interviewee 1.3)
		Advantage FCEV	"In this respect, the fuel cell definitely has advantages for long ranges." (Interviewee 1.4)
Interview Study 2	Drivers of automotive business models	Charging infrastructure	"I would clearly say no; OEMs won't make any money with charging infrastructure." (Interview 2.10)
		Management and vision	"That's a matter of your own strategic orientation and the focus of your own company. That also has something to do with what my brand should stand for in the future. [...] Now let's take a very, very flat example, I want to leave automotive now, do I want to be a laptop manufacturer, or do I want to be at the core of every laptop?" (Interviewee 2.7)
		Cooperations	"And of course, it's possible that car manufacturers will also somehow start something like this and say that we, as Volkswagen, will now cooperate even more with Ionity and build charging stations here and there that are perhaps also branded Volkswagen." (Interviewee 2.14)
		Recycling	"Yes, we see it [recycling] becoming a business case." (Interviewee 2.11)
		Battery technology	"So, they [car manufacturers] definitely want and need to make money with the battery." (Interviewee 2.2)
		The customer	"In this respect, the issue will be to focus even more on customer loyalty and dialog with customers in order to

			find alternative sources of business models." (Interviewee 2.3)
		Car sharing	"What we are seeing is that companies are partly trying to get into this sharing market. In part, however, I have the feeling that this will be given up again after a few years." (Interviewee 2.11)
		Bidirectional charging	"… the keyword is bidirectional charging. This will probably become much, much more important in the next few years, and we will also see how the electric vehicle can be used as a battery storage system and then return energy the other way around… These things are somehow new business models." (Interviewee 2.14)
		Service	"Service ... will and must be the big profit driver. That is, earning money in the traditional way by financing and producing vehicles, i.e., through car sales, will change dramatically to business cases around service, …, the new big profit driver." (Interviewee 2.2)
		Autonomous driving	"… I would say that in practice we will see new business models because we also have to talk about autonomous driving … We have to talk about data, data control, … [and] software." (Interviewee 2.11)
		Software/Addons	"But above all, we will also have to earn money in the area of software services." (Interviewee 2.2)
	Main business model orientation	Service-based mobility models	"I believe that this is a change in the sense of car manufacturer becoming mobility provider, … and the value of a car will fall very sharply in society." (Interviewee 2.8)
			"Moving away from being a car manufacturer to becoming a mobility provider means portfolio expansions, a greater focus on services." (Interviewee 2.5)
		Vehicle production business model	"So, manufacturers in the lower price segment such as Citroen and Peugeot are more likely to become mobility providers that also offer services and try to drive up their margins a bit ..." (Interviewee 2.10)

			“Mercedes has officially communicated that they will only make premium. And premium will continue to sell over the next few years. [...] And I have also noted that these vehicles in particular will also be capable of long-distance travel...When we look in the direction of premium, it's mostly the big vehicles." (Interviewee 2.10)

The results of the interview studies 1 and 2 were the starting point for the development of plausible scenarios to describe possible future states of the mobility system. The scenario axes technique is used, which is an approach that “… is aimed towards identifying the two most important driving forces, i.e. those that are both very uncertain (and therefore can develop into different directions) and could have a decisive impact for the region, the subject, the company, etc.” (van 't Klooster and van Asselt 2006, p. 17) Based on the literature analysis, powertrain technologies and business models are identified as relevant drivers of the mobility transition. According to van 't Klooster and van Asselt (2006), the driving forces characterized by high uncertainty and high impact should serve as a scenario axes. Thus, by crossing the technology and business model dimensions in a two-by-two matrix, four scenario narratives are derived that denote potential future directions of the mobility system. These narratives represent the descriptions of the future states and are elaborated and detailed based on the insights gained from the interviews (Epprecht et al. 2014). The first interview study was used to derive a possible and plausible technological orientation of car manufacturers, while the second interview study formed the basis for identifying potential directions for business models. These scenarios are then assessed by experts in terms of their likelihood of occurrence. It is noteworthy that the application of the scenario axes technique to the automotive industry is not new, as it has already been applied in the context of future studies, e.g. by Epprecht et al. (2014).

The four scenarios are evaluated by 20 experts, many of whom have participated in the second interview study. The experts were sent an e-mail with a description of the scenarios and the procedure to be followed for the evaluation. Each participant had to assign a probability of occurrence to each scenario over a period of 15-20 years on a numerical scale with four values: 1, 2, 3, and 4 with 1 being the least likely and 4 being the most likely. It is important to note that the experts are not expected to prioritize the scenarios by suggesting a ranking from most likely to least likely. While experts may assign a different value to each scenario and thus suggest a ranking, they may also rate different scenarios as equally probable. For example, an expert may rate one scenario as most likely (value = 4) and all other three scenarios as least likely (value = 1). This allows for the most accurate scoring that reflects the individual beliefs of the experts can be achieved. In addition, all experts are given the opportunity to comment on their choices if they choose to do so.

4. Results

This section presents the main findings of the interview studies and the scenario building exercise. Section 4.1 specifically describes the results of the first interview study, which was designed to capture possible options regarding the powertrain technology that will be dominant in the future. Before going into the details of these options, the advantages and disadvantages of BEVs and FCEVs that have emerged from the interviews are recapitulated. Section 4.2 addresses the key findings of the second interview study by presenting the identified business model drivers in the automotive industry. Section 4.3 then addresses the question of whether future automotive business models in the future will be product-based or service-based. Finally, section 4.4 presents the results of the scenario-building exercise, elaborates on the scenario narratives in detail, and reports on the evaluation of the proposed scenarios by 20 experts.

4.1 BEV vs. FCEV?

4.1.1 Advantages and Disadvantages

BEVs and FCEVs have positive and negative aspects. In addition to driving comfort and quietness, BEVs have excellent driving performance (acceleration) combined with driving pleasure, emotionality, and zero local emissions. The main disadvantage is the short driving range, mainly due to the relatively low charging capacity of the batteries. The low density of charging stations exacerbates the problem. In addition, the charging experience from a customer perspective remains at a low level due to the long charging times for BEVs. The lack of urban charging, insufficient public charging infrastructure, and high price are other negative aspects of BEVs. One way to address this issue is to use street lamps that are available in a city as possible charging points. While there are prototypes of street lamps that have been retrofitted to serve as charging stations for electric vehicles, they have yet to be widely deployed in cities. Several disadvantages of BEVs are advantages of FCEVs: driving range, refueling time, suitability for heavy-duty transportation, and long-distance travel. However, issues such as charging infrastructure and price are the main drawbacks.

4.1.2 Coexistence of BEVs and FCEVs

Nine out of eleven experts believe that both technologies will coexist. However, two out of nine respondents expect fuel cell technology to be used exclusively in commercial vehicles or in other modes of transportation such as rail, water, and air:

> *"So, if we take a broad view, i.e., if we consider the navy, aircraft, and commercial vehicles, then with the fuel cell. Regarding the passenger car sector, I would say it is also possible without a fuel cell." (Interviewee 1.4)*

FCEVs can be used to transport heavy loads and drive long distances. As such, FCEVs seem appropriate for the commercial vehicle sector. With the current battery technology, BEVs are neither economical nor environmentally friendly over long distances due to the number of battery cells required. The use of fuel cell technology in the commercial vehicle sector could lead to significant efficiency gains, resulting in greater environmental benefits. However, the option of using fuel cell powertrain technology in passenger cars should not be ignored, as there are significantly more passenger cars than commercial vehicles. Economies of scale would significantly reduce the cost of FCEVs, potentially making passenger cars a profitable market segment. In addition to range and charging time, one respondent mentions the area where the vehicles are used. FCEVs may be more suitable for rural areas due to the difficulty of establishing BEV charging infrastructure with sufficient coverage and density outside of cities.

For passenger cars, the coexistence of both technologies does not necessarily mean that all vehicle models will be available in BEV and FCEV versions, as both technologies can be used in different vehicle segments. For example, small, short-range vehicles could be BEVs, while

SUVs and trucks, which can carry heavy loads and need to travel long distances, are good applications for fuel cell technology. As one interviewee noted:

"For urban traffic, a battery-powered vehicle is a very good option; for short distances and small loads and for one or two people, i.e., the typical small city runabout, a Smart or something similar is very nice, and usable. So, a large part of the urban mobility needs could be covered, but that's where it ends. The larger the vehicles and the longer the distances, the less you can get past the fuel cell." (Interviewee 1.9)

In some vehicle segments, both technologies are possible. One expert argues that the limited range of battery-powered SUVs, for example, could lead to the use of fuel-cells in SUVs to meet customer demand:

"[...] a SUV with a battery is already very heavy, does not have enough range, and that is not enough for drivers. Then perhaps the fuel cell makes sense. I say, for the upper vehicle segments." (Interviewee 1.2)

4.1.3 BEVs but conditional introduction of FCEVs

One expert bases his argument on the current pressures of climate change and sustainability. For him, electric mobility should start without fuel cell technology. First, the current development of BEVs is more advanced than that of FCEVs. Second, automakers should focus on zero-emission vehicle production, use, and energy generation, which is possible with BEVs. FCEVs would only make sense if a surplus of electricity based on renewable electricity can be produced. This surplus can then be used to produce hydrogen:

"I think that because you have a better control over these two issues [production and use phase, authors' note] in the overall chain and can influence them better, it's important for sustainable CO_2-free mobility to take the first step in the direction of BEVs, because you can control that." (Interviewee 1.3)

4.1.4. Only BEVs without FCEVs

One expert believes that fuel cell technology has no future at all. First, the learning effects and innovation will significantly reduce the current limitations of battery technology in terms of weight, charging capacity, and charging time. Second, an adequate hydrogen refueling infrastructure is still lacking. Third, the cost of FCEVs is high, making large-scale market introduction extremely difficult. Forth, while it took (German) automakers a long time to embrace battery electric mobility, it is expected that fuel cell mobility will take even longer. Therefore, fuel cell technology will not become established in the long term:

"Fuel Cell, if this takes another 20 years, I don't know if the demand will still be there." (Interviewee 1.7)

It is noteworthy that the same respondent considers the suitability of fuel cells for the commercial vehicle sector to be valid in principle, but outdated, since it is also possible to increasingly electrify commercial vehicles—especially trucks—if battery cell production can reach a certain performance threshold.

4.2 Automotive business model drivers

While in the traditional business model of car manufacturers the core competencies lie in the technology of the internal combustion engine with a focus on production, sales, and after-sales, the interviewees expect major changes in future business models. From the interview coding, the key drivers for business model innovation in the automotive industry are: i) management vision; ii) market (customer); iii) willingness to cooperate; iv) future automotive trends (sustainability and autonomous driving); v) battery, charging technology and infrastructure; vi) digital technology; and vii) services.

4.2.1 Management vision, market, and cooperation

Management vision is a business model driver. Tesla is mentioned as a good example of a visionary company. In addition, the market can provide valuable impetus for new business models by engaging in dialog with customers and identifying their needs in order to tailor specific solutions. The focus should be not only on the vehicle, but also on the complete package offered to the customer. In addition, the complexity of electric mobility is seen as a major challenge for automakers. Therefore, collaborations with other companies can help automakers generate diversified revenue streams and reduce business risk through broad diversification:

"So, from my point of view, it would also be smart if the companies would simply enter into cooperative ventures instead of somehow acting as competitors." (Interviewee 2.9)

4.2.2 Future trends

Trends can drive automakers to develop new business models. Sustainability trends, particularly recycling, are expected to lead to a successful business case in the future. Autonomous driving is another trend that has the potential for widespread adoption, although some experts see it as more of a niche application. Experts differ on when and to what extent autonomous driving will shape society:

"I think it could be done in 5 years, that we really experience autonomous driving…but of course already in such a way that it is practical." (Interviewee 2.1)

4.2.3 Battery, charging technology and infrastructure

Charging technology and infrastructure can have an impact on the generation of business models in the automotive industry. While charging infrastructure is seen as basic requirement for a functioning electric mobility system, the ability of battery-powered vehicles to act as energy storage devices by stabilizing the energy system through bi-directional charging is seen as a business model driver. The vehicle-to-grid concept opens up opportunities for business models, as car users can partially offset their costs by feeding energy into the grid. It is noteworthy that most respondents rather expect significant technological progress in battery technology (by comparison, only one expert emphasizes that there is still enough potential to improve electric motors). For this reason, automakers are striving to integrate more activities into the automotive value network and to position themselves more broadly, in particular by internalizing battery production.

"They actually have to consider their entrepreneurial model because most of the profit, so to speak, is with the battery." (Interviewee 2.11)

4.2.4 Digital technologies

Vehicles are becoming increasingly digital, with in-vehicle digital technologies such as Internet connectivity, connectivity to mobile phones and other devices, and integrated entertainment systems. Software services, and in particular the ability to add features to the vehicle on demand can become a significant source of revenue. Examples range from add-ons for specific entertainment features to navigation systems and temporary engine performance enhancements. The importance of software in the new mobility system is captured in the following statement:

"They [European automakers] have all understood that they have to invest in software and new mobility, which is software-based." (Interviewee 2.2)

4.2.5 Services

In terms of services, repairs will be less relevant for electric vehicles. However, due to the increased level of digitalization on board, car manufacturers are expected to establish high-quality customer service to strengthen customer loyalty and create new revenue streams. Experts expect a variety of mobility concepts in the future, with car sharing being a key concept, especially in cities.

"And that really means offering the customer much more demand-oriented ad hoc mobility. But also, everyday activities around the family ecosystem, that means not just seeing the customer as a customer [...] but selling […] new mobility potentials, driver services, mobility services, fleet services, event services, and leisure activities. This means to completely rethink the business model as such […] and thus compensating for the shrinking margins and revenues…" (Interviewee 2.3)

4.3 Production-based or service-based business models?

With BMW and Mercedes abandoning their car-sharing business at a time when other manufacturers are expanding this model, an interesting question is which is the better strategic choice in the automotive transition: either to focus on the core business, i.e. car manufacturing, or to strengthen service-based models. Experts agree that, in general, the business models of car manufacturers will change, moving away from vehicle-centric business models towards complex mobility concepts that incorporate various elements of the electric mobility ecosystem, as illustrated by the following statement:

"I believe that this will definitely lead to a change in all business models of the OEMs. And I also believe that it will lead to a shakeout in the market because those who are not fast enough and diversified…will be swept away." (Interviewee 2.8)

A plausible explanation is offered by some experts, who expect that premium manufacturers will concentrate more on high-priced vehicle segments and thus be able to focus more on the vehicle itself, while manufacturers in the lower price segments will increasingly develop broader mobility concepts.

"They have always been premium; they will always remain premium and sell high-priced cars. And that is how I think it will develop for BMW, Audi, and Mercedes, but in the lower price segment, there will be other models." (Interviewee 2.10)

4.4 Scenarios for automotive manufacturers

This section focuses on scenario building for automobile manufacturers (OEMs), which play a central role in the current value chain of the mobility system. As explained in the literature background and methodology sections, powertrain technologies and business models are the driving forces with the highest uncertainty and impact on the mobility transition. Based on the findings of the first interview study, there are two possible directions in which the automotive industry can evolve with respect to powertrain technologies. The first is “only BEV”, i.e. only electric vehicles are produced and sold by OEMs. The second is the coexistence of BEVs and FCEVs, in the sense that both technologies are produced and marketed, either as complements (e.g., BEVs for smaller cars and FCEVs for larger cars such as SUVs) or as alternatives for the same car models (e.g., SUVs in the BEV and FCEV versions). A third direction “only FCEVs” does not seem to be realistic in view of the experts’ opinions and the current development path of the technology. Therefore, this option is not considered.

Regarding OEM’s business models, the results of the second interview study confirm that service-oriented models supported by digital technologies can be considered very realistic option in the context of future mobility. Furthermore, product-oriented business models will not become obsolete and will still be a reasonable option, at least in the premium car segment. This option reflects a strong focus of carmakers on their core business, which is the production and marketing of vehicles. In our opinion, this possibility has been unfairly devalued by the current literature (Genzlinger et al. 2020), which tends to place service-based models at the center of future business model developments of automotive manufacturers (Hanelt et al. 2015).

The results are summarized in four scenarios using the scenario axis technique, as shown in figure 2. The scenarios are represented by means of a 2x2 matrix with powertrain technology on the x-axis (pure BEV or coexistence of BEV and FCEV) and business model on the y-axis (mostly product-centric or mostly service-centric). Figure 2 also provides detailed descriptions of all four scenarios for automotive OEMs: (i) simply BEV, (ii) technology diversification, (iii) service-oriented BEV production, and (iv) maximum versatility. The “simply BEV” scenario describes a model that manufacturers have used for decades, with the only difference being that BEVs are produced and marketed instead of internal combustion engine vehicles. Technology diversification refers to a scenario where both BEVs and FCEVs are produced and sold. An essential element for models (i) and (ii) is the availability of a charging infrastructure with good coverage, while a direct connection between OEMs and customers is not required. Digital technologies are expected to support efficient production and charging processes as well as maintenance and after-sales services. In addition, third parties can develop and offer digitally oriented services around the manufacturer’s product-based value proposition. In scenarios (iii) and (iv), the OEMs perform more activities within the value chain. In addition to producing BEVs (scenario iii) or BEVs and FCEVs (scenario iv), the automaker connects directly with its customers, collects relevant data, and provides them with a menu of services such as shared mobility services or digitally enabled value-added services such as entertainment or connectivity services. Therefore, the automaker’s activity system (Zott and Amit 2010) in these scenarios integrates more activities (production and services) than in scenarios (i) and (ii).

Based on the expert ratings, the probability of occurrence is calculated for each scenario. It is equal to the average of all the expert ratings for a given scenario. The calculation of the mean values shows that scenario (iii), service-oriented BEV production, has the highest mean value (2.90), while scenario (i) “simply BEV” seems to be the least likely (2.05). Scenario (iv), called maximum versatility, has a mean of 2.65 and is the second most likely scenario, followed by technology diversification (scenario ii) with a mean of 2.35.

The results are interesting for three reasons. First, the overall picture shows a trend toward service-oriented business models, as simply BEV and maximum versatility scenarios have higher probabilities of occurrence than the scenarios proposed for the product-oriented business. Second, for product-based models, the coexistence of BEVs and FCEVs seems more likely than simply BEV. For service-based models, however, the opposite is true, as the simply BEV scenario seems more likely than the coexistence of BEVs and FCEVs. This result may reveal a pattern underlying the experts' reasoning. If OEMs increasingly integrate services into their business models, they are more likely to focus on one powertrain technology (BEV) than developing both. Conversely, if OEMs rather focus more on their core business of producing vehicles, then developing more than one powertrain technology is the more likely scenario. While this cannot be said with certainty, it seems a plausible conclusion. Third, it is noteworthy that the average probability of service-oriented models (regardless of powertrain technology) is about 2.77 (out of four), while the probability of product-oriented business models is equal to 2.2 (out of four). Obviously, this is not a clear result in favor of service-oriented models, as the difference can be interpreted as relatively small. In addition, calculating the probability of occurrence for BEVs and the case where BEVs and FCEVs coexist (regardless of the business model) leads to about 2.48 and 2.5 (out of four), respectively, which means almost equal probabilities and confirms the current fuzzy picture on powertrain technologies.

Mostly service-centered business models

Scenario *Service-oriented BEV production*

The traditional business model is an obsolescent model. Car manufacturers produce and sell only BEVs, with a large portion of profits generated elsewhere besides vehicle sales. Digital technologies (connectivity, add-on services such as entertainment features, etc.), personalized software and hardware specifications, and new types of mobility such as shared mobility and autonomous driving form complex business models with versatile revenue streams. An increasing number of cooperations with other companies (e.g., with technology companies) leads to a broadening of the OEMs' product and service portfolio (e.g., offering additional digital features in cooperation with tech companies, discount promotions with charging station operators, providing the car display to game developers for e.g., digital gaming during charging breaks). A very high level of customer orientation is crucial for successful business models.

Scenario *Maximum versatility*

The traditional business model is an obsolescent model. Car manufacturers produce and sell BEVs as well as FCEVs, with the two technologies being used in different vehicle classes (e.g., small cars vs. SUVs and trucks). A large portion of profits is generated elsewhere besides vehicle sales. Digital technologies (connectivity, add-on services such as entertainment features, etc.), personalized software and hardware specifications, and new types of mobility such as shared mobility form complex business models with versatile revenue streams. An increasing number of cooperations with other companies (e.g., with technology companies) leads to a broadening of the OEMs' product and service portfolio (e.g., offering additional digital features in cooperation with tech companies, discount promotions with charging station operators, providing the car display to game developers for e.g., digital gaming during charging breaks). A very high level of customer orientation is crucial for successful business models.

Mostly product-centered business models

Scenario Simply BEV

Automotive manufacturers focus on their traditional business model: production, sales and aftersales. They produce and sell only BEVs. Optimizing value creation processes plays a major role in maximizing profit margins. The cost-effective production of high-performance batteries is a key value-adding factor. Services are important for customer loyalty but are hardly used to generate profits.

Scenario *Technology diversification*

Automotive manufacturers focus on their traditional business model: production, sales and aftersales. They produce and sell BEVs as well as FCEVs, with the two technologies being used in different vehicle classes (e.g., small cars vs. SUVs and trucks). Optimizing value creation processes plays a major role in maximizing profit margins. The cost-effective production of high-performance batteries is a key value-adding factor for the BEV production. Services are important for customer loyalty but are hardly used to generate profits.

Only BEV

Co-existence BEV & FCEV

Figure 2: Description of scenarios for automotive manufacturers

5. Discussion

When powered by renewable energy, BEVs and FCEVs can significantly reduce global greenhouse gas emissions (Chandran et al. 2022). From a technical perspective, both powertrain technologies can be used in all road transport applications. However, there are differences between the two powertrain technologies in terms of their characteristics and suitability for different vehicle classes (Miotti et al. 2017). In recent years, the scientific community has increasingly ascribed different application areas to the two technologies. On the one hand, the use of fuel cells seems to be particularly useful for vehicles with high loads and long distances, such as trucks used in freight logistics (Cunanan et al. 2021). On the other hand, battery vehicles are a better option for passenger transport, i.e., for light loads and shorter distances (Miotti et al. 2017). Therefore, our findings based on the first interview study are mainly in line with previous research that expects the coexistence of both powertrain technologies. However, it also shows that passenger cars can even be differentiated into small cars for short distances and SUVs for longer distances. While small cars are BEVs, SUVs are equipped with fuel cells.

Whereas most of the experts involved in the first study predict the coexistence of BEVs and FCEVs, two experts do not. In line with Plötz (2022), who sees battery technology playing a major role in passenger and freight transportation, one key informant predicts BEVs as the dominant technology and thus future mobility without FCEVs. In other words, BEVs will also be used in freight logistics. Comparing these results with the findings from the scenarios, we can say that when asked directly about future powertrain technologies, most experts predict a coexistence of both technologies in the future. However, in terms of probability of occurrence, BEV alone and BEV-FCEV coexistence scenarios are equally likely. This is not easy to explain and only confirms the difficulty of predicting the technologies for the mobility transition. Nevertheless, experts agree that future mobility with FCEVs alone is very unlikely. One expert even predicts a sequential introduction of BEVs and FCEVs, because—from a purely environmental point of view—FCEVs would only make sense if there is a surplus of green electricity that can be used to produce hydrogen.

For the conventional car, the internal combustion engine seems to have significantly shaped business models in the automotive industry due to its complexity in terms of components and technologies used. The electric motor, however, is not considered to be a major driver of business models for electric vehicles. Instead, battery technology is expected to play a key role in business models, especially for BEVs. The battery represents about one third the value of an electric vehicle (Abdelkafi and Hansen 2018), and business models are more likely to change over time depending on advances in battery technologies.

Digital technologies for mobility (Hanelt et al. 2015) and autonomous driving (Athanasopoulou et al. 2019) offer new opportunities to design innovative business models (e.g., Bohnsack et al. 2021). Acciarini et al. (2022) found that firms in the automotive industry are aware of the significant impact of digital technologies, but they are still uncertain about adopting them. While digital technologies increase the design options of business models (Bohnsack et al. 2021), customer orientation should not be neglected, as emphasized by Schweitzer et al. (2019). Moreover, various factors influence the attractiveness of electric vehicles, such as environmental benefits (He and Hu 2022), cost, comfort and safety (Tarigan 2019), and customers' green self-identity (Barbarossa et al. 2017). How to target customers by offering the right value proposition (Bohnsack et al. 2014) will become an increasingly important question for automakers. Customer orientation is also linked to a corresponding management vision to retain customers in the long term, especially with regard to customers' growing awareness of sustainability (Schmidt et al. 2021). Furthermore, cooperation with other firms can support the establishment of successful business models. Interaction with other firms, such as IT firms (Kukkamalla et al. 2021), can support the implementation of new knowledge about digital technologies (Ziegler and Abdelkafi 2022) and could lead to new collaborative business models (Acciarini et al. 2022).

Because electric engines are more robust than internal combustion engines, they require less maintenance and repair services. From this perspective, there is less need for such value-added services. However, future business models are expected to become more service-oriented and less product-centric (Athanasopoulou et al. 2019) due to increased customer demand for mobility services (Epprecht et al. 2014), as the scenario assessment also shows. This service orientation is facilitated by business models enabled by digital technologies (Ziegler and Abdelkafi 2022). Nevertheless, premium brands may still adopt product-oriented business models, in contrast to small car manufacturers. One possible reason is that customers may value product ownership more in the premium segment than in the lower-priced segment, where the focus is more on mobility services than on other aspects, such as expressing social status (Chng et al. 2019).

In the scenarios developed, there is a slight trend toward service-oriented business models. However, some experts believe that product-centric business models will be relevant in the future. The answer to the question of the role of the FCEV in the future is also not clear. It should be noted, however, that in the case of service-oriented business models, a pure focus on BEVs is seen as the most likely. These results also confirm the high degree of uncertainty about the evolution of the automotive industry (Turienzo et al. 2022) with regard to future technology and market development (Günther et al. 2015). It was also found that for the service-oriented model, experts rated the probability of occurrence of the only BEV scenario higher than the BEV-FCEV coexistence scenario; for the product-oriented model, the opposite was true. This can be explained as follows. Manufacturers using a product-oriented business model tend to focus on the product itself and are therefore more likely to develop additional powertrain technologies. However, service-oriented models may lead OEMs to focus on providing services. This can "distract" them from developing other powertrain technologies, putting more emphasis on the BEV and less on other powertrain technologies such as FCEVs. This fits the case of Volkswagen, for example, which is betting more on services and less on FCEV technology. For premium manufacturers such as BMW and Mercedes, this study suggests that these manufacturers are more likely to be involved in the development of new powertrain technologies than their service-oriented counterparts.

6. Conclusions

This study sheds light on the current and future developments in the automotive industry. First, which powertrain technologies (BEV or FCEV) will be dominant in the future? Second, what are the key drivers of new automotive business models? Third, are service-based models the winning business models in the automotive industry? Two interview studies were conducted to answer these research questions.

The first study shows that most experts expect BEVs and FCEVs to coexist, but the use of both technologies differs in terms of vehicle classes and applications. However, the evaluation of the scenarios puts this assessment into perspective, as a larger proportion of respondents consider an exclusive focus on BEVs to be the most likely. The second interview study identified several key drivers for automotive business models: management vision, the market (especially the customer), cooperation, sustainability, autonomous driving, battery and charging technology, and digital technologies and services. These key drivers are important indicators of what will guide and shape successful business models in the future. In addition, it should be clarified to what extent this list of key drivers is complete and what importance can be attached to each key driver.

In terms of mobility service models, this research shows that a shift to more complex, more service-oriented business models is expected. This is also confirmed by the experts' assessment of the scenarios. The traditional business model of car manufacturers will be replaced by other models in the future. In particular, manufacturers in the lower price segment will focus more on broader mobility concepts than premium manufacturers such as BMW or Mercedes, which are expected to be more product-centric. In fact, analysts criticize this strategic move by both manufacturers, pointing out that shared mobility will be an important business model in the future and that automakers are missing an opportunity to learn from their customers by not experimenting with this model now.

Despite the insights that this work provides to the current research on powertrain technologies and business models in electric mobility, some limitations are worth mentioning. As the data is based on qualitative interview studies, the limited number of interviewees can be considered a point of criticism, although it can be assumed in this study that information saturation has been reached. In addition, the findings are based on the insights of interviewees based in Germany. Therefore, the number of respondents as well as the geographical scope can be expanded in future research studies.

The research also leads to many open questions that need to be answered. Do automakers have the resources to focus on developing BEVs and FCEVs? Is it wise to focus on one technology, or could this be a fatal mistake in the medium to long term? To what extent could digital technologies make the hardware, the car itself, less valuable compared to the data needed to operate e.g., autonomous cars? To what extent could the mobility transition lead to a redistribution of power and technological leadership between countries and regions and between actors within the same value chain? These and many other questions need to be addressed if companies are to find the right strategies for the future.

To return to Jules Verne's quote at the beginning of this article. In line with many expectations, Jules Verne will be right in that hydrogen will be used, at least in part, as a fuel. However, the transition of the automotive system is not only about technological progress, but also about creating sustainable business models. While the complexity of the engine is decreasing as we move from conventional cars to BEVs and FCEVs, the complexity of business models appears to be increasing significantly, going well beyond the traditional model of manufacturing and selling vehicles.

Appendix

Table: Research questions investigated and their data sources

RQ1	What powertrain technologies (BEV or FCEV) will be dominant in the future?	Interview study 1
RQ2	What are the key drivers of new automotive business models?	Interview study 2
RQ3	Are mobility service-based models the winning business models in the automotive industry?	Interview study 2

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