The Future of the Automotive Industry – How will Energy Transition Unfold in Europe?

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Dissertation written under the supervision of Professor Peter V. Rajsingh

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ABSTRACT

Tittle: The Future of the Automotive Industry – How will Energy Transition Unfold in Europe?

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The transportation sector is responsible for significant CO2 emissions in the world. To tackle this problem, governmental entities, organizations, and consumers have pushed the industry towards a phase of energy transition. The European Union announced that from 2035 on, internal combustion engine (ICE) cars would no longer be sold, which accelerated the transition. This change opens up a space that needs to be filled with greener technologies. Electric cars (both BEVs and FCEVs) are examples of emerging technologies.

This thesis analyzes how different types of engines can fill the space left by ICE vehicles in different sectors of the automotive industry. BEVs and FCEVs are subject to limitations (confirmed by consumers) that may or may not be addressed depending on the behavior of industry stakeholders over the next 10 years.

To analyze the consequences of uncertain behaviors of various stakeholders, a Scenario Planning tool (Davis, 1989) was used where the different behaviors gave rise to 3 scenarios. The base scenario was the most likely to happen where there is stable development in the automotive industry, and BEVs are the main solution for passenger cars while FCEVs dominate for heavy-duty transport and buses.

Keywords:

Energy Transition, Automotive Industry, Electrification, Sustainability, Battery Electric Vehicle, Fuel Cell Electric Vehicle, Hydrogen, Scenario Planning

SUMÁRIO

Título: O Futuro da Indústria Automóvel – Como se vai desenrolar a Transição Energética na Europa?

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O setor dos transportes tem uma grande responsabilidade nas emissões de CO2 no mundo. Para combater esta problemática, agentes governamentais, organizações e consumidores têm "empurrado" a indústria automóvel para uma fase de transição energética. A União Europeia anunciou que a partir de 2035 os carros de motor a combustão interna (ICE) deixariam de ser vendidos, o que acelerou esta transição. Esta mudança abre um espaço que necessita de ser preenchido por tecnologias mais ecológicas. Os carros elétricos (tanto BEVs como FCEVs) são exemplos de tecnologias emergentes.

Esta tese analisa a forma como diferentes tipos de motores podem vir a preencher o espaço deixado pelos veículos ICE em diferentes setores da indústria automóvel. Os BEVs e os FCEVs estão sujeitos a limitações (confirmadas pelos consumidores) que podem ou não vir a ser ultrapassadas de acordo com o comportamento dos *stakeholders* da indústria durante os próximos 10 anos.

Para analisar as consequências de comportamentos incertos de vários *stakeholders* foi utilizada a ferramenta *Scenario Planning* (Davis, 1989) onde os diferentes comportamentos deram origem a 3 cenários. O cenário base foi considerado o mais provável pelos especialistas, onde há um desenvolvimento estável na indústria automóvel, em que os BEVs são a principal solução para carros ligeiros de passageiros e os FCEVs para veículos pesados.

Palavras-Chave:

Transição Energética, Indústria Automóvel, Eletrificação, Sustentabilidade, Carro a Bateria Elétrica, Carro Elétrico a Célula de Combustível, Hidrogénio, Planeamento de Cenários

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I end this stage humbled and excited to be challenged and to challenge those around me to leave a positive mark on the world as professionals and individuals. A profound thank you to all who have contributed to this journey.

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1 INTRODUCTION

Since pre-industrial times, global temperatures have increased by more than 1ºC (Annual 2021 Global Climate Report, 2022). This rise has happened primarily due to increasing greenhouse gases, namely CO2. Statisticians state that despite the decreasing slope of CO2 emissions (Global Carbon Project, 2021), they have yet to reach their peak, meaning there is still a long way to go before achieving a net-zero world.

Transportation is responsible for 20% of CO2 emissions. Breaking these down, we find that 74.5% comes from road vehicles for passengers or freight (Ritchie, 2020). Given these figures, it is crucial to achieve efficient and rapid methods to decrease the environmental impact of transportation.

Battery Electric Vehicles (BEVs) are an excellent solution being increasingly utilized, and governments worldwide are promoting and incentivizing the substitution of the internal combustion engine (ICE) with BEVs. Incentives include tax exemptions, vehicle subsidies, and supporting infrastructure, namely charging stations. Besides these, the European Union, for example, intends to prohibit the sale of diesel and gasoline cars and vans by 2035 (European Parliament News, 2022). Corporate organizations are also carrying out this fight. In 2021, 27 companies, including Uber, Volvo, Coca-Cola, and IKEA, made an open call appealing to the EU to "end gasoline and diesel cars by 2035" (Transport & Environment, 2021).

Nevertheless, BEVs also present significant challenges. The first is the difficulty of shifting from diesel and gasoline vehicles to electric cars. BEVs are more expensive than ICE vehicles on average. Additionally, BEVs currently have an average autonomy range of 330 km (Electric Vehicle Data Base, 2022), which has yet to match conventional cars, whose range is about 650 km (U.S. Department of Energy, Vehicle Technology Office, 2016).

Moreover, there is the environmental impact of lithium-ion batteries. Studies increasingly point out the harmful effects of the production and disposal of batteries where cobalt, copper, Nickel, thallium, and silver generally exist in toxic quantities (O. Heidrich, 2021). On the other hand, the availability of these minerals is also being called into question with rising demand for BEVs – "*There simply isn't going to be enough lithium on the face of the planet, regardless of who expands and who delivers*" (Stuart Crow, Lake Resources Chairman to the Financial Times) (WEF, 2022)

Fuel Cell Electric Vehicles (FCEVs) are a technology that may be an alternative. Unlike BEVs, FCEVs achieve their power from a hydrogen fuel cell where the only by-product is distilled water instead of a battery (California Air Resources Board). Once energy is generated within the vehicle, a much smaller battery is needed for FCEVs, improving the environmental impact associated with BEV lithium-ion batteries. Also, the charging/fuelling time is much shorter in an FCEV (about 5 minutes) when compared to an EV (about 6 hours in a standard station), as well as the autonomy range is more significant, which is between 480 and 650 km (Selmi, *et al.*, 2022).

However, hydrogen does not exist in free form, so it must be acquired via electrochemical processes that are more expensive than simply charging a battery. Besides, fuel cell technology is also more expensive than battery systems. (Technology and Fuel Cell Technology Office, 2014). Additionally, right now, the distribution grid of hydrogen stations is sparse. In Portugal, there is presently only 1 station available, even though the target is to reach between 50-100 stations by 2030. (EN-H2 - Estratégia Nacional para o Hidrogénio, 2020.

1.1 ACADEMIC & MANAGERIAL RELEVANCE

Scholars and specialists are far from in agreement about how the future of the automotive industry will look. While some state that hydrogen-fuelled cars will not be a reality (Plötz, 2022) due to high costs and the head start of BEVs, there are also predictions that point to a promising future for FCEV technology arguing that its True Cost to Own (TCO) will be lower than BEVs in the next ten years (Deloitte, 2020). It is also stated that shortages of raw materials will limit the fabrication of the batteries needed globally for BEVs (IEA, 2022).

Given the uncertainties, assessing how matters will unfold regarding vehicle power is relevant. This research will help stakeholders gain insights into the future of the automotive industry and transportation, uncovering investment opportunities and key factors relevant to their business models.

This thesis will address the following Research Question:

1) What type of engine is likely for the future of the automotive industry?

2 LITERATURE REVIEW

2.1 THE AUTOMOTIVE INDUSTRY

At the global level, historically, the automotive industry has been mainly dominated by the U.S. (by 1960, about 75% of the worldwide production was from the U.S.) (Ferràs-Hernández, et al., 2017). However, in 2020 China was the biggest producer, with a market share of roughly 32%, the USA 11%, and Japan 10%. Regarding the European market, the EU has an 18% market share; inside this area, Germany stands out with 5% (OICA, 2020).

The industry in Europe is an integral part of the economy, accounting for 7% of the EU's annual GDP and 13.8 million jobs totaling roughly 2.9% of the EU's population (European Comission, n.d.).

Regarding sales, the last decade has had a positive trend, only disrupted in 2020 by the Covid-19 pandemic (Figure 1). Recently, from the first semester of 2021 to the first semester of 2022, a 14% decrease on sales, in the EU, has occurred (ACEA, 2022). This decrease happened mainly due to the semiconductor shortage caused by the pandemic (J.P. Morgan, 2022). It was further exacerbated by the Ukraine war, which caused a shortage of other materials (ACEA, 2022).

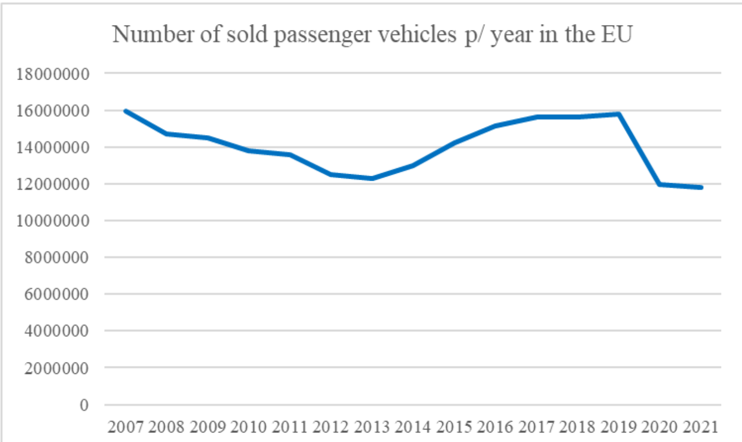


Figure 1 - Number of sold passenger vehicles in the EU (2007 - 2021)

Concerning competitiveness, the automotive industry has been characterized as a "fortress industry" (Ferràs-Hernández, et al., 2017). Traditionally, when applying Porter's Five Forces framework, this was a stable industry where entrepreneurs had little room to gain market share because of the enormous initial investments needed and the scale of prominent existing players. Research and development costs are also a barrier for new entrants due to the amounts incumbent companies spend. Volkswagen Group led the way with $ 15.8 billion in R&D in 2018, the third-highest amount worldwide among all industries[1] (PwC, 2018).

Until the end of the 20th century, there was no substitute for ICE vehicles that offered comfort and independence for drivers and low fuel consumption (National Grid, 2021). However, in 1997 the first mass-produced hybrid vehicle, the Toyota Prius, appeared and gained traction that persists into the present day. Following this trend, in 2006, Tesla Motors announced the production of a luxury sports car, pushing the industry toward the BEV revolution (U.S. Department of Energy, 2014)

Thus, today the automotive grid is comprised of ICE vehicles, Hybrids, Mild Hybrids, Plug-in Hybrids (PHEVs), BEVs, and FCEVs are also available, which has transformed the once stable and predictable industry. Varieties of vehicles have various advantages, challenges, different stages of development, and varied acceptance levels from the consumer (Osswald, et al., 2012).

2.2 ICE VEHICLES

As the name suggests, an internal combustion engine works by burning fuel. When combustion occurs, gas releases push the piston inside cylinders that rotate the crankshaft, creating movement (U.S. Department of Energy, 2013). Gasoline engines differ from diesel engines in the "igniting process". For the former, combustion happens through a spark, while in the latter, the ignition occurs through air compression. (Universal Technical Institute, 2019)

Despite still having the largest market share, rising demand for more sustainable alternatives has decreased sales of ICE cars. ICE vehicles in the EU lost market share from 63% to 53% in the first quarter of 2022 compared to the same period (The European Automobile Manufacturers' Association, 2022).

Advantages and Challenges

In Europe, when cars with the same characteristics but different engines (BEV/PHEV vs. ICE) are compared, ICE cars have a consistently lower purchase price (Nickel Institute,

[1] See Appendix A

2021). Also, as mentioned previously, the range of approximately 650 km of these vehicles is the highest among the available options (U.S. Department of Energy, n.d.). On the downside, there is the emissions problem, oil dependence, and air and noise pollution (Weiss, et al., 2015).

2.3 Plug-in Hybrid Vehicles

Often**,** PHEVs are described as a "transition technology" (Frank & DeMauro, 2015) for moving from diesel and gasoline to an electric future. Essentially, a Plug-in Hybrid Electric Vehicle has both electrical and combustion engines. The former has a battery (smaller than the one from the BEVs) that can be charged by a wall outlet, a charging station, by the combustion engine itself, or through the regenerative braking system (Figure 2). Once the battery runs out, the system switches automatically to the ICE, working as a conventional vehicle (U.S. Department of Energy, n.d.)

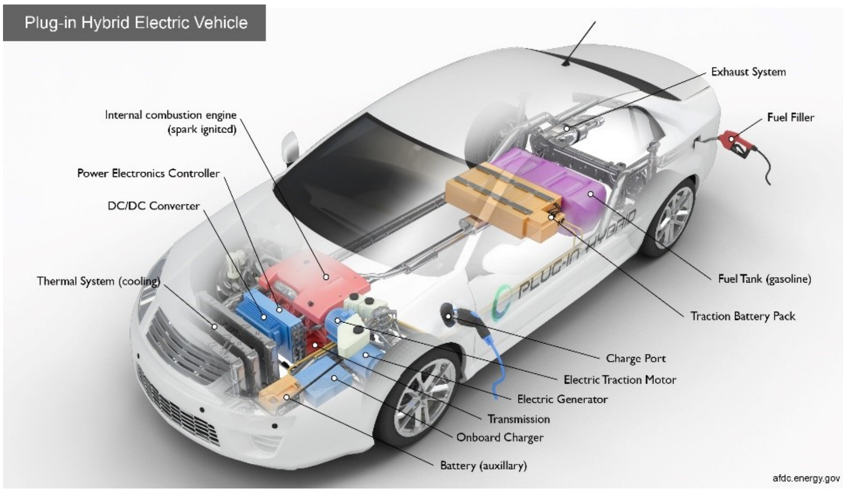


Figure 2 - Plug-In Hybrid Electric Vehicle (U.S. Department of Energy, n.d.)

In the EU's first quarter of 2022, sales of PHEVs dropped 6% when compared to the previous year. Despite this, the market share increased by about 1% due to the dramatic decline in sales of gasoline vehicles (ACEA, 2022).

<u>Advantages and Challenges</u>

The flexibility of hybrid vehicles is undoubtedly one of the leading value propositions since they can run on gasoline or electricity. Most European countries have subsidized these vehicles

(AIRUSE, 2016) (Figenbaum, et al., 2015) based on their ability to reduce gasoline/diesel consumption (Silva & Farias, 2010). Moreover, studies predict that in 5 years, the TCO of some PHEVs "could be less than an equivalent-sized conventional internal combustion engine" (Hamza, et al., 2021), even though this will likely only happen in an optimistic scenario. The baseline prediction is lower costs of motors and batteries, as well as an increase in gasoline prices (Nickel Institute, 2021).

However, several recent studies concluded that PHEVs are not as ecological as we think, arguing that fuel consumption in Europe by these vehicles is, on average, 3 to 5 times higher than Worldwide Light Vehicles Test Procedure (WLTP) approved values (Plötz, et al., 2022) (Figure 3). Also, WLTP uses a reference value of the electric driving share (distance driven on the electric motor with the combustion engine) of 70%-85%. At the same time, the same study presents empirical data on 45%-49% of private cars and 11%-15% of company cars in Europe. Because of this, PHEVs have been suffering from various drawbacks. Several European countries are halting subsidies, namely the UK and Germany (Bloomberg, 2022), increasing their costs. Overall, the transition phase is looking to be over, and PHEVs may likely see their demise as a result.

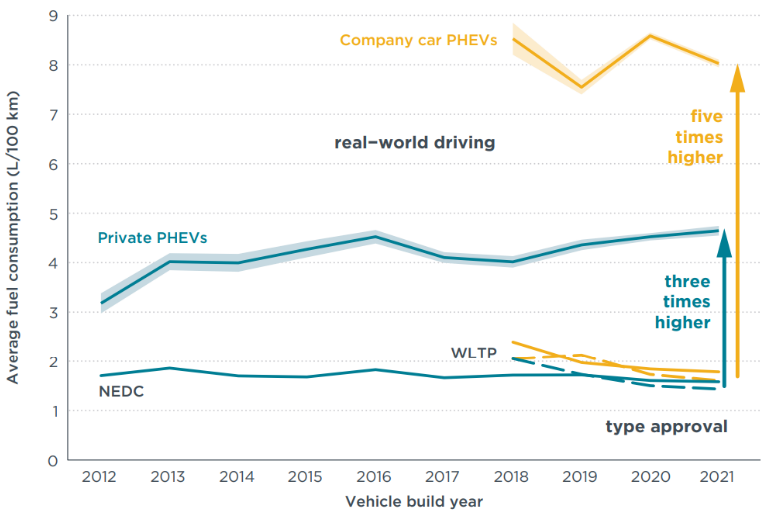


Figure 3 - Comparison between type-approval and real-world fuel consumption (2012-2021) (Plötz, et al., 2022)

2.4 Battery Electric Vehicles

The story of BEVs goes back to the 1830s, even though they might appear to be a recent phenomenon. With the introduction of rechargeable batteries in the United States at the beginning of the 20th century, more than one-third of automobiles were electric (U.S. Department of Energy, 2014). However, ICEs quickly took over due to lower costs of mass production, greater driver autonomy, and low fuel prices.

BEVs are 100% electric, using a large battery pack to power the electric engine and generate locomotion. These vehicles must be plugged into charging equipment or a wall outlet to charge their batteries (U.S. Department of Energy, n.d.) (Figure 4). Lithium-ion Batteries are the most common form (Frost & Sullivan, 2009) in the automotive industry (and in other electronics) because of their energy/size and weight efficiency (Wh/L and Wh/kg) (Landi, et al., 2009), reliable high-temperature performance and low self-discharge rates (U.S. Department of Energy, 2021).

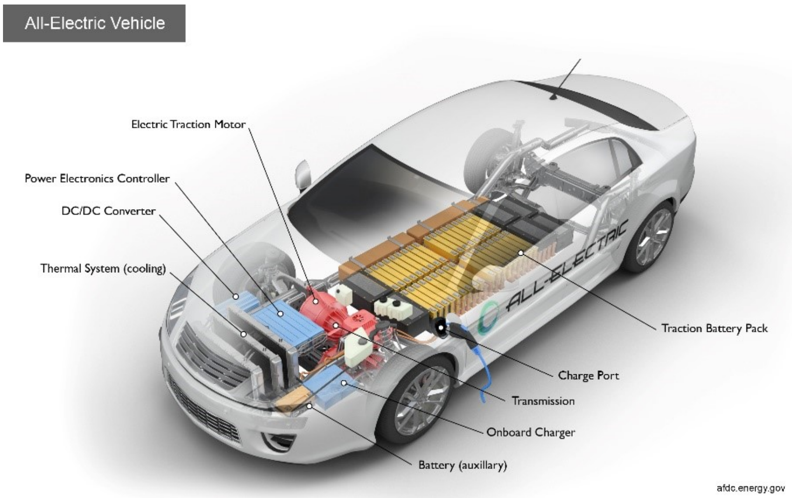


Figure 4 - Battery Electric Vehicle (U.S. Department of Energy, n.d.)

In the EU's first quarter of 2022, BEV sales had a market share of 12% (behind ICEs and HEVs), but there was an increase of 61% in sales compared to the first quarter of 2021 (ACEA, 2022). BEVs have been experiencing exponential growth, with sales increasing roughly 2,710% between 2014 and 2021 (European Environment Agency, 2022) (Figure 5).

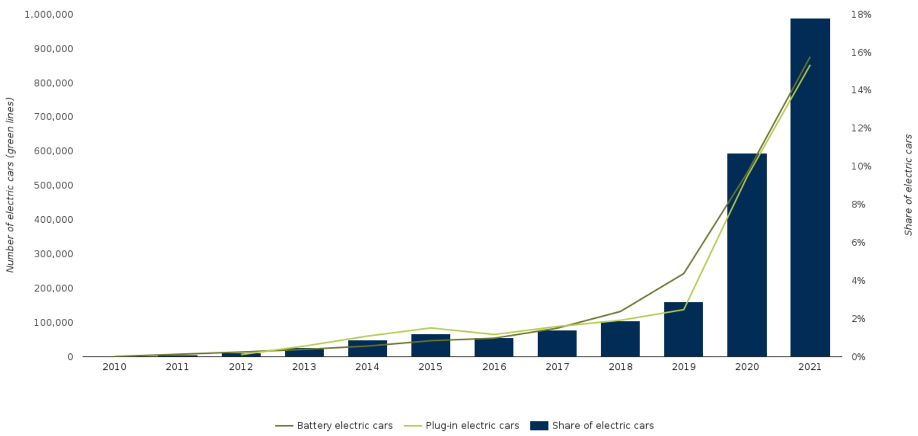


Figure 5 - New registrations of BEVs in EU-27 (2010-2021) (European Environment Agency, 2022)

Looking at the future, predictions suggest that roughly 50% of the yearly sales of passenger vehicles will be BEVs by 2030 (Forbes, 2022)

Advantages and Challenges

As a relatively recent trend, BEV performance and technology are constantly being updated. Their performance is frequently compared with ICEs, which still represent the *status quo* of the automotive industry.

A BEV, nowadays, is better for the environment than an ICE in 95% of the world due to increased renewable energy production, and this number is expected to increase (Knobloch, et al., 2020). An ICE can produce from 151 to 245 CO2-eq/km (CO2 equivalent of greenhouse gases), while a BEV ranges between 0 to 187 CO2-eq/km (IEA, 2022), taking electricity sources into account (Figure 6). Also, BEVs continue to cost more than both ICEs and PHEVs. However, when analyzing their TCO, and adding in maintenance and fuel costs, subsidies, and residual value, small and medium BEVs are generally cheaper over a 3-7- and 10-year horizon, both for low and high mileage uses (Nickel Institute, 2021).

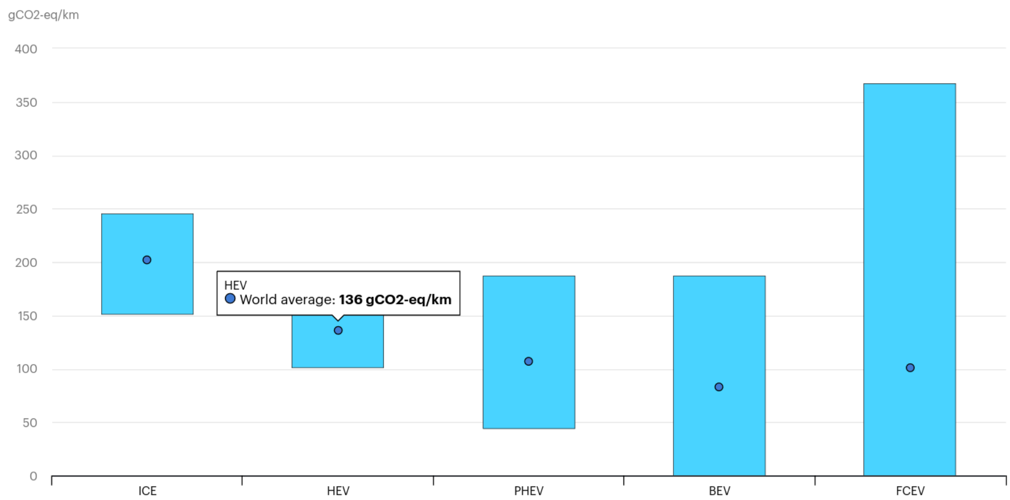


Figure 6 - Well-to-wheel range of GHG emissions for different powertrains (IEA, 2022)

Regarding efficiency, it is safe to state that BEVs are more efficient than ICEs. While a BEV can reach a maximum of 77% wall-to-wheel efficiency (Parajuly, et al., 2020), ICEs reach a maximum of 37% tank-to-wheel efficiency (Albatayneh, et al., 2020). Regarding reliability, experts tend to state that BEVs are more dependable due to fewer components. However, consumer polls indicate the opposite, with 31% of BEV's owners reporting an issue in the first four years, while users of gasoline and diesel vehicles report problems in the first four years, 19% and 29% of the time, respectively (Bloomberg, 2022).

With BEVs introduction and expected growth, a central resource might be overshadowed – oil. Being a relatively scarce resource only available in a few countries, oil, in contrast with renewables such as wind and sun, might be losing its place as the lifeblood of mobility. It is possibly being displaced by a new commodity – batteries. (Crabtree, 2019). However, lithium-ion batteries also have their issues. Firstly, when compared to ICEs, BEVs are limited by the range associated with a battery charge. Despite improvements in the energy density of batteries, "range anxiety" continues to be one of the main arguments against this technology (Chakraborty, et al., 2022). Lithium is not a problem when talking about battery composition since this mineral has adequate quantities to supply electric vehicles until 2050 (BloombergNEF, 2022) (Figure 7). This is true even if demand does not level off and present conditions of extraction and processing continue (WEF, 2022). Of course, lithium extraction has an environmental toll, with vast quantities of water and energy used to mine this mineral. However, renewable energy advances and weaning off fossil fuels mitigate these problems (Castelvecchi, 2021).

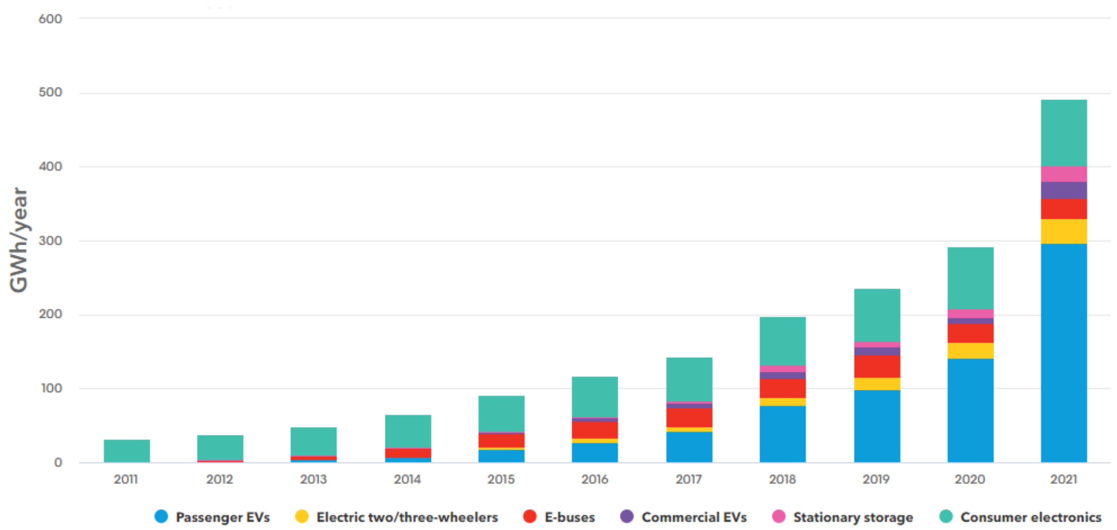


Figure 7 - Annual lithium-ion battery demand by application (BloombergNEF, 2022)

On the other hand, other minerals might face severe shortages, most notably cobalt, where supply constraints look inevitable in the short and medium terms, "even under the most technologically optimistic scenario" (Zeng, et al., 2022). Besides, more than 60% of cobalt is exported from the Republic of the Congo, where concerns about human rights and child labor have been raised (Castelvecchi, 2021). Another critical battery component, Nickel, faces similar problems (Baars, et al., 2021). Because of these issues, a new alternative has appeared – lithium iron phosphate (LFP lithium Ferro-phosphate) batteries. The chemistry associated with these does not require expensive materials in limited supply, like cobalt and Nickel. Nevertheless, there are drawbacks, namely, smaller battery range which means decreased vehicle autonomy (Yang, et al., 2022).

The future charging infrastructure is also a challenge for BEVs. Despite having appropriate charging infrastructure nowadays, it is easy to imagine issues given the numbers predicted for BEVs in 10 years (WEF, 2022).

BEVs remain a dynamic technology evolving while also having issues, most notably the environmental impact of batteries and concerns surrounding materials needed to build them (Castelvecchi, 2021).

2.5 FUEL CELL ELECTRIC VEHICLES

Fuel Cell Technology began to be developed in the 19th century but only had commercial use in the mid-20th century with NASA's Project Gemini. In 2007, Honda presented the first mass-produced fuel cell vehicle, the model FCX Clarity (J.M.Andújar & F.Segura, 2009). As stated, an FCEV is also an electric car, but it generates energy by transforming hydrogen into electricity with a fuel cell (Figure 8). The hydrogen is pumped into the car similarly to an ICE vehicle and then stored in compressed tanks (Hwang & Varma, 2014). The car also has a small battery that is charged by regenerative braking, providing extra power to the engine (U.S. Department of Energy, n.d.).

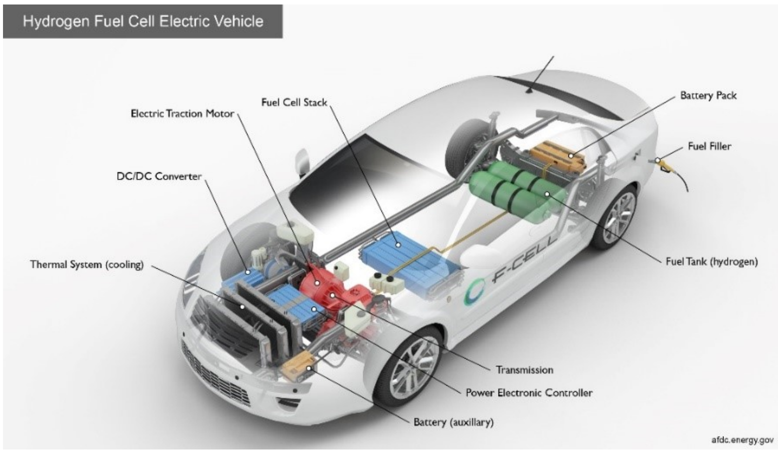


Figure 8 - Fuel Cell Electric Vehicle (U.S. Department of Energy, n.d.)

Europe is clearly behind in FECV investment compared to Asia and the USA. Asia has a market share of 66%, the USA has 27%, and Europe has only 7% of the FCEVs presently in circulation (Selmi, et al., 2022). In Europe in 2014, only 65 vehicles were sold, all of them for passengers. In 2018, there were 1,269 new registrations, of which 65% were for the passenger category, and the other categories were for light commercial vehicles, buses, and coaches. In 2021, 2,426 new registrations were recorded, and the passenger category remained dominant, with a market share of 84% (Figure 9). Even though hydrogen vehicles have experienced a pronounced growth (3,600% from 2014-2021), the numbers are still relatively modest compared to other categories (FCHO, 2022). Nevertheless, in the EU, some targets were defined, namely reaching 750 hydrogen refueling stations by 2025 (European Commission, 2017). Presently, roughly 200 stations are available (gplautogas.info, 2022). Large automakers, such as BMW and Audi, are investing in FCEV technology (Reuters, 2022), showing that FCEVs might have a promising future in Europe.

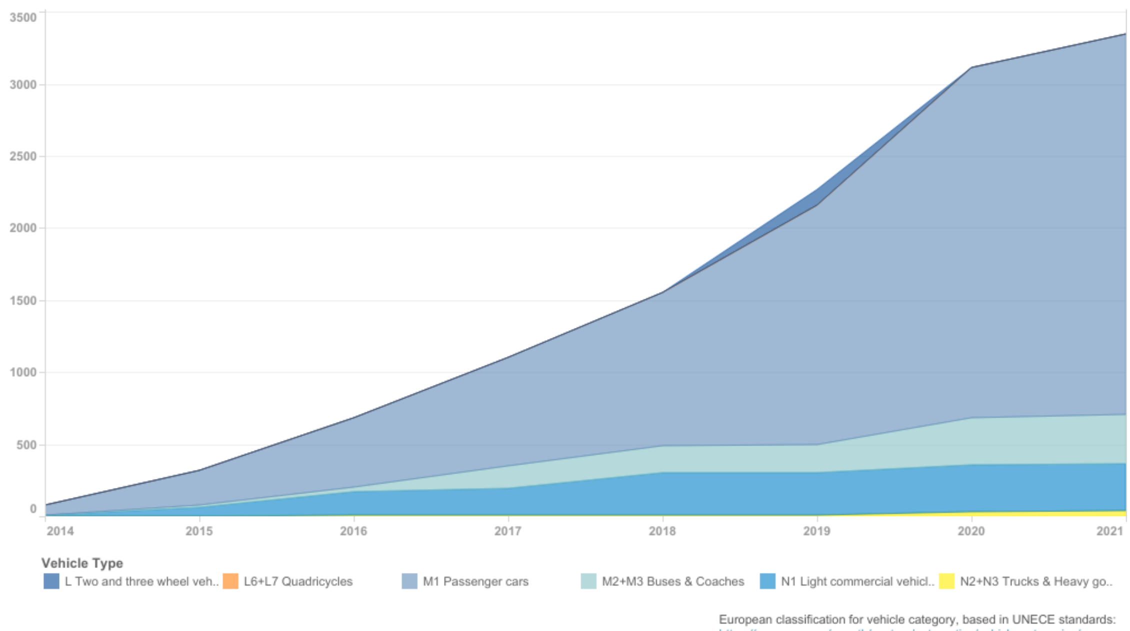


Figure 9 - Number of new FCEVs registrations by type in Europe (2014-2021) (FCHO, 2022)

Advantages and Challenges

Despite being less popular, FCEVs are a potential alternative to BEVs. Firstly, as already stated, both fuelling time and range are better for FCEVs when compared with BEVs. There is a range difference of almost 200km and similar refueling times as ICEs (Wróblewski, et al., 2021). This difference happens because even though BEVs are more efficient than FCEVs (Deloitte & Ballard, 2020), BEVs have much heavier batteries that need to store the maximum amount of energy possible. Also, since FCEVs have much smaller batteries, they are lighter and consume much fewer natural resources, namely Lithium, Cobalt, and Nickel.

Also, fuel cells are stationary when working, making them more reliable with no moving parts. This is coupled with low manufacturing costs (Pollet, et al., 2014). Regarding costs, at present, FCEVs are more expensive and have a higher TCO due to high hydrogen prices. However, a decline of about 44% is expected in Europe for hydrogen over the next ten years (Deloitte & Ballard, 2020). Drops in prices will likely be accompanied by significantly lower manufacturing costs (and consequently vehicle purchase prices) which would end up being 15% and 12% cheaper than BEVs in a 5- and 15-year TCO, respectively (Chen & Melaina, 2019).

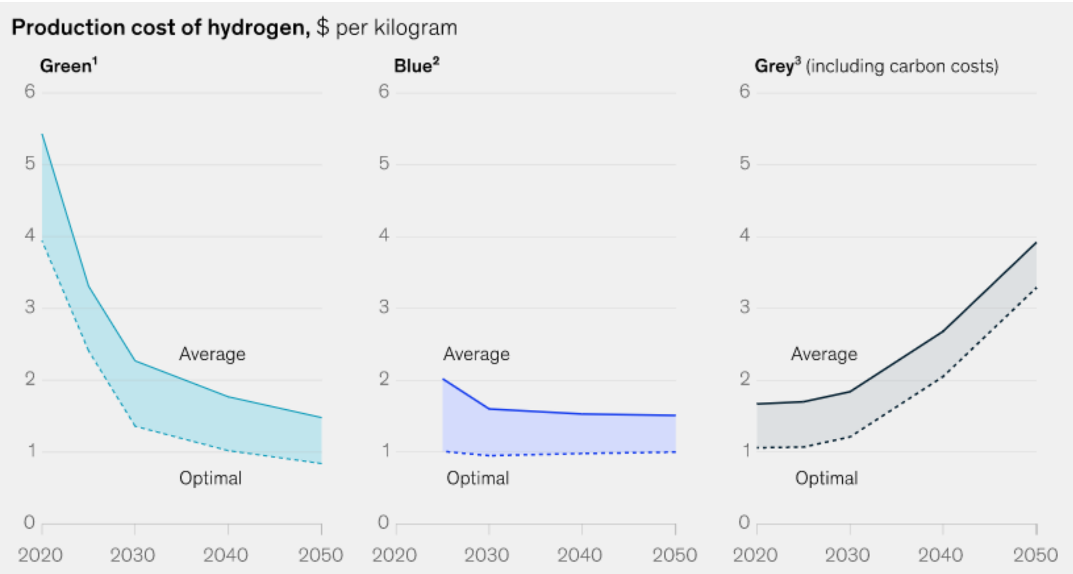


Figure 10 - Prediction of production cost of hydrogen by color (2020-2050) (McKinsey Sustainability, 2022)

On the other hand, FCEVs still face considerable challenges, some related to the nature of the technology and others to its early stage of development. Hydrogen continues to be expensive compared with fossil fuels or the cost of charging a battery, even though different production methods for hydrogen lead to price variances. Each production method has a color associated with it. Grey Hydrogen is produced by fossil fuels, the cheapest among the three types. Blue Hydrogen is where fossil fuels are also used, but GHG emissions are partially captured. Furthermore, Green Hydrogen is produced through renewable energy, *i.e.,* without harming the environment, and is the most expensive form (National Grid, n.d.) (Figure 10).

When it comes to energy efficiency, FCEVs are no match for BEVs. Green hydrogen is obtained via electrolysis, which is between 70-80% efficient (Mori, et al., 2013). Then with compression and transportation, another 10% is lost. Moreover, finally, the fuel cell itself is roughly 60% efficient (U.S. Department of Energy, 2015). In other words, for 1 kW of energy, a BEV gets 800 kW, and an FCEV gets 380 kW. Another challenge is the refueling infrastructure for these cars. This issue is often termed a “chicken-egg” problem since the lack of FECVs on the road means no steady hydrogen demand for these stations. At the same time, the lack of refueling stations is a barrier for consumers to acquire FCEVs (Caponi, et al., 2021). However, as was already stated, some changes should be expected with several hydrogen mobility projects in the works. Ultimately, the situation depends on public and private project funding (Hydrogen Council & McKinsey & Company, 2022). There are also the usual challenges of new technologies, such as lack of scale and awareness, public misconceptions, and risk aversion (Greene, et al., 2020).

Nevertheless, there is a niche where hydrogen will likely play an essential role in the future – for Heavy Duty Transport (McKinsey & Company, 2022). Long routes, strict driving time rules, and the importance of the weight of these vehicles accentuate BEVs’ challenges and FCEV opportunities with longer ranges, more minor and considerably lighter batteries, and less investment needed for refueling stations.

As technology grows in popularity, FCEVs still have an uncertain future. Growth depends on predicting consumer acceptance, and investments have a speculative side. Further investigation is required to understand the role of hydrogen in the future and its potential niches.

2.6 Recent Events

2.6.1 Covid-19 and Microchip Shortage

The Covid-19 pandemic had an enormous impact on most, if not all, industries around the world. The automotive industry was no exception. By February 2020, European sales had dropped 80% (McKinsey & Company, 2021). Despite this, sales have recovered from the pandemic. However, some lasting indirect pandemic outcomes are still affecting the industry, namely the global microchip shortage (MIT Management Sloan School, 2022), estimated to have cost $210 bn (AlixPartners, 2021). Apart from Covid, there were other aggravating factors, such as a lack of raw materials, diplomatic issues, and the growth of 5G technology, which require more chips than earlier generations (MIT Management Sloan School, 2022). Currently, there is no immediate solution, but it is predicted that demand will level off between 2023 and 2024 (Bain & Company, 2022)

2.6.2 Russia-Ukraine War

The war has also aggravated issues. It caused higher oil prices, inflation, and rising interest rates, all of which negatively impact demand. Additionally, since Russia hosts 34 auto manufacturing plants (KPMG, 2022), there was a disruption in supply. Regarding raw materials, Russia is the third most significant supplier of Nickel in the world, impacting the production of lithium-ion batteries. Furthermore, it is also a significant source of neon gas and palladium, which are also crucial for components of car parts (Sopra Banking Software, 2022). Overall, there was an increase in the prices of precious metals by roughly 20% (KPMG, 2022).

2.7 ENERGY SOURCES

The eventual transition from ICEs to EVs and Hybrids also requires changes in electricity production. In 2014, Europe's electricity share used by electric vehicles was approximately 0.03%, which is predicted to reach 4-5% by 2030 (European Environment Agency, 2016). This implies increased energy production in Europe. Additionally, electricity production must come from renewable sources to fight GHG emissions effectively. Looking at electricity generation in 2020, nuclear power and gas were still the most common sources (these account for 24.6% and 20.1%, respectively), with gas increasingly used and nuclear power declining. Wind power and hydropower are next, with both making up roughly 14%, showing an increasing trend. Solid fuels accounted for 12.6%, with a negative slope of almost 50% between 2014 and 2020 (PORDATA, 2022) (Figure11). Even though progress is being made, roughly 60% of European electricity comes from non-renewable sources (although nuclear energy does not cause GHGs, it still produces nuclear waste) (U.S. Energy Information Administration, 2022).

Hydrogen is produced either by fossil fuels or water electrolysis. As mentioned above, it is classified into different colors according to how it was produced. Green hydrogen is manufactured by electrolysis sourced from renewable sources (without creating GHGs). Blue hydrogen, or "low-carbon hydrogen," is mainly obtained through natural gas and with reduced CO2 emissions due to carbon capture systems. Grey hydrogen has a similar process but without the capturing process (National Grid, n.d.). Currently, hydrogen accounts for less than 2% of Europe's energy (mainly being used for chemical products like fertilizers), and only approximately 4% of this can be denominated as "green" (European Comission,

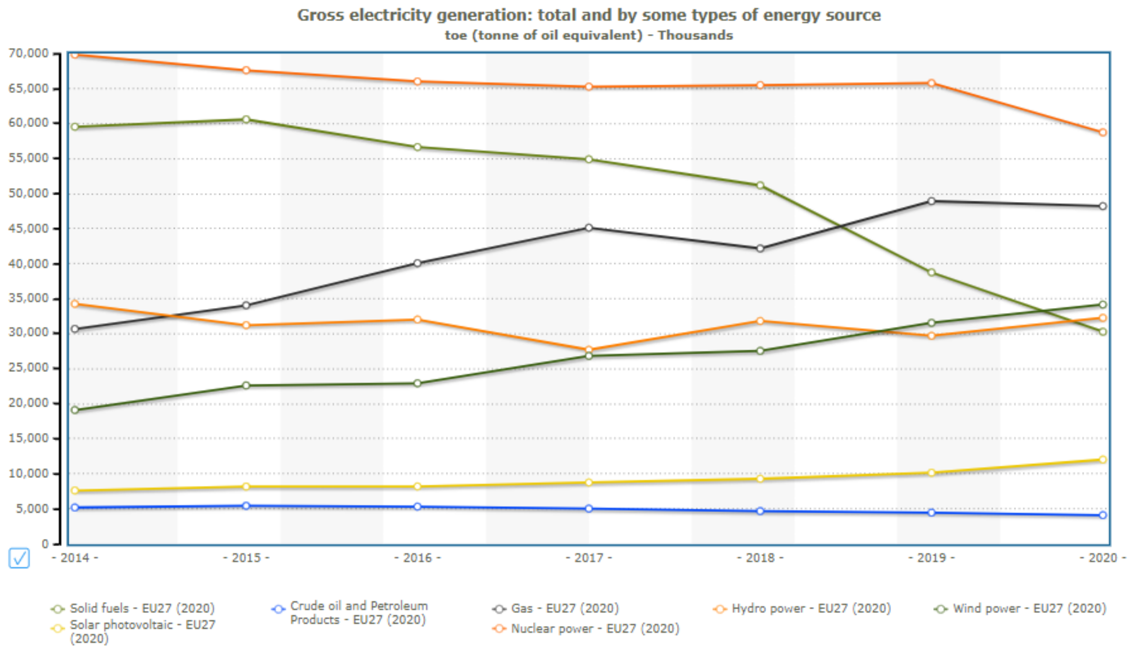


Figure 11 - Gross electricity generation and by (main) types of energy source in the EU27 (2014-2020) (PORDATA, 2022)

2022). Green hydrogen production is considerably more expensive than other forms due to the electricity consumed in electrolysis (Sojoudia, et al., 2021). However, due to the increasing interest, demand for electrolyzers is rising while prices are decreasing, helping decrease green hydrogen costs (S&P Global, 2021).

2.8 Management Theory

Technology Acceptance Model (TAM)

The Technology Acceptance Model (Davis, 1989) is widely used to predict technology acceptance. Initially, the model was applied to employee acceptance of organizational software. The model has since been expanded and is applied to other technologies, elaborating variables that predict user acceptance (Chau, 1996).

Davis derived a psychological-based theory (Marangunić & Granić, 2015), the Theory of Reasoned Action (TRA) (Ajzen & Fishbein, 1972), which links influence that creates intentions to action.

TAM (Figure 12) states that Perceived Usefulness (PU) – is "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989). Perceived Ease of Use (PEOU) – is "the degree to which a person believes that using a particular system would be free of effort (Davis, 1989)" and is the decisive variable when predicting user attitudes toward technology adoption. Following the model, PEOU influences PU since a technology that is easy to use is also more helpful.

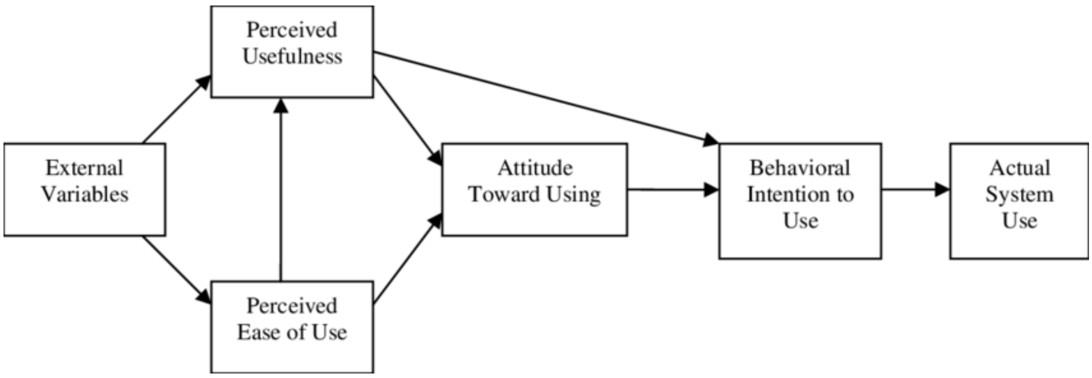


Figure 12 - The Technology Acceptance Model (Davis, 1989)

As mentioned, TAM has had further iterations. The Car Technology Acceptance Model (CTAM) (Osswald, et al., 2012) was an extension applied to the automotive industry to determine the Unified Technology Acceptance and Use of Technology (UTAUT) (Venkatesh, et al., 2003) (Figure 13). This model integrated elements from several other models and has five elements – Performance Expectancy, Effort Expectancy, Facilitating Conditions, Social Influence and Behavioural Intention to use technology. It also included age, gender, the voluntariness of use, and experience as moderators, but these are often dismissed for understanding (Osswald, et al., 2012).

CTAM further added *Attitude Towards Using Technology* - "aims at reflecting the beliefs of the user regarding system usage and its effects," *Anxiety* – "the degree to which a person responds to a situation with apprehension, uneasiness, or feelings of arousal," *Self-Efficacy* – "a person's belief in his/her ability and competence to use a technology to accomplish a particular task," and *Perceived Safety* – "the degree to which an individual believes that using a system will affect his or her well-being" (Osswald, et al., 2012).

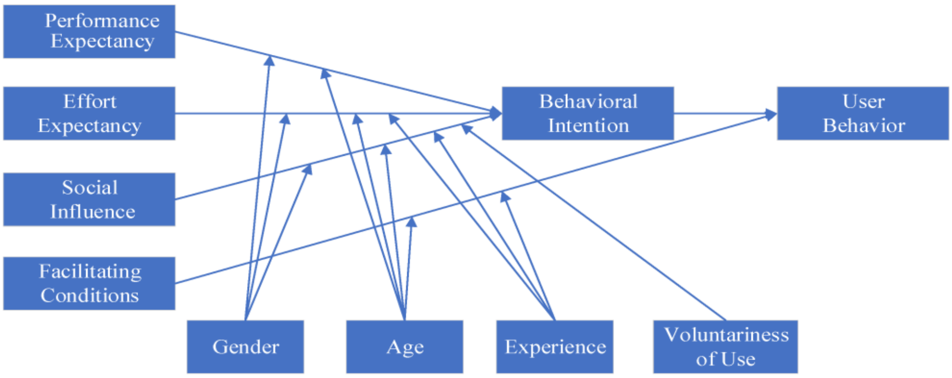


Figure 13 - Unified Technology Acceptance and Use of Technology (Venkatesh, et al., 2003)

3 Methodology

3.1 Research Design

The fundamentals associated with the industry, such as natural resources, available infrastructure, and technological advancement, represent a challenge for a reliable prediction about the future of energy transition in the automotive industry. Thus, after the literature review, which described the industry's current state with the positives and negatives of each main power train technology, this research explored uncertainties surrounding critical factors about the industry's future. Scenario Planning (Schoemaker, 1995) was used to analyze these different uncertainties to reach three different scenarios.

3.1.1 Scenario Planning

Scenario Planning (Schoemaker, 1995) is a strategic tool to predict the medium and long-term future under specific conditions (Lindgren & Bandhold, 2016). It is mainly used to build up different plans for an uncertain future. This way, there is a learning process that prepares one for and increases awareness of eventual extraordinary events, trends, and strategic moves of potential competitors.

Firstly, the scope needs to be defined. The main topic, time frame, and stakeholders are defined during this stage. Afterward, there is the search phase, where literature is reviewed, and industry professionals and other stakeholders from various segments and organizations are interviewed (Schoemaker, 1995).

After the data-gathering phase, the main uncertainties that might affect the organization's or industry's future are assessed. After that, the scenarios are constructed based on correlations between uncertainties in a positive, base, and negative scenario (Schoemaker, 1995).

3.2 Data Collection

3.2.1 Primary Data Collection

Semi-structured interviews

A semi-structured interview is a valuable tool for collecting data in qualitative research (Adams, 2010). Most of the data was obtained from experts in the automotive industry and industries directly related to the energy transition. The experts were selected so that a range of different roles and specialties were inquired, preventing eventual biases in the analysis. In a posterior phase, three second-order interviews were made to validate the built scenarios and their probabilities. The list of interviewees included consultants specialized in the industry, NGO directors, and experts in the automotive and energy sector.

Consumer survey

Consumer acceptance plays a key role when technological innovations are introduced in the market (Herbig & Day, 1992). The adoption of new types of vehicles depends on consumers' acceptance level UTAUT model suggests that four factors drive behavioral intention. Performance expectancy, effort expectancy, social influence, and facilitating conditions. However, researchers suggest that other determinants affect behavioral intention when applying this model to the automotive sector, specifically BEVs. Among these, the following were selected: hedonic motivation (Manutworakit & Choocharukul, 2022), financial incentives (Li & Zhao, 2017), and price (Venkatesh, et al., 2012). Each determinant's influence on behavioural intention was tested with a hypothesis (Table 1). In this case, the actual use was not assessed for its redundancy with the behavioral intention determinant since the scenario presented in the survey was purely theoretical and had scope for future acquisition of BEVs (Figure 14).

A 5-point Likert Scale was used to assess the behavioral intention of each consumer (Preedy & Watson, 2010). Each determinant value was obtained from an average of the answers associated with that same determinant.

In the second and third sections, actual price comparisons between 2 models, a BEV and an ICE of the same brand with similar characteristics, and financial incentives were added to assess a realistic reaction to both determinants.

The survey collected 273 answers in total. It was distributed via LinkedIn, Facebook, Reddit, Instagram, and WhatsApp.

Hypothesis	Relationship tested
H1	*Performance Expectancy has significant effects on the Behavioural Intention of the system*
H2	*Effort Expectancy has significant effects on the Behavioural Intention of the system*
H3	*Social Influence has significant effects on the Behavioural Intention of the system*
H4	*Facilitating Conditions has significant effects on the Behavioural Intention of the system*
H5	*Hedonic Motivation has significant effects on the Behavioural Intention of the system*
H6	*Financial Incentives has significant effects on the Behavioural Intention of the system*
H7	*Price has significant effects on the Behavioural Intention of the system*

Table 1 - Selected hypotheses

3.2.2 Secondary Data Collection

Secondary data was obtained from journal articles, scientific papers, consultancy firms' reports, and European public projects' reports to consolidate the knowledge obtained through interviewing experts and surveying consumers.

Methodology	
Primary Data	Secondary Data
- Expert Interviews (n=15) - Consumer Survey (n=273)	- Journal Articles - Consultancy Firms Reports - European Projects Reports

Table 2 - Primary and Secondary Data Sources

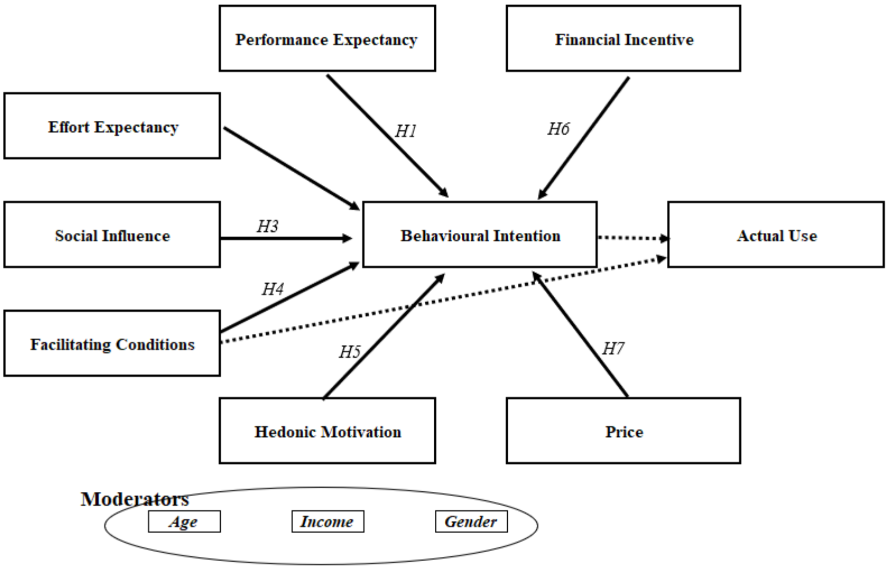


Figure 14 - Used model for hypotheses testing

4 ANALYSIS & FINDINGS

4.1 EXPERT INTERVIEWS

The interview findings were clustered into six groups. In each topic, subtopics were selected and classified according to the agreement of each expert.

#	Name	Country	Role and Company
I	Marcos Paulo Schlickmann	Portugal/Brazil	Manager at Deloitte (Future of Mobility and Smart Cities)
II	Luís Martins	Portugal	Technical Expert in Electric Mobility at EDP
III	Diogo Almeida	Portugal	Head of Business Development for Hydrogen at Galp
IV	Nuno Marques	Portugal/Spain	Iberian Director at Citröen
V	Doron Myersdorf	Israel	CEO and Co-Founder at Storedot (battery charging unicorn)
VI	André Botelho	Portugal	Head Energy Storage & Flexibility at EDP Inovação
VII	António Lobo	Portugal	Senior Researcher and Teaching Assistant and Porto University
VIII	Filipe Nunes	Portugal	Product & Planning Manager at Hyundai Portugal
IX	Eloísa Macedo	Portugal	Ph.D. Researcher in low carbon and sustainable mobility at Aveiro University
X	Alberto Lima	Germany/Brazil	Country Sales Manager at Hyundai Germany
XI	Rui Vieira	Portugal	Head at Electric Mobility at Galp
XII	Ana Casaca	Portugal	Head at Innovation at Galp
XIII	Mafalda Martins	Portugal	CFO at Mobi. E
XIV	Pedro Gouveia	Portugal	Commercial Lead at Galp
XV	Eurico Correia	Portugal	Innovation for Renewables Specialist at Galp

Table 3 - Interviewed Experts

Environmental Impact

The main driver for the energy transition in the automotive industry (and all industries in general) is decarbonization (All Experts). However, the impact of new solutions such as BEVs is unknown (Expert VI, Expert VII, Expert IX, Expert X, Expert XI), especially regarding mineral extraction, where it is uncertain whether human rights and environmental guidelines are being followed. The same issue exists in the disposal phase, where battery recycling is still in an early stage of development. Because of this, experts are still uncertain if this method can be sufficiently efficient to reduce the impact of battery disposal and if these are valuable sources of raw materials for new batteries (Expert VI).

Environmental impact

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	Ratio
Transition motivated by decarbonization	X	X	X	X	X	X	X	X	X	X	X	100%
BEVs enviornmental impact to be discovered						X	X		X	X	X	45%

Table 4 - Environmental Impact Interviews Outputs

Batteries and their limitations

Batteries arose as a crucial product in producing BEVs. However, this technology has several limitations that prevent the BEV from being the "perfect solution" for the automotive industry. The first is the range of these batteries, which is lower than those of ICE vehicles and a cause of "range anxiety" (Expert I, Expert VI, Expert IX). This happens because of the low energy density ratio of the batteries, which are usually deemed too heavy and oversized (Expert III, Expert V). Lithium-ion batteries are the most used, which use rare metals for their production. Since the availability and the mining speed of these are limited, bottlenecks have been appearing, causing supply shortages (Expert II, Expert IV, Expert V, Expert VII, Expert VIII, Expert IX, Expert XI). The development of new battery chemistries is a potential solution, but penetration of these in the market may take a long time (Expert VIII). Battery recycling is also seen as a possible (and necessary) alternative. However, since most batteries did not finish their life cycle, the efficiency of this process was not assessed (Expert II, Expert IV, Expert IX).

Batteries and their limitations

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	Ratio
Uncertainty with Battery resources availability		X		X	X		X	X	X		X	64%
Uncertainty with new battery solutions		X	X		X		X		X		X	55%
Recycling supply chain will not be ready				X	X	X	X		X		X	55%
BEVs autonomy is expected to increase	X	X						X				27%
Range anxiety as main issue in BEVs	X					X			X			27%
Battery recycling as solution for resource shortage		X		X					X			27%
BEVs batteries are too heavy			X		X							18%

Table 5 - Batteries and their Limitations Interviews Outputs

Delivery Issues

As was stated, one fundamental uncertainty is whether supply will match the demand for BEVs. Experts suggest that it is an unavoidable problem for the future to depend on other factors such as technological evolution and political trade wars (Expert I, Expert III, Expert IV, Expert V, Expert VI, Expert VII, Expert VIII, Expert X). Another factor is the misalignment between car and battery-producing companies and mining companies. Experts suggest integrating mining companies as an essential part of these companies' value chain, which is not happening except for some companies like Tesla (Expert V, Expert XI).

Delivery issues

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	Ratio
Demand will be higher than offer	X		X	X	X	X	X	X		X		73%
Heterogeniety of infraestructure within Europe								X		X	X	27%
Misalignment between mining and car companies					X						X	18%

Table 6 - Delivery Issues Interviews Outputs

Hydrogen and FCEVs

FCEVs have several issues that might be hindering their development in the next ten years. Hydrogen has an intrinsic issue with its efficiency (Expert I, Expert II, Expert IV, Expert V, Expert VII, Expert XI). Its need for transport means a loss of efficiency in the production (that already utilizes electricity), compression process, and transport itself. This means that when the hydrogen is pumped into the car, it has already lost a significant stake in its efficiency. Besides, green hydrogen still has problems with its cost, mainly because of the cost and lack of scale of electrolyzers, which use renewable energy as a source, and are currently the only ecologic way of producing hydrogen (Expert I, Expert II, Expert III, Expert IX, Expert X, Expert XI). Poor infrastructure in most of Europe was seen as another reason for the lack of current investment in hydrogen (Expert I, Expert II, Expert III, Expert IV, Expert V, Expert VII, Expert VIII, Expert X, Expert XI). Nevertheless, the number of refueling stations is expected growth through both private initiatives and public sector support. FCEVs, however, bring advantages compared to BEVs in specific sectors where the distances are longer.

Hydrogen and FCEVs

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	Ratio
FCEVs weak non-existent infraestructure	X	X	X	X	X		X	X		X	X	82%
Hydrogen/FCEVs are inneficient	X	X		X	X		X				X	55%
Uncertainty with cost of Green Hydrogen	X	X	X						X	X	X	55%
Several hydrogen stations will open			X									9%

Table 7 - Hydrogen and FCEVs Interviews Outputs

Heavy-duty transport, buses, and other niches

Most experts suggest that FCEVs will not be useful in the light passenger vehicle sector. However, the disadvantages of fuel cells associated with this sector tend to be alleviated where longer distances and fixed routes are traveled (Expert I). As a result, most experts predict a penetration of hydrogen in heavy-duty transport, where longer routes and lighter batteries are essential, and for buses, where weight is also substantial and vehicles are operating continuously, taking advantage of short refueling times and fixed routes (Expert I, Expert II, Expert III, Expert V, Expert VI, Expert VIII, Expert XI). The only niche where experts see a likely penetration for light passenger cars is car rentals (for travelers who seek to be independent while traveling long distances) and taxis due to their continuous operation (Expert III, Expert VI, Expert VIII, Expert X, Expert XI). With fixed routes, it is easier to build refueling stations strategically and avoid high infrastructure costs (Expert VIII). However, some experts disagree, arguing that there is more investment in heavy-duty (BEVs) despite their disadvantages, showing that FCEVs will not have a place in the heavy-duty sector in Europe in the next ten years (Expert I).

Heavy duty transport, buses and other niches

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	Ratio
FCEVs for heavy-duty transport and buses	X	X	X		X	X		X			X	64%
FCEVs for taxis and car rental			X			X		X		X	X	45%
There are more heavy duty BEVs than FCEVs		X	X								X	27%
BEVs and ICEs as solution for heavy-duty	X											9%

Table 8 - Heavy-duty Transport, Buses and other niches Interviews Outputs

Key Players and Trends

The energy transition process in the automotive industry is not only a responsibility of companies in the sector. Governments and regulators are vital players. In fact, they are the entities that were the catalyst, pushing energy transition with the ICE vehicle ban in the EU from 2035 on. Experts consider these players crucial for the support of the transition. Since BEVs and hybrids are not competitive with ICEs, prices are out of reach for most of the population. Thus, governments have been supporting consumers with tax incentives, buying discounts, and free charging, for example. Another common public investment target is infrastructure. However, some experts suggest this intervention is excessive and is creating a dependency of producers and consumers on public funding (Expert I, Expert VIII, Expert IX). They argue that the market could reach environmentally friendly solutions without public aid since consumers' environmental awareness is also increasing. They also claim that the energy transition was pushed too early and as an illogical reaction to the Volkswagen scandal[2]. The argument is that there was room for ICE technology to develop solutions that were cheaper and less polluting, but the industry was hit with a sales ban. Nevertheless, most experts agree

[2] "In September 2015, German car manufacturer Volkswagen came under fire after admitting defective devices were installed on 11 million vehicles to cheat on emissions tests" (MSCI, n.d.)

that public aid is essential (Expert II, Expert IV, Expert V, Expert VI, Expert VIII, Expert IX, Expert X, Expert XI).

The geopolitical situation is also important for the industry. Right now, Chinese companies comprise 56% of the BEVs battery market (Elements - Visual Capitalist, 2022) and 8% of rare metals imported by the EU (European Commission, 2020). In matters of political tension where China is usually on the opposing side of the EU, the West can be held hostage (Expert IV, Expert V, Expert VI, Expert VIII, Expert IX, Expert XI). This resource dependency jeopardizes the energy transition. At the same time, it may be pushing Europe towards technological alternatives, such as new battery chemistries and business models, in the next ten years (Expert VIII). On the other hand, with their centrally planned economy and fewer bottlenecks than European companies, the Chinese are already entering the European automotive market with generally cheaper vehicles and optimized delivery (Expert VIII).

PHEVs and HEVs are expected to lose relevance and eventually become obsolete because of their inefficiency and for still being sources of pollution as well as due to the loss of incentives in several European countries (Expert VII, Expert VIII, Expert IX).

The “less is more” philosophy is being followed by some companies to decrease production costs and democratize access to BEVs. There are already concept cars being developed and tests being carried out so that in the following years, solutions like these can come to market (Expert IV).

Key Players & Trends

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	Ratio
Governments crucial for infraestructure and cars incentive		X		X	X	X		X	X	X	X	73%
China as main player				X	X	X		X		X	X	55%
Trade wars and political tension				X	X	X		X	X		X	55%
Governments interfere too much	X							X	X			27%
Autonomous driving impactful for ET			X			X	X					27%
ET pushed to soon				X				X	X			27%
Plug-in hybrids will become obsolete							X	X	X			27%
Cars will loose functionalities for lower prices				X								9%

Table 9 - Key Players & Trends Interviews Outputs

4.2 SURVEY ANALYSIS

From the 273 answers collected, 244 were used, and 29 answers were excluded for being incomplete or out of Europe. Data analysis was conducted using RStudio.

Analysis and Results

Figure 15 presents the summary of the demographic data of respondents. Most respondents were female, roughly 58%. Regarding the country of residency, the vast majority lived in Portugal (82%). 1001€-2000€ was the most selected interval of monthly income, followed by 2001€-4000€. Finally, the age data was quite balanced, with the most common being 55-64 years.

The car characteristics displayed throughout the study were of a Peugeot 208 vs. a Peugeot e208 in Portugal (where the prices are close to the average over Europe). This means that both models are highly similar except for the engine, where one is electrical, and the other is an ICE. When asked about the cost of the BEV (32,000€), only 19% of the respondents agreed or strongly agreed with the price (Figure 16).

After the first question about the price, the respondents were presented with a new price that included a subsidy of 4000€ (the value given by the Portuguese state for the purchasing of a BEV) (Ambiente e Ação Climática - Gabinete do Ministro, 2022). The new value of 28000€ for the BEV was better accepted, with 56% agreeing or "strongly agreeing" with the new price.

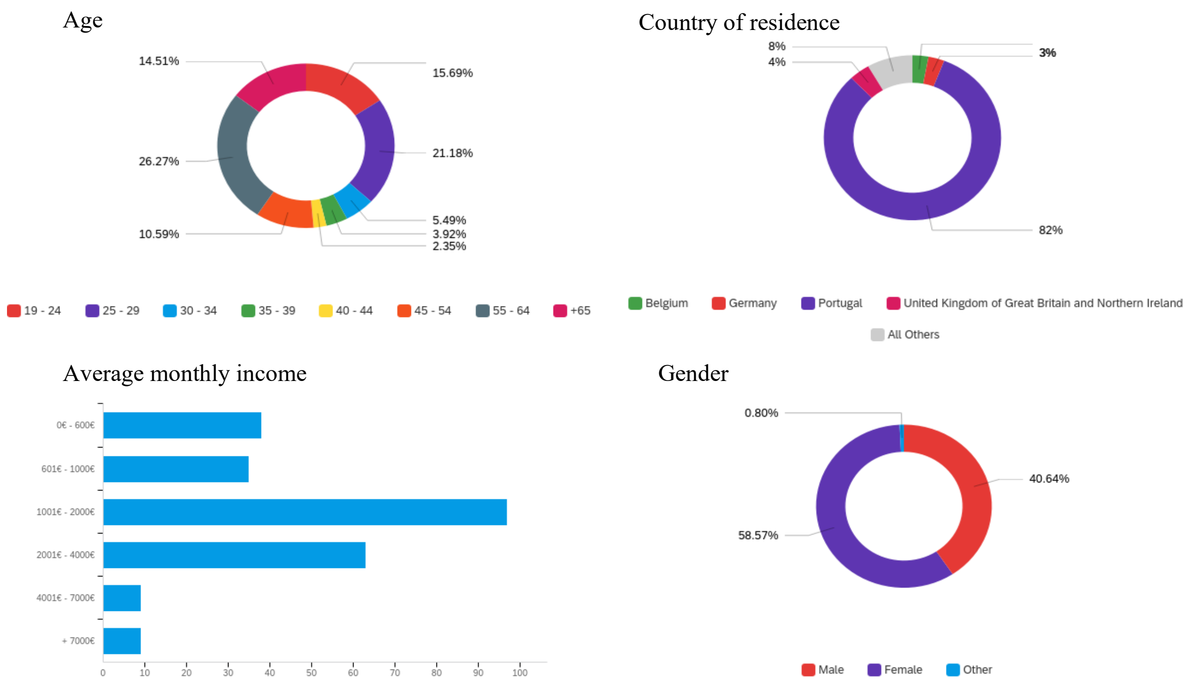


Figure 15 - Survey demographical data

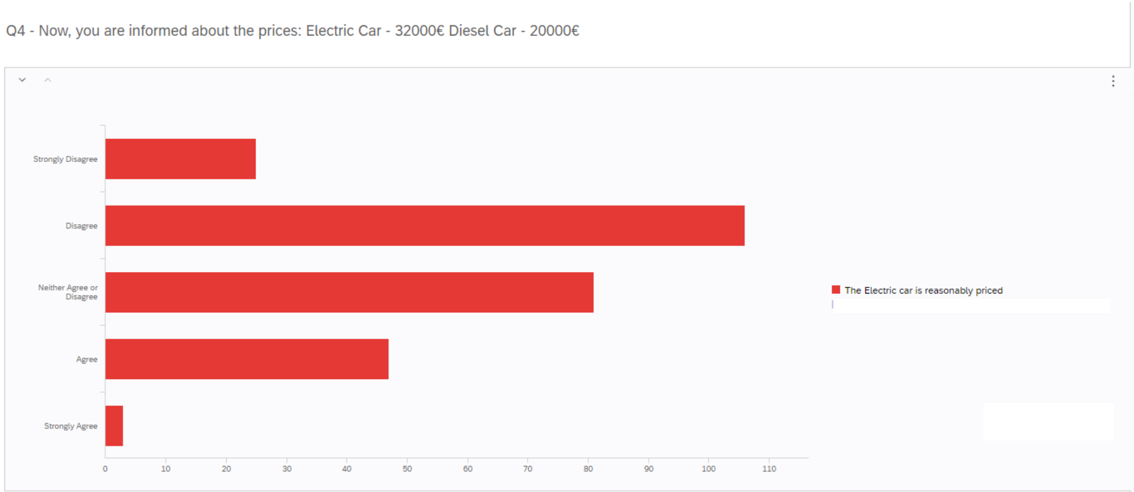


Figure 16 - Agreement with the affirmation "Is the electric car correctly priced?"

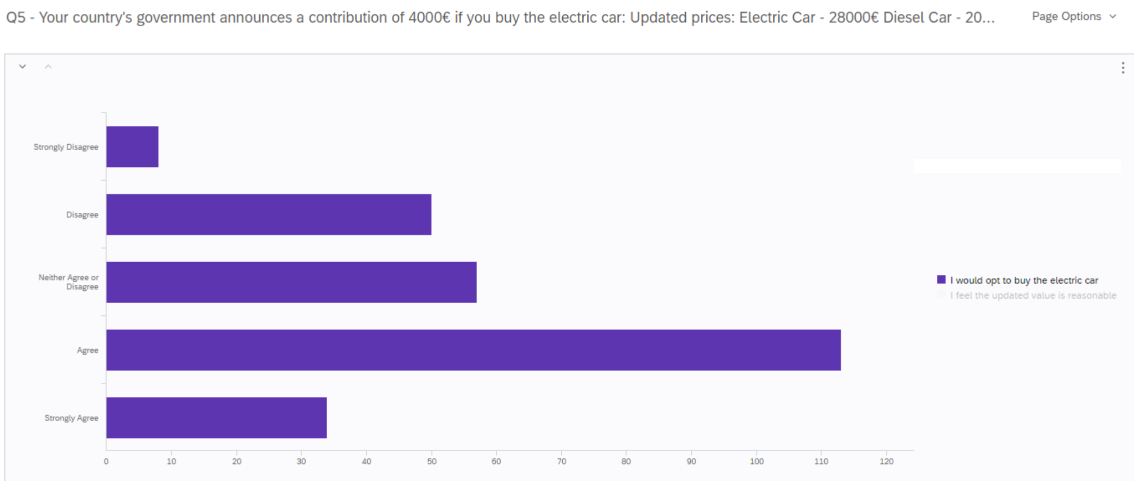


Figure 17 - Agreement with the affirmation "Is the electric car correctly priced?" after public funding

Table 9 displays the summary statistics of the determinants used in the hypotheses testing analysis. Two behavioral intention determinants were created: an actual price of a BEV was neither disclosed nor any financial incentives (Behavioural_Intention1), and one where both were (Behavioural_Intention2).

Summary Statistics

Statistic	Mean	St. Dev.	Min	Pctl(25)	Median	Pctl(75)	Max
Performance_Expectancy	3.717	0.703	1	3.3	3.7	4	5
Effort_Expectancy	3.889	0.747	1.500	3.500	4.000	4.500	5.000
Facilitating_Conditions	4.321	0.911	1.000	4.000	5.000	5.000	5.000
Hedonic_Motivation	3.101	0.845	1.000	2.500	3.000	3.500	5.000
Social_Influence	3.704	0.775	1.000	3.500	4.000	4.000	5.000
Price	4.358	0.744	1.000	4.000	4.000	5.000	5.000
Behavioural_Intention1	3.561	0.956	1.000	3.000	3.500	4.000	5.000
Financial_Incentive	3.123	1.043	1	2	3	4	5
Behavioural_Intention2	3.439	1.023	1	3	4	4	5

Table 10 - Summary statistics

When testing the pre-established hypotheses, not all were deemed to significantly affect the behavioural intention of a consumer to use a BEV. Table 10 presents the values of the variables that significantly affected behavioural intention. Hedonic Motivation had a significantly negative effect on behavioral intention with a p-value smaller than 0.01. Also, the result of this determinant, on average, had more impact on male respondents. This effect may connect to factors that label electric vehicles “boring.” This may also be related to the lack of noise or the fact that the most popular motorsport competitions like Formula 1, NASCAR, or IndyCar still use ICEs (and there are no indications of this changing any time soon). With a significance of 0.05, Performance Expectancy also affected the behavioural intention to buy a BEV. As suggested by several experts, Financial Incentives were also considered to affect the dependent variable with a significance level of 0.1. Although, again, the effects of Financial Incentives seemed more relevant for male respondents in their behavioural intention than female respondents.

On the other hand, as expected, Price harmed consumers’ intentions. In other words, consumers who agree that price is a decisive factor for acquiring a BEV tend to have a lower behavioral intention, proving correct those experts who believe that BEV prices will be a key determinant of the future of Energy Transition. Of the three moderators (age, gender, and income), only gender had a significant influence.

Ultimately, consumer perception corresponded to most of the experts' main concerns. Price was several times mentioned as a barrier to the democratization of BEV as a “mainstream” technology, which was confirmed in the survey. Financial Incentives also were significant, reiterating the importance of public support already suggested (Expert II, Expert IV, Expert V, Expert VI, Expert VIII, Expert IX, Expert X, Expert XI). The factor “Facilitating Conditions” did not show significant results, where the question was related to the necessity of infrastructure. Nevertheless, the answers were related to the infrastructure nowadays, meaning that infrastructure needs to keep growing as the number of BEVs also increases.

	Dependent variable: Behavioural_Intention2
Performance_Expectancy	0.826**
	(0.367)
Hedonic_Motivation	-0.677***
	(0.251)
Price	-0.565**
	(0.247)
Financial_Incentive	0.345*
	(0.181)
Hedonic_Motivation:male	0.370**
	(0.167)
Financial_Incentive:male	0.217*
	(0.117)
Observations	239
R2	0.426
Adjusted R2	0.340
Residual Std. Error	0.834 (df = 207)
F Statistic	4.960*** (df = 31; 207)
Note:	*p<0.1; **p<0.05; ***p<0.01

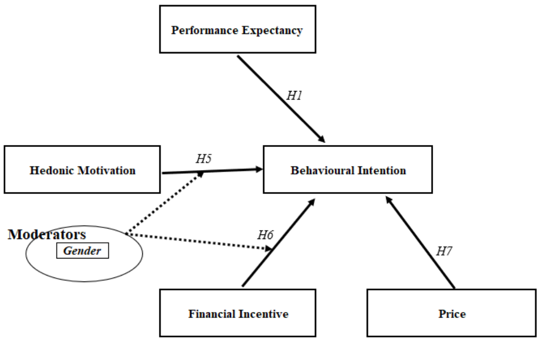


Table 11 – Linear Model for hypotheses testing

5 Discussion

5.1 The future of energy transition in the automotive industry

To answer the research question, it is necessary to elaborate on how the industry may change and suggest factors on which this depends. For this, three scenarios were developed – positive, base, and negative[3]. As a positive scenario, we considered where energy transition in the automotive industry is a priority in Europe and where the global political tension alleviates. Both factors are related since some events, such as the Ukraine-Russia war and the trade war between the USA and China, have been raising energy prices (Zakeri, et al., 2022), meaning higher productions costs and increased difficulty accessing resources such as minerals to build batteries and electrical components (Expert IV, Expert V, Expert VIII).

5.1.1 Stakeholders

Stakeholder definition

A stakeholder is any entity with a relevant interest in a specific activity or project (McGrath & Whitty, 2017). Including the stakeholder in scenario planning is crucial to increase the knowledge of the industry and the factors that might affect its future and, eventually, to plan

[3] Scope definition of the scenarios in *Appendix B - Scenario Planning Scope Definition*

strategies based on the scenarios established (if the scenario applies to an organization) (Andersen, et al., 2021).

Primary Stakeholders

Primary Stakeholders are agents that participate continuously in a corporation's activity and on which the corporation's success is dependent (Clarkson, 1995), having a solid and direct influence on the future of energy transition in the automotive industry (Donaldson & Preston, 1995).

Regulators: Regulators are very influential stakeholders in the automotive industry since they can create rules and policies to reach goals such as reducing GHG emissions. The prime example of this is the prohibition of ICE vehicles sales from 2035 on in the European Union, enforced by the European Commission, which is the main lever for the energy transition in Europe's automotive industry (Expert IV, Expert VII, Expert VIII, Expert IX)

Automotive Companies: Automotive Companies have a central role in the industry. They are responsible for providing new technologies that meet customers' and other stakeholders' requirements. Their ability to establish new supply chains, articulate with suppliers, invest in charging/refueling infrastructure, to provide new technologies at affordable prices will have a determinant role in the future of the industry (Expert II, Expert IV, Expert V, Expert VII)

Battery Producers: Battery producers are critical players in the importance of the battery as a commodity in the future success (or unsuccess) of BEVs and FCEVs. Many uncertainties in the market are related to the development and evolution of batteries' range, energy density, usage of more abundant minerals, and price. (Expert I, Expert II, Expert III, Expert V, Expert VI, Expert XI)

Consumers: The increasing environmental awareness of consumers in Europe is also an essential driver for the increasing investment of companies and governments in the energy transition of automotive vehicles. Indeed, the demand levels for BEVs will likely be higher than the supply in the following years. (Expert I, Expert IV, Expert VI, Expert VII)

Governments: The energy transition is also the responsibility of governments. Governments are usually responsible for incentivizing purchases of more ecologic solutions such as BEVs and FCEVs for companies and individuals (Expert V, Expert VI, Expert VIII, Expert X, Expert XI). The contribution of public entities to increasing infrastructure and creating ecosystems is also significant.

Secondary Stakeholders

Secondary Stakeholders are those that have an indirect impact on an organization or industry. These might also connect with primary stakeholders (Scheijndel, et al., 2021).

Mining Companies: Mining companies are essential stakeholders for their influence on batteries' price and environmental and social impact. Experts suggest that some of the BEVs' delivery issues, related to the lack of materials to build batteries, are also caused by a lack of coordination between car companies and mining companies (Expert V, Expert XI).

Energy Producers: Energy producers play a crucial role in the automotive industry. The success of FCEVs is highly dependent on green hydrogen prices, which depend on how much these producers can scale them (Expert III). Also, BEVs' environmental impact depends on how the electricity they are charged with is produced (Expert I).

Influencers

Influencers are agents that are not involved in the value chain of a corporation but can influence decisions and affect stakeholders' vision (Miller & Lewis, 1991).

Media: Media is an important agent since it provides information about new technologies and their eventual drawbacks. It can influence consumers' opinions and perceptions of the automotive industry's new technologies (Expert II, Expert VII).

Thought Leaders and Industry Experts: As an industry facing many changes and uncertainties, the automotive sector keeps being guided by trends and philosophies often portrayed by influential personalities. Elon Musk is the top of mind, but other concepts such as Citröen Ami and Oli (that have the objective of democratizing BEVs) (Citröen, 2022) are proof of the importance of these stakeholders for the future (Expert IV).

5.1.2 Uncertainties

Experts agree that an energy transition is happening. This is due to several reasons, such as the ICE vehicles sales ban from 2035, growing environmental awareness, etc. However, there are uncertainties about factors that may influence this future. Hydrogen's success depends on how efficient it is, its levels of consumption, and so forth (Expert II). BEVs are unanimously the future of passenger cars. However, some barriers to expansion may or may not be surpassed in the future, namely several bottlenecks. The availability of mineral resources affects not only new and better types of batteries (with other types of minerals and energy density) (Expert II, Expert VI, Expert VIII) but is also shaped by political events that slow down globalization and open commerce (Expert IV, Expert V, Expert VI, Expert XI). At the same time, these bottlenecks may enable Chinese brands to penetrate the European market with more products and competitive prices (Expert VIII). All these factors affect the future gap between demand and supply that already exists (Expert I, Expert III, Expert IV, Expert V, Expert VI, Expert VII, Expert VIII, Expert X). Available infrastructure is an uncertainty that is considered vital. It depends on private investment from energy producers, automotive companies, and public entities (Expert V, Expert VIII, Expert XI). Government support is essential for the whole energy transition, where the infrastructure is included in every specific city project, such as building hydrogen ecosystems (Expert X).

To assess the correlation between these uncertainties, affirmative questions were asked. When two questions positively affected each other, their correlation was also positive (+). These can also be non-related (0) or negatively correlated (-). Table 13 presents the behavior of each uncertainty in each scenario on a scale of 1-3, with 1 being a low probability of a positive answer and 3 a high probability of a yes answer.

U_1 = Will there be new battery chemistries that avoid minerals with limited supply?
U_2 = Will hydrogen consumption become more efficient?
U_3 = Will batteries improve its energy density?
U_4 = Will governments support hydrogen ecosystems?
U_5 = Will BEVs price decrease and become competitive with ICE vehicles?
U_6 = Will infrastructure for charging and refuelling rise at scale?
U_7 = Will Chinese brands penetrate successfully in the European market?
U_8 = Will trade wars and political tensions alleviate?
U_9 = Will the offer level the demand for BEVs?

Technology	U_1	U_2	U_3	
Public Support	U_4			
Market	U_5	U_6	U_7	U_9
International Relations	U_8			

	U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8	U_9
U_1		0	+	-	+	0	-	-	+
U_2			0	+	0	+	0	0	0
U_3				+	-	+	+	0	0
U_4					-	+	0	-	-
U_5						+	+	+	+
U_6							+	+	+
U_7								+	+
U_8									+
U_9									

Table 12 -Key Uncertainties and Correlation Matrix

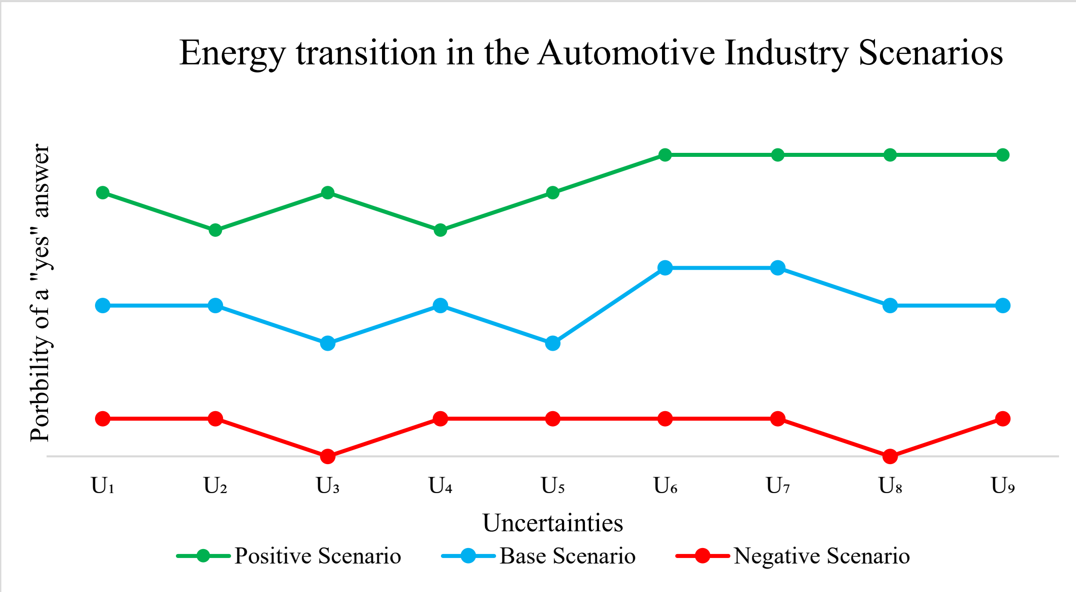


Table 13 - Profile of Automotive Industry Scenarios

5.1.3 Future Scenarios

Energy transition was a certainty for all experts interviewed. The 2035 ICE sales ban from the EU pushed public and private organizations towards investing in environmentally responsible technologies that represent valid alternatives to oil. BEVs and FCEVs are seen as the leading alternatives. The former is mainly for passengers and the latter for heavy-duty vehicles (even though there is also a considerable amount of investment in BEVs for this segment). The experts are also confident about a gradual decrease in PHEVs and HEVs with an eventual sales ban on sight. On the other side, both BEVs and FCEVs are surrounded by challenges and uncertainties that may alter the expected trajectory of these technologies. The main factors are the geopolitical tension, where the trade war between China and the USA and the Russia-Ukraine war stand out, and the continuous investment in new technologic solutions for the energy transition, where new battery technologies and infrastructure stand out.

These two uncertainties are correlated with other uncertainties that can affect the market positively or negatively. Experts' predictions point to three scenarios where different uncertainties behave differently, given geopolitical tension and investment in the energy transition. Despite the diversification of industries and roles within different organizations, the probabilities of each scenario are subject to a time scope bias since experts project their predictions based on data that may develop and change in a short amount of time. Taking all these into consideration and based on further approval from the second-order interviewees (Expert XII, Expert XIII, Expert XIV, Expert XV), the likelihoods of each developed scenario are the following: Positive Scenario (S1) - 15%; Base Scenario (S2) - 60%; Negative Scenario (S3) - 25%.

Positive Scenario (S1)

In this scenario, geopolitical tensions worldwide are alleviated, and investment in sustainable technologies in the automotive industry keeps increasing. There is a joint effort among the industry's main stakeholders to integrate each other into their supply chain and make decisions that push the automotive industry to the carbon-neutral target in the EU.

Regulators in the EU keep promoting further developments to achieve the objective of carbon neutrality by 2050. Further sales bans for PHEVs and HEVs happen, betting on a free-of-oil automotive industry. At the same time, to restrict ICEs bought before 2035, regulators restrict the circulation of ICEs, mainly in urban centers, protecting the citizens from air and noise pollution. New rules about the origin of car parts and the respect for human rights during the productive process are established, creating a much cleaner value chain in the automotive industry. On the other hand, regulators across Europe change the legislation paradigm, creating a more flexible legal framework that allows the implementation of innovative solutions such as the lack of charging infrastructure for BEVs.

Automotive Companies will keep investing in new technologies to make BEVs more affordable, environmentally responsible, and efficient. Chinese car companies penetrate the European market with a value proposition based on value-for-money, making cheaper options available to consumers. Companies will be more open to synergies with startups fostering innovation and the creation of different concepts of cars for different niches and customer segments, such as the Solar BEV or minimalist cars. In the heavy-duty segment, most trucks are BEVs due to critical developments in battery technologies, taking down two crucial barriers – autonomy range and battery weight. Companies will see recycling and second-life usage as an opportunity for fixing and updating cars, creating the possibility for consumers to update vehicles without needing new purchases, sparing money and the environment. Thus, the after-sales business will considerably grow. The pressure from regulators and consumers will force automakers to review their supply chains, namely in mineral extraction for batteries and parts in general.

Battery producers benefit from significant investments in research and a collaborative global environment. New battery chemistries get developed and used in BEVs, such as sodium-ion batteries (sodium is cheaper, safer, and more abundant than lithium), to diversify and ensure the non-exhaustion of certain minerals such as lithium, cobalt, and nickel. This investment in new battery solutions also targets improving charging times and energy density. Producers create partnerships and coordinate their production with mining companies, eliminating some bottlenecks which will accelerate the delivery and eventually match supply with demand in Europe. With public incentives and a European effort to decentralize battery production, some European factories are built. However, since most trade wars and tensions dissipate, most of the market is still concentrated in China.

Consumers gradually accept Chinese brands becoming dominant players, mainly in the low-cost segment. At the same time, in Europe, the demand for environmentally responsible brands increases, pushing companies to more sustainable practices, namely in battery and parts recycling and with new business models with less waste. With more accessible access to cars, individual ownership of a car will remain the *status quo*. However, due to a shift from a hedonic to a utilitarian perspective, the number of cars in cities will decrease, and sustainable public transport will be more used, whereas some European cities (in countries like Germany and Netherlands) with more developed hydrogen infrastructures use FCEVs.

Governments keep incentivizing the purchase of BEVs, for passenger cars, in the first years to encourage consumers to opt for BEVs instead of ICE vehicles. Gradually over Europe, these incentives start to cease. Together with automotive companies and energy producers, governments support infrastructure growth and different solutions to avoid overusing the electric grid, mainly in urban centers. At the same time, the EU supports research projects to reach new solutions that make the automotive industry more efficient and affordable, particularly both BEVs and FCEVs (for specific niches). Together, these stakeholders in the EU try to align politics, infrastructure, and processes to decrease the heterogeneity between systems.

With the coordination with car companies, mining companies start adopting more sustainable practices, respecting the environment and human rights. Nevertheless, mining activity remains mainly out of Europe.

Energy producers keep shifting from fossil fuels to renewable energies in Europe. Some countries will reach values close to 100% of renewable energy by 2035, such as Sweden, the

Netherlands, Germany, and Scotland. Green hydrogen is included in this bundle. Its main application will not be for electricity in the automotive industry. Energy producers will also be responsible for building infrastructure and reaching innovative solutions for charging stations in city centers. Intrapreneurship and partnerships with startups are critical for attaining these.

Media will exacerbate these effects by systematically informing consumers about innovations and new solutions that might bring advantages to the environment and consumers. The transition from ICEs to BEVs is highly affected by the dissemination of the importance of the TCO and the overestimation of the importance of range autonomy in city life. At the same time, thought leaders will affect the direction of new car concepts and value chains. Specific segments will have more tailor-made technologies, improving performance in the automotive industry.

Base Scenario (S2)

In this scenario, geopolitical tensions carry on, with a slight alleviation. The USA and Europe keep having commercial issues with China despite being forced by the market to rely on China's mineral resources and production. Nevertheless, the 2035 ICE vehicles ban in Europe pushes the development of new environmental alternatives that can avoid European dependence on China. There is a shared effort among the European stakeholders to decrease GHG emissions while remaining skeptical regarding BEVs' environmental and political impacts.

Regulators maintain the current rules without considering a future ban on PHEVs and HEVs. Urban centers have limited circulation for ICE vehicles discouraging the city population from acquiring these vehicles. Due to the desire to decrease dependency on China and the need to increase supply to match the increasing level of demand, legal limits for production and extraction are broadened, affecting mainly mining sites and manufacturing plants out of Europe. Legislation for infrastructure is made more flexible, eliminating bureaucracies needed to implement new models for charging, such as battery-swapping or integrating charging stations with public lighting.

Automotive companies keep seeing BEVs as the leading technology, especially for the light-passenger segment. At the same time, Chinese companies begin penetrating the European market with lower prices, although facing some difficulties due to negative public perception, aggravated by political tensions. Besides, eventual integration systems between cars and infrastructure are more difficult due to differences in software between Chinese and other car brands. With a global environment lacking cooperation, European automakers have difficulties decreasing their electric car prices due to a lack of technology development and raw materials. For lower prices, automotive companies rely on production from low-cost countries, with assembly plants in Indonesia, China, and Thailand, among others. In the heavy-duty sector, more FCEVs appear due to the lack of lighter battery chemistries and the low autonomy range of BEVs. By 2030, fuel cell buses are also a standard technology in Europe. By the end of the 10-year scope, FCEVs for heavy-duty transport are usually more numerous than BEV trucks. Recycling and second-life usage is driven by cost, not developing their full potential in terms of positive environmental impact.

Europe sees the number of battery producers in the continent increasing. With government support, these entities develop new batteries to decrease reliance on Russia and China's rare metals and manufacturing plants. Chemistries such as sodium batteries do not depend on lithium but have lower energy densities, creating issues in improving batteries' energy density. At the same time, the focus on developing new battery solutions means that supply does not match demand, perpetuating the BEVs shortage. Besides this, battery prices struggle to decrease, increasing the cost of vehicles. Battery producers also focus on producing smaller batteries for FCEVs. Battery recycling increases its value alleviating the need for rare metals extraction.

Consumers keep supporting the shift from ICEs to BEVs. Over the ten-year time horizon, supply gradually levels with demand, and consumers stop having to wait six months to get a new car. Chinese brands have difficulty finding customers due to the skepticism and bad brand image caused by geopolitical tensions and questionable production methods. Gradually the number of cars *per capita* in Europe decreases due to the increasing environmental consciousness of the population, high purchase prices of BEVs, and more ecological public transportation, namely fuel cell buses.

Governments continue to support energy transition but face difficulties in developing this without increasing their dependence on Russia and China. To avoid Russian gas and oil, (green) hydrogen gains relevance and is supported by several European and public projects over Europe. Governments heavily subsidize buses and infrastructure for heavy-duty vehicles in the automotive industry, incentivizing the creation of hydrogen ecosystems. Meanwhile, despite not collaborating with China, governments raise funds to develop BEVs, their batteries, and responsible mineral extraction in Europe to create sustainable value chains independently from potentially unstable players.

Some mineral exploration starts in Europe for minerals like lithium and cobalt, but there is persistent opposition from vocal environmental groups who sway public opinion. Because of this, a considerable percentage of rare metals for both BEVs and FCEVs are shipped out of Europe. Simultaneously, automotive and battery producers rationalize their activities, offsetting some bottlenecks.

Energy producers see hydrogen as a significant opportunity due to the desire for energy independence of European countries, increasing the number of electrolyzers (for green hydrogen), and other renewable energy sources such as wind and solar. Gas usage drops, mainly in Central and East Europe. Hydrogen refueling infrastructure grows considerably across Europe, facilitating the operating of fuel cell trucks. With startups and government support, new solutions for charging BEVs are reached, gradually decreasing the "range anxiety" associated with BEVs.

The media has an active role in highlighting the environmental advantages of BEVs and FCEVs but also disclosing their issues, namely the environmental impact of mining of lithium and other metals. This influences Europeans to fight against mining in natural landscapes, for example.

Negative Scenario (S3)

In this scenario, political tensions continue to rise. China takes control of Taiwan, aggravating and extending the trade war to Europe. All industries suffer severe setbacks, including the automotive industry. Due to economic sanctions, the prices of rare metals increase as their availability decreases, causing the evolution of BEVs and production to stagnate. Nevertheless, the EU keeps its ICE vehicle ban until 2035, decreasing public investment in the energy transition. The rate of innovation falls due to less international collaboration and less funding. Investment in other supporting infrastructure, such as charging/refueling stations, also declines. Nevertheless, due to the ban on Russian fossil fuels, renewable energies accelerate, bringing some positive side effects to Europe.

Regulators' directives fail to accelerate the energy transition in the automotive industry for passengers due to a lack of financial support and no materials to keep up with the demand.

ICEs are banned in most European urban centers, causing city populations to rely more on public transportation. Legal flexibility also increases to facilitate implementing of new solutions for environmentally responsible transport and charging infrastructure. At the same time, taxes increase to support the issues arising from the global conflict, lowering consumers' disposable income.

Automotive companies suffer heavy losses with the shortage of materials, mainly batteries and microchips. PHEVs and HEVs keep being sold but with declining velocity. Investment capacity is channeled to BEVs, anticipating the "death" of ICE vehicles. Due to the lack of capacity to democratize BEVs, companies invest in renting models, such as car sharing, where the number of cars and the need for consumer purchases is lower. At the same time, car production concentrates in low-income countries to decrease production costs. The demand for buses increases, beneficiating fuel cell technology and scaling hydrogen infrastructure for both buses and heavy-duty transport.

Battery manufacturers increase in number outside China, where Australia stands out. Europe also develops its battery production, despite being limited due to environmentalist movements fighting mineral extraction projects. New chemistries are developed but do not serve as a substitute for Lithium-ion batteries over the 10-year time frame. This limits production and delivery capacity for automotive companies. Battery recycling does not develop due to a lack of investment and this limits the growth of BEVs.

Due to the high prices of ecological alternatives, consumers become skeptical and do not support the ICE vehicle ban in general in 2035. Thus, there is a shift away from car ownership, and most of the population has come to rely on public transport. Lift apps and car-sharing models gain traction.

Governments face enormous difficulties with the global political situation. Subsidies and tax incentives are cut earlier than expected to manage the budget deficits related to international conflicts. Governments heavily invest in improving public transport to compensate for the population's lack of access to cars. Buses are the easiest solution due to the limited need to adapt street infrastructure from what already exists. Public transport evolves and ends up contributing to an environmentally cleaner Europe. Fuel cells gain in relevance, causing the EU to fund infrastructure and invest in hydrogen routes, facilitating the growth of FCEVs in the heavy-duty transport segment.

Some mining sites appear in Europe but face criticism from the public due to the environmental lobby and similar NGOs. Australia becomes the leading EU partner in lithium extraction due to its reserves and willingness to mine this metal.

Energy producers in Europe are heavily incentivized to invest in renewable energies due to cuts in imports from Russia. Most European countries can increase their renewable energy share despite a lack of materials. Green hydrogen gains scale, and its price decreases gradually, becoming more and more accessible, collaborating with the shift to heavy-duty and public hydrogen transport.

The media mainly focuses on political issues, depriving consumers of knowledge about the energy transition in the automotive industry. Nevertheless, when scandals appear, these are widely shared and influence the whole industry's image. Thought leaders in the industry focus on services associated with cars instead of car sales, creating new paradigms for transportation in the automotive industry, including the introduction of autonomous driving lift apps at the end of the 10-year time horizon.

Stakeholders	Positive Scenario	Base Scenario	Negative Scenario
Regulators	- Sales ban for PHEVs and HEVs; - Increasing on Human Rights requirements in the supply chain; - Reduced bureaucracy for implementation of innovations.	- ICEs are prohibited in some city centers; - Legal limits for mining activity are broadened.	- Directives fail to accelerate energy transition; - ICEs are banned in most city centers in Europe; - Taxes increase to support the global conflict, decreasing consumers' wealth.
Automotive Companies	- Chinese companies penetrate in the market; - Creation of synergies with startups; - Recycling and second-life usaage seen as an opportunity.	Chinese companies have difficulties to penetrate in the market due to public image; - Car prices stagnate and a part of the population stops having access to these. - FCEVs appear as the best solution for heavy-duty transport and buses.	- Automotive companies suffer from materials shortage; - ICE vehicles' end is antecipated due to lack of investment; - Companies focus on buses and heavy-duty transport increases.
Governments	- Tax incentives for the purchase of BEVs until these reach parity with ICE vehicles; - Financial support to increase charging stations coverage; - Creation of research projects that incentivize the discovery of new solutions for the industry.	- Green hydrogen arises as a solution to fight Russian and Eastern dependency; - Funding and tax incentives for hydrogen ecosystems; - Funding for mining and development of new battery solutions within Europe.	- Subsidies and tax incentives are cut earlier than planned; - Heavy investment in public transport to fight lack of access to passenger cars; - Investment in hydrogen and fuel cells to support public transport and heavy-duty transport.
Battery Producers	- Development of new battery chemistries; - Coordination with mining companies to eliminate bottlenecks.	- Increase in the number of battery producers in Europe; - Research and development of new battery solutions; - Issues in leveling the demand for batteries.	- Battery manufacturers increase in number outside China, where Australia stands out; - New chemistries are developed but without substituting Lithium-ion batteries in the 10-year frame; - Battery recycling does not develop.
Consumers	- Acceptance of Chinese brands; - Market push to more ecological solutions.	- Consumers are skeptical regarding Chinese brands; - Environmental consciousness, high BEV prices and improvement in public transports, decreases the intention to buy a car.	- Consumers become skeptical and do not support the ICE vehicle ban due to high prices; - Shift in the car ownership status, reinforcing the usage of public transports.
Mining Companies	- Adoption of ecological practices during and after the extraction process; - Most mining activity remains out of Europe	- Some mines are opened in Europe despite populations criticism and concern.	- Some mining sites appear in Europe, facing criticism from the consumers and environmentalist NGOs; - Australia becomes the leading EU partner in lithium extraction.
Energy Producers	- Full shift from fossil fuels to renewable energies; - Green hydrogen is crucial despite not having the automotive industry as its main application.	- Hydrogen gains traction due to the energy independence wish of Europe; - Eletrolyzers and refuelling stations coverage increases.	- High investments in renewable energies due to the cut of imports from Russia; - Green hydrogen becomes cheaper and more accessible.
Media	- Has an informative role to the consumer, colaborating to the energy transition.	- Interventive role, highlighting the environmental advantages of BEVs and FCEVs but also disclosing their issues	- Main focus is on political issues; -Scandals are widely shared and influence the whole industry's image.
Thought Leaders and Industry Experts	- Influence the indsutry creating new car concepts and philosophies.	- Thought leaders focus on high-income consumers with new car concepts, creating value through innovation and driving experience.	- Focus on services associated with cars isntead of sales; - Introduction of autonomous driving lift apps at the end of the 10-year frame

Table 14 - Scenarios Summary

6 CONCLUSION

This thesis sought to understand the impact of energy transition in the automotive industry in Europe over the next ten years. The research was built on the underlying research question, "What type of engine is likely for the future of the automotive industry?". Several drivers were analyzed, including their main challenges and opportunities. Experts were unanimous regarding the demise of ICE vehicles, enforced by the EU ban on these in 2035. PHEVs and HEV were also considered fleeting technology. BEVs were amply considered the leading future technology, especially for passenger vehicles.

Nevertheless, FCEVs were also frequently mentioned as an alternative to heavy-duty vehicles and buses. In the end, the base scenario was considered the most likely by the experts interviewed, with a 60% chance. Political tensions tend to remain over the ten years, and the EU considers energy transition in the automotive industry as an essential issue.

In general, experts are confident in a future where the automotive industry ceases to have one singular solution for the ICE but instead takes a multi-pronged approach with different solutions for various segments, all of which improve energy consumption and performance of the vehicles.

Implications for both academic and management domains were assessed throughout this research. Literature about the impact of the energy transition on the automotive industry in Europe was scarce. It did not consider the delta associated with the various uncertainties that can have an extended impact on the industry's future. Moreover, this study assessed potential reactions from industry stakeholders who have knowledge about energy transition as a disruptive factor.

This research is also subject to several limitations. Firstly, most of the experts interviewed in this study are based in Portugal, suggesting that despite having Europe as the scope of the thesis, some biases may exist due to perspectives associated with a single geography. In the same way, the survey respondents were also mainly Portuguese, meaning that cultural elements may affect the determinant factors held to drive consumer intention to buy a BEV. The scenario planning framework also has limitations. Subjective opinions of experts were used to determine the probability of each scenario. Probabilities are used to translate into numbers perceptions and opinions of experts that one scenario is more likely to happen over another. Moreover, with scenario planning, there is a tendency to discount extreme cases and propose that a base case is more likely, despite the fact that so-called black swan events frequently occur throughout history.

In addition, the automotive industry is a highly dynamic sector. The energy transition is not an isolated trend, and further research should incorporate the influence of autonomous driving and car-sharing since these factors were also mentioned as being relevant by experts, as well as the use of new energy sources such as biofuels. Moreover, throughout the expert interviews, two topics were mentioned several times as needing further investigation – homogeneity of infrastructure and regulations within European countries and the future of the heavy-duty segment specifically.

7 APPENDICES

APPENDIX A - WORLD'S 10 LARGEST PUBLICLY LISTED CORPORATE R&D SPENDERS

2018 Rank	Company Name	Country	Industry group	2017	2018	2017	2018
1	Amazon.com, Inc.	United States	Retailing	16.1	22.6	136.0	177.9
2	Alphabet Inc.	United States	Software and Services	13.9	16.2	90.3	110.9
3	Volkswagen Aktiengesellsc…	Germany	Automobiles and Components	13.8	15.8	260.9	277.0
4	Samsung Electronics Co., L…	South Korea	Technology Hardware and …	14.3	15.3	189.0	224.3
5	Intel Corporation	United States	Semiconductors and Semic…	12.7	13.1	59.4	62.8
6	Microsoft Corporation	United States	Software and Services	13.0	12.3	85.3	90.0
7	Apple Inc.	United States	Technology Hardware and …	10.0	11.6	215.6	229.2
8	Roche Holding AG	Switzerland	Pharmaceuticals, Biotechno…	11.8	10.8	54.0	57.2
9	Johnson & Johnson	United States	Pharmaceuticals, Biotechno…	9.1	10.6	71.9	76.5
10	Merck & Co., Inc.	United States	Pharmaceuticals, Biotechno…	10.1	10.2	39.8	40.1

APPENDIX B - SCENARIO PLANNING SCOPE DEFINITION

Scenario Planning Project Goal: Explore and create scenarios for the future of the automotive industry in the next 10 years with Energy Transition as a disruptor.

Analysis Level: The analysis will be made at an industry level

Stakeholders: Regulators, Automotive Companies, Governments, Battery Producers, Consumers, Mining Companies, Energy Producers, Media, and Thought Leaders and Industry Experts

Time Horizon: A 10-year timeframe is appropriate for a predictive study, given the characteristics of the automotive industry. A smaller one would not explore enough new events and technologies since this is an industry that plans and heavily invest ahead, meaning that a lot of variables for the next 5 years are already defined. (Expert I, Expert II)

Appendix C - Expert Interviews Reports

Interview I – Marcos Paulo Schlickmann

Marcos is specialized in smart cities as a Manager at Deloitte and has deep knowledge of BEVs for their close connection with smart cities and autonomous driving.

The most significant issues associated with the automotive industry are sinistrality and pollution.

Even though BEVs have some degree of pollution associated with them, in the production of vehicle and electricity, it does not produce local pollution (noise and atmospheric).

The already developed infrastructure targets BEVs. Since the investment is already made, Marcos defends that the correct path is to solve and minimize issues related to BEVs and take advantage of the already done investment. He identifies issues in charging public transports, heavy-duty vehicles, autonomy, and mineral extraction for batteries and charging infrastructure that could have difficulty meeting demand in the next ten years.

Governments interfere too much. For example, these incentivize excessive extraction with subsidies and end up causing more pollution and eventual imbalances between supply and demand in the present and the future.

Regarding hydrogen, fuel cells are too inefficient, hindering their expected penetration into the market. Currently, it does not solve the pollution issue, and the pricing is out of reach for most of the population. He defends that while no solutions for heavy-duty vehicles and buses are met within BEVs, these will remain working with ICEs.

Interview II – Luís Martins

Luís is a Manager in the Mobility area at EDP Innovation, specifically with cars, scooters, and charging stations.

Luís does not see a bright future for hydrogen in the automotive industry. Hydrogen production presently is not sustainable, and its transportation is complicated. Fuel cells are also relatively inefficient when compared to a BEV. In heavy-duty transport, he points out that the number of BEVs, despite its issues, keeps being higher than FCEVs.

On the other hand, when it comes to BEVs, we can see that batteries' autonomy keeps increasing. Despite the issues caused by lithium extraction and minerals shortage, Luís considers that media are using the transport industry as a scapegoat since electronic devices, namely smartphones, have a more extensive influence on these.

The semiconductor shortage is still an issue even though the predictions suggest that the market will return to its “usual” production in the next two years.

Luís sees recycling as a solution to the problem of shortage of resources, suggesting that as soon as players feel the need to get more resources that are not available directly, recycling will be pushed and will become a more developed business.

In the end, Luís considers that “we are changing problems” from CO2 emissions to batteries, which is how technology works.

The biggest uncertainties mentioned by Luís were hydrogen efficiency, which could change the paradigm if technology made it more efficient, mineral resources available for batteries, and new battery chemistries that could avoid the latter issue.

Interview III – Diogo Almeida

Diogo is the Head of Business Development for hydrogen at Galp.

In his opinion, hydrogen will have a bright future in the automotive industry despite not being for every type of car. The mainstream passenger cars will most likely be BEVs, but hydrogen will play a key role if we talk about segments with intensive use and where long-distance transport is needed. Some examples of targets are car rentals for long distances, taxis, and most definitely heavy-duty vehicles. These segments are hard to electrify and may face problems in the recharging process of their duration and availability. Hydrogen brings benefits at an operational level.

Heavy-duty vehicles consume roughly half of the energy used in vehicle transport. Even though there are few heavy-duty vehicles fuelled by hydrogen, several projects are being developed in that sense. Galp is planning on opening several hydrogen refueling stations next year. City buses will also use hydrogen since BEV buses have problems with range, weight, and temperature control both in winter and summer.

The main issue with hydrogen is the current price for its "green version," which is quite expensive, and its distribution since hydrogen needs to be very pure. Japan has local electrolyzers, which is viewed as a reasonable solution.

Autonomous driving is also a trend related to the energy transition. In heavy-duty transport, autonomous driving will increase the importance of hydrogen since there will be no more required stoppage time for the drivers, meaning no charging time "excuse."

In the end, the most significant uncertainties are the green hydrogen price, which is very much influenced by the electrolyzer's price, the energetic density evolution of batteries, and the price of both BEVs and FCEVs.

Interview IV – Nuno Marques

Nuno is the Iberian Director at Citröen.

In the next ten years, there will be a revolution like the industry has not seen in the last 80 years, with an energy transition in how vehicles are delivered to the consumer and how the consumer uses the vehicle.

The energetic revolution was pushed too earlier by governing bodies, namely with the ICEs sales ban from 2035 on by the EU. The electrification for the future is unavoidable since the decisions made today have that time horizon.

For Nuno, the infrastructure is the most important thing for both BEVs and FCEVs. If it is good enough for BEVs, range anxiety will not be a problem anymore, while for the FCEVs, the simple fact that they exist will enable the sale of these cars. Another issue is the price of both these technologies. FCEVs, for now, are extremely expensive and out of reach for most of the population. Although BEVs are more affordable, their prices are still far from ICE cars. It is essential that the price can decrease, which depends mainly on the technological evolution and the automotive firm's mindset. Nuno defends that to be affordable and competitive, cars must "get rid" of all the superfluous devices, mainly in the cockpit.

The topic of natural resources is a "black hole" full of uncertainties. The availability of these for the batteries, and the sourcing countries, of which China stands out. Constant trade wars will not play in favor of competitive prices. Also, regarding recycling, the supply chain is underdeveloped since most batteries used did not reach their end-life.

When it comes to hydrogen, its main challenges are infrastructure and distribution. The technology is still in an early stage and very dependent on incentives from public entities.

Interview V – Doron Myersdorf

Doron is the CEO and Co-Founder of Storedot, a company valued at $1.5 bn, with investors such as Volvo and Polestar, specializing in fast-charging batteries for cars and other electric devices.

Doron says that governments are a critical player and that these are pushing for 0 emissions in city centers. Also, people/society in general also seeks a positive environmental impact. On the other hand, political forces are also pushing for the opposite, with lobbies favoring oil companies. "It will be difficult to eliminate the use of gasoline in transportation." Range anxiety used to be also a problem, but with the growing city infrastructure, that issue is being covered.

Some recent events are not helping with BEVs' production, namely the microchip shortage, the Ukraine-Russia war, and the trade war between the USA and China. The latter is an uncertainty factor because many resources for batteries come from China. Also, there is little alignment between batteries/car companies and mining. The supply chain will take a long time to align with the demand. There will be a lower supply when compared to the demand.

Hydrogen must pass through much processing until it gets to the car, which means that there will likely be a lot of different technologies. The infrastructure is a problem, probably the biggest one. Everyone wants a more straightforward solution, and hydrogen will not be in the following years.

In the end, the most considerable uncertainties are the challenge of the producers to keep up with the demand and the lack of producers and resources for batteries, mainly fast-charging batteries.

Interview VI – André Botelho

André is the Head Energy Storage & Flexibility at EDP Inovação.

He starts by stating that there is a clear divisor line between mobility for long and short distances, where different models will feat for each in the future.

There are new types of battery chemistries being developed that can have a better energy density, but these will take years to get in the market if they do. There is also regulatory pressure for battery recycling. However, since most car batteries did not reach their end-life stage, the supply chain is not adequately established.

Another issue is the purchasing price of BEVs. The technology keeps being too expensive, and the cost of batteries has been increasing because of events such as Covid and the Ukraine-Russia war and the consequent unstable political situation. There is a problematic geographic concentration of resources for batteries. This increases the prices and decreases supply relative to demand that, in normal conditions, is already above productive capacity.

The infrastructure suffers from the "chicken-egg" issue. The push from public entities and governments is no longer needed because the market can install recharging stations for BEVs.

Regarding FCEVs, the technology is less efficient and too expensive. It can have a word to say in buses, taxis, and heavy-duty transport (the latter might not be that useful if new and better batteries arrive).

Also, autonomous driving is a relevant trend and one that influences the energy transition due to the number of available cars. With autonomous cars, there will probably be fewer cars.

Interview VII – António Lobo

António is a Senior Researcher and Teaching Assistant at Porto University.

António started by talking about autonomous vehicles. The sense of ownership will change. However, the legislation is in a very early stage. António mentioned some scenarios, such as future autonomous car owners putting their cars "going around by themselves" and eventually spending more energy than needed, while public transport would be much more ecological. Nevertheless, we will not see completely autonomous cars in 2040 in the streets.

ICE's “death” was a precipitated reflex after the Volkswagen scandal, stagnating innovation related to these engines. Plug-in hybrids are “falling in disgrace,” giving a hint that private cars will mostly be BEVs.

When it comes to the environmental impacts of the production of cars and batteries, the impact is unknown because of the different production methods and the countries where these are produced. BEVs can also be segregated mean since their prices are still an issue, being accessible to only part of the population. Maintenance was also mentioned since this operation does not fit with the maintenance of ICEs. Standard mechanics cannot fix a complex electronic issue of a BEV.

As uncertainties with potentially high impact, António mentioned the public perception that can be affected by any discovery of more significant environmental impacts associated with BEV production. Also relevant is technological innovation in battery capacity and density and the capability of car companies to deliver solutions (supply does not level the demand).

Interview VIII – Filipe Nunes

Filipe is a Product & Planning Manager at Hyundai Portugal.

He starts by saying that this energy transition was anticipated by a regulatory push made by the EU, which decided to ban ICE vehicle sales from 2035. The lack of supply will probably slow the transition since car companies did not expect such high demand.

FCEVs are still too expensive, and if the decrease in prices does not accelerate, it will be tough to see private cars fuelled by hydrogen in the next ten years. More prominent than this problem is the refueling infrastructure, which does not exist. Even though FCEVs are cleaner than BEVs, consumers are dependent on brands and governments to install a refueling structure that is good enough. On the other hand, FCEVs will probably have a stronger position on heavy-duty transports. In Central Europe, mainly Germany, Austria, Netherlands, and France, the infrastructure is evolving at a reasonable rate. FCEVs will most likely be a niche technology.

BEVs are more established, and the infrastructure is slowly growing even though it did not reach an optimal point. The cars will face problems because of the lack of microchips and natural resources. The fact that a lot of these resources come from China makes the importation of these harder and brings uncertainties to the future of car companies that are not Chinese. Much bigger ranges are unlikely because even though new battery chemistries are being developed, these will be much more expensive. BEVs already have a problem with the price, entirely dependent on subsidies, for example. These subsidies also represent uncertainty with high impact since some countries are abandoning these subsidies, namely Sweden, and the consequences are still unknown.

Because of this, a new player is looking to capture some market share in Europe - Chinese car companies. Several brands are looking to bid in the European market in the following years, with competitive prices and supply that might match demand.

Interview IX – Eloísa Macedo

Eloísa is a Ph.D. Researcher in low carbon and sustainable mobility at Aveiro University.

Eloísa started by approaching the safety issues related to the hydrogen tanks and de fact that this gas is explosive, which can have severe consequences if a crash causes some leak.

The governmental force and the imposition of some rules are uncertain, such as enlarging no ICEs zones and increasing subsidies for acquiring BEVs. Eloísa adds that the GHG emissions levels will still be too high after 2035 since many ICE vehicles will still be on the streets. (Literature suggests that by 2040 2/3 of the fleet in Europe will be ICEs). This transition was made too early. There was still a margin to improve the efficiency of these vehicles. The emissions of these vehicles keep being false (even after the Volkswagen scandal).

The BEV transition can also harm the environment. The number of electrical components needed, not only for the battery but also for the rest of the car that nowadays has more and more "gadgets." Besides, the battery disposal issue is uncertain. The impacts can be huge, and the recycling method is unclear since most batteries in the market did not reach the end-life stage.

Interview X – Alberto Lima

Alberto is the Country Sales Manager of Hyundai in Germany.

The biggest bottlenecks of BEVs are batteries and microchips. In the sales process, subsidies are significant. Germany has many incentives for cars and infrastructure, making it the country with the biggest ratio of Plug-in + BEVs in Europe. Another problem is the unstable demand caused by this subsidization. With some subsidies being terminated, like in Sweden, suddenly, a huge demand still wants to "use" these subsidies. After these are terminated, the demand suddenly drops. Besides, this varies within each European country, meaning it very does establish a general strategy.

FCEVs do not have an appropriate infrastructure. However, this fuel will be essential in specific ecosystems within limited areas where public transports and heavy-duty vehicles use hydrogen. This should happen sooner than later. For general use, the cars are too expensive despite their high incentives.

For infrastructure, governmental support is significant for both BEVs and FCEVs. The expansion for these technologies to reach a "mainstream" status is dependent on that since the demand for charging stations in places such as highways that suffer from seasonality, meaning that there is a need to support stations that may not be used during most of the year but in summer have high demand. (Gave the example of the highway between Lisbon and Algarve).

Interview XI – Rui Vieira

Rui is the Head of Electric Mobility at Galp.

In the next ten years, legislation and the regulatory dimension will be essential factors in Europe. However, at the same time, the market mechanism will react with the best solutions since, nowadays, the demand is also driven by the ecologic side of the product, despite the greater importance of price.

The technological disruption topic is highly unpredictable and highly impactful. The proof that this is difficult to get is the fact that a couple of years ago, nobody thought we would have made the advances that were made.

When it comes to TCO, the BEVs one is better than the ICEs a lot because of the tax incentives and subsidies, mainly to companies.

Regarding charging, the infrastructure still has a problem of coverage, which is very heterogenous over Europe. Also, due to the war between Ukraine and Russia, the electricity price is very high, creating another difficulty.

Governments are crucial players in the market. The support these will or will not give in the future is decisive. They will be a defining force in the transition from the "early stage" to the "boom phase." New batteries with better energy density would solve almost all issues of BEVs, including solid batteries, but it is unlikely to happen in the next ten years. Their production is still an issue, and the expansion of the BEVs is dependent on geographic diversification in mining (a difficult situation because we do not control where the resources are) and battery plants.

FCEVs have an efficiency issue. It will most likely not be a viable solution for private cars, but for heavy-duty transport and buses, it might be. Despite that, we still see more projects for heavy-duty BEVs than FCEVs, which shows that the investment in BEVs is more significant than in FCEVs.

Interview XII – Ana Casaca

Ana is the Head of Innovation at Galp.

Many factors might affect and alter the trajectory of the automotive industry. One of the future bottlenecks identified is the infrastructure. Presently, the number of charging stations is appropriate and fits the demand. However, maintaining the scale will be a logistic "nightmare." Urban centers do not have enough space to build new charging stations for all-electric mobility in the automotive industry. Some solutions include charging stations from public light poles, for example. However, legislation is a barrier to this type of innovative solution. Governments and regulative institutions must react quickly and make more flexible rules to keep up with new solutions for these problems. Another solution is the substitution battery system, where a fully charged battery changes the battery being used. However, Ana defends that these will always be a complementary service for car charging in stations, never the primary model.

Ana agrees that hydrogen usage for the automotive industry is in an early stage, which puts it clearly behind the BEVs, including in heavy-duty transport. However, the needs of these niches make more fit with FCEVs, meaning that once the fuel cell and hydrogen production are fully developed, a crucial role of FCEVs is expected in the market.

Ana agrees with the correlation between geopolitical tensions and the evolution of technology. Because of the dependency on China to produce batteries, hydrogen might gain relevance as an alternative, which needs smaller batteries (which means fewer mineral resources and less dependency on China). Nevertheless, China will still have a significant influence on fuel cell production. On the other hand, if political tensions alleviate, Ana believes that the BEV technology will significantly improve the battery's chemistry and energy density. This would decrease the hydrogen influence in the automotive industry, even though it would still be relevant in some niches, namely buses (although she thinks the scenario is unlikely).

Interview XIII – Mafalda Martins

Mafalda is the CFO of Mobi. E, a public company that allows the consumer to charge his car in any station independently of the station's operator.

Mafalda highlighted that energy transition is a reality, not a trend. Regulatory pushes, namely the 2035 ICE vehicle sales ban, did not provide an alternative to this transition. Passenger cars will mainly be BEVs. In Portugal, there are excellent conditions to own a BEV, namely its low TCO and a good charging network.

When it comes to FCEVs, it will mostly be a heavy-duty technology, even though it is quite uncertain. There are several projects to create refueling stations for these vehicles, but these are expensive. The EU has very ambitious objectives, but the "we are late."

BEVs are more and more accessible to the population. Mafalda agrees that we are walking to price parity which is the most likely scenario in the next ten years. Some barriers might include integrating the charging infrastructure, which in most of Europe is complicated and increases the effort for the consumer.

If political tensions increase and that enlarges production bottlenecks and increases the costs, it is expected paradigm change in the ownership of a vehicle. Mafalda recognizes that there are already some changes in this topic with younger people, even though we still see records of car acquisitions every year. Mafalda agrees that this scenario is possible despite agreeing that a base scenario is still more likely.

Interview XIV – Pedro Gouveia & Eurico Correia

This interview had two interviewees. Pedro, who is Galp's Commercial Lead, and Eurico, a specialist in Innovation for Renewables in the same company.

They started by highlighting the importance of the TCO of BEVs. Presently there are several situations where a BEV's TCO is lower than an ICE vehicle. However, because its purchasing price is higher, consumers tend to step away before assessing all the costs involved in both vehicles. There is a need for a change in the mentality. To help with this, government subsidies and tax incentives are significant, even though Pedro and Eurico believe we will not need these in the future.

A bottleneck that might be slowing down this transition in the future is the dependency on China's productive power and mineral resources.

When it comes to FCEVs, Pedro suggests that this technology is where BEVs were ten years ago. A big issue for these is the considerable CAPEX needed for each refueling station. However, they both say this technology will be needed in the future since the charging process for heavy-duty BEVs is much more complicated and demands much more power from the grid. That is why the new vehicle disposition will be a mix, with each solution adapting to specific niches.

The heterogeneity of resources in Europe is evident. However, the trend is convergent, and it is expected that, in one way or another, electrification will reach every state by 2035.

Pedro and Eurico agreed with the three scenarios, considering the negative one more likely than the positive one.

Appendix D - Survey Context

Please, visualize yourself in the following situation:

You are thinking about buying a new car for daily use.

Because of recent climatic events you have been more and more aware of the impacts of Green House Gases emissions. An electric car might be a solution.

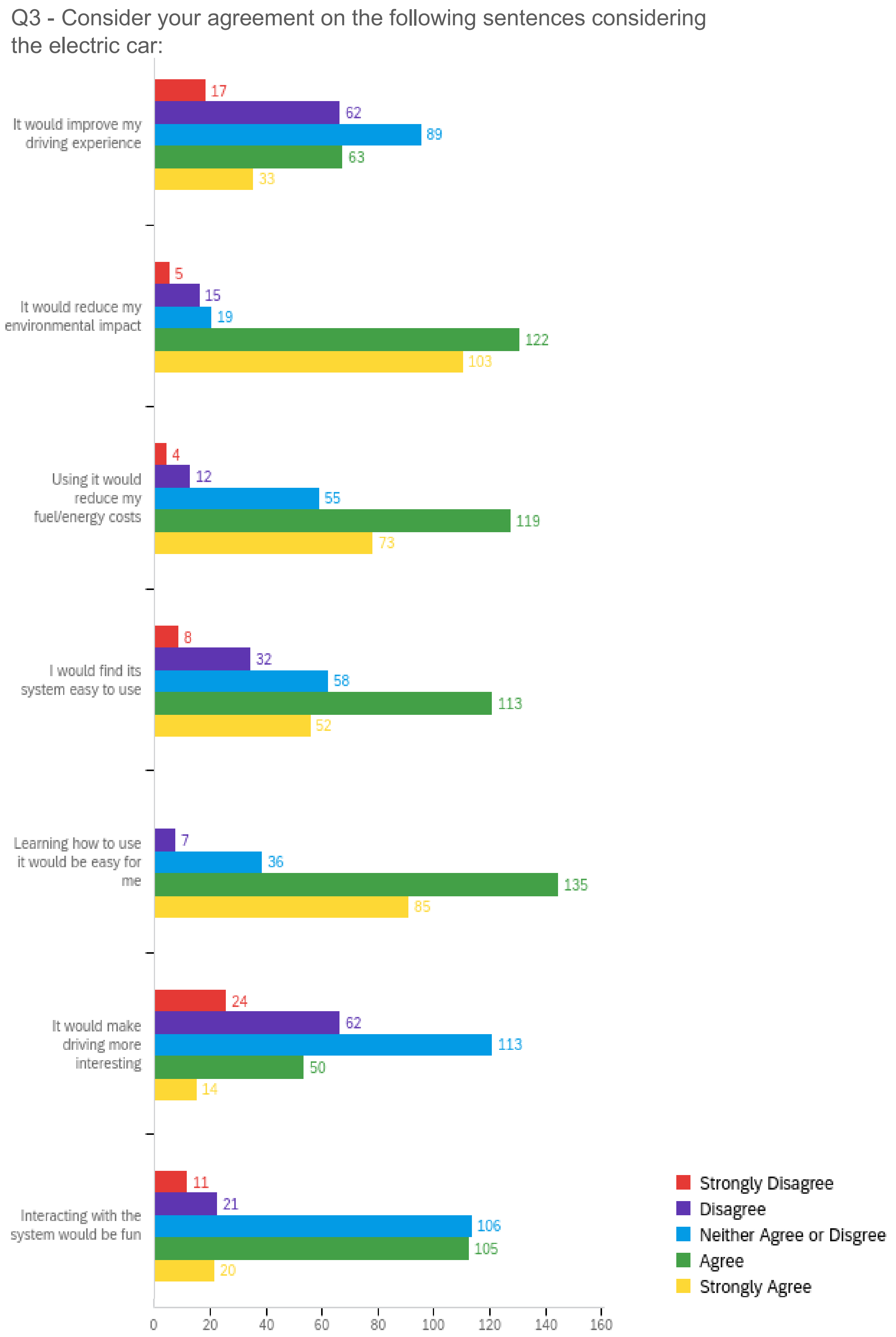
When arriving to the dealership, the car you are shown is a Battery Electric Vehicle with 4 seats and has the following characteristics:

_ **From 0 to 100km/h -** 8.1 seconds
_ **Top Speed -** 150 km/h
_ **Autonomy -** 340 km
_ **Gearbox** - Automatic
_ Simple interior with a basic Control Panel with radio, GPS and Free-hand call system.

On the other hand you are also shown a Diesel car with the following characteristics.

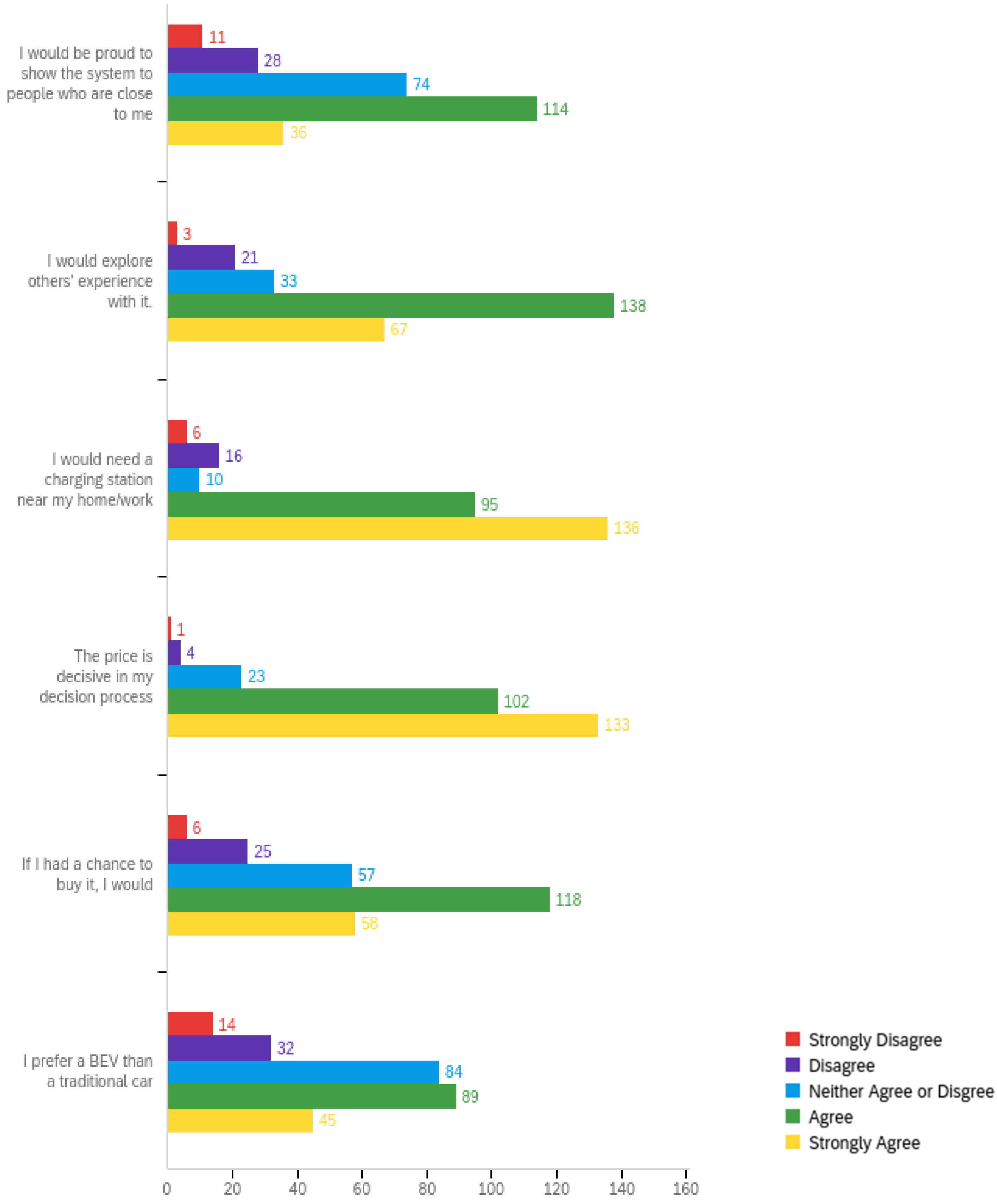
_ **From 0 to 100km/h -** 8 seconds
_ **Top Speed -** 190 km/h
_ **Autonomy -** 750 km
_ **Gearbox** - Manual
_ Simple interior with a basic Control Panel with radio, GPS and Free-hand call system.

Appendix E - Survey Answers: Q3.1



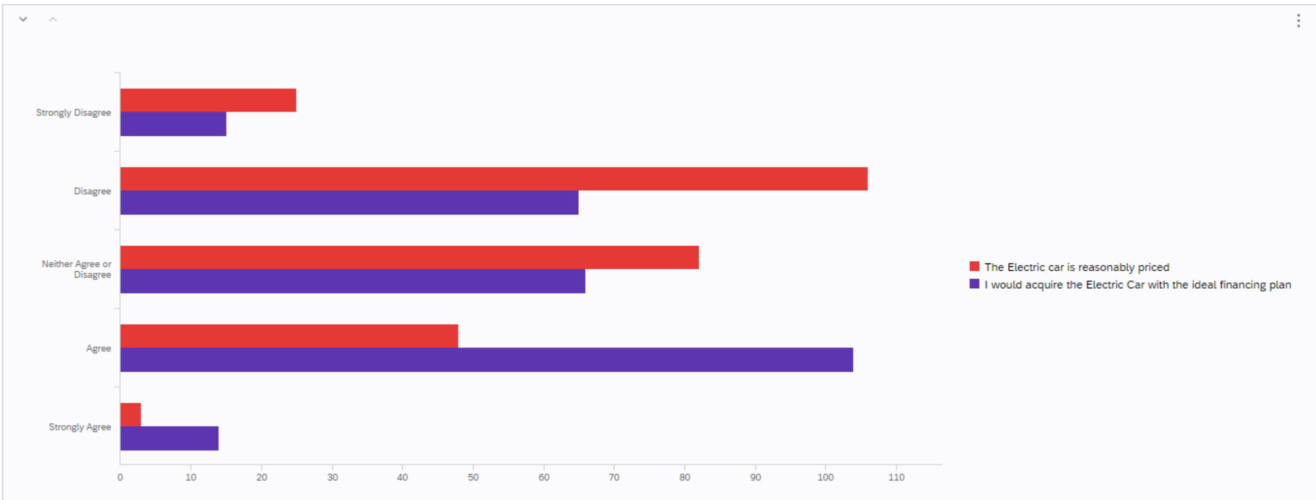
Appendix F - Survey Answers: Q3.2

Q3 - Consider your agreement on the following sentences considering the electric car:



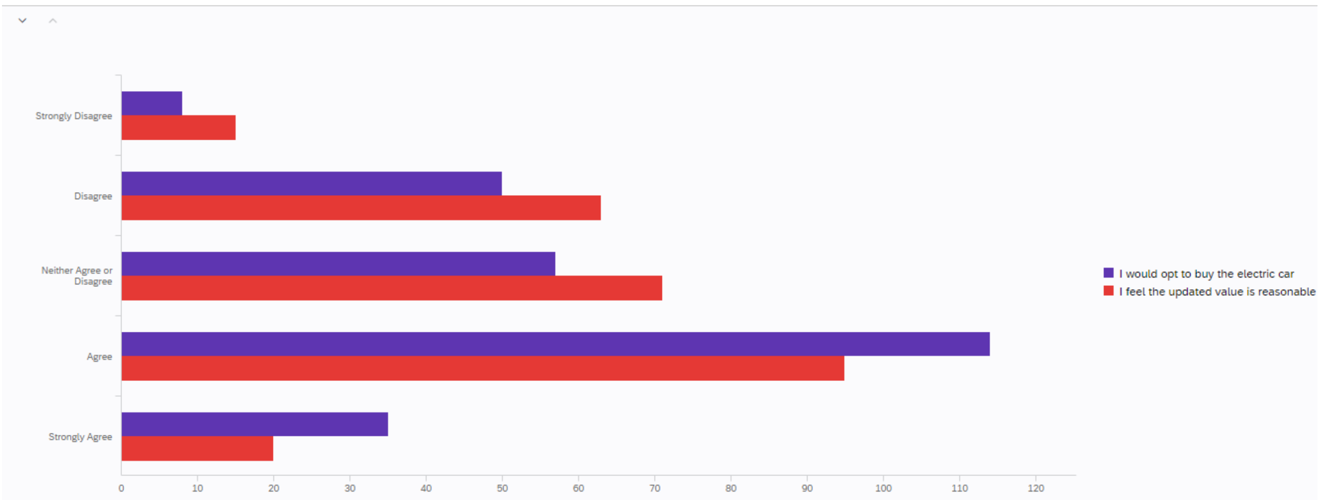
Appendix G - Survey Answers: Q4

Q4 - Now, you are informed about the prices: Electric Car - 32000€ Diesel Car - 20000€ Page Options



Appendix H - Survey Answers: Q5

Q5 - Your country's government announces a contribution of 4000€ if you buy the electric car: Updated prices: Electric Car - 28000€ Diesel Car - 20... Page Options



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