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Adoption and Growth of Fuel Cell Vehicles in China: The Case of BYD

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Abstract: Compared to battery electric vehicles (BEVs), fuel cell vehicles (FCVs) have been developing since the early 2000s due to their efficiency and environmental advantages. However, unlike the battery industry which has already achieved economies of scale, the scale of fuel cell manufacturing is still in its early stage in China. In this exploratory study, using the case of BYD, we identify and analyze the key economic and environmental factors that might facilitate and propel the adoption of FCVs in China. Utilizing quantitative (i.e., the statistically descriptive method) and qualitative (i.e., a semi-structured interview and Porter's model) reasoning, this study finds that by systematically addressing two factors, (i) customers' misperceptions about the safety and environmental friendliness of FCVs and (ii) lack of technical competencies in the upstream and downstream of the FCV industry's value chain in general and for BYD in particular, the sustainable development and adoption of FCVs in China can be achieved.

Keywords: new energy vehicles; fuel cell vehicles; consumer perceptions; China; adoption of technology; cost of technologies

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1. Introduction

Environmental pollution is one of the biggest problems in the world and many countries are currently trying to have low-carbon economies [1,2]. At the same time, the automobile industry, an important area of fossil fuel consumption and carbon emissions, is also facing revolutionary challenges. New energy vehicles (NEVs) are widely believed to effectively contribute to the solutions to these challenges. However, battery electric vehicles (BEVs) and fuel cell vehicles (FCVs) are the main technological trends of NEVs [3–5].

With numerous local participants' massive production of BEVs for several years, an integrated industry chain has been built in China to deliver economies of scale. For example, the expansion of battery manufacturing capacity has been largely driven by the projected size of the BEVs market. Local battery manufacturers have experienced rapid development during the past decade and helped China to catch up to the leading-edge technology in this field. Benefiting from the economies of scale, the cost of BEV batteries is falling markedly with better product performance. Industry reports show that sales-weighted battery pack prices in 2019 were an average of USD 156 per kilowatt-hour, which recorded an 86% decrease from 2010 [6]. As the heart of a BEV, battery cost usually accounts for about 30% to 40% of the total production cost of the vehicle. Chinese consumers have witnessed the continuous decline in BEV selling price which is mainly driven by the cost decreasing from batteries. The pricing of BEVs is getting close to fossil-fueled vehicles which also makes BEVs much more attractive to end-users. In October 2020, the global leader in the BEVs industry, Tesla, cut the starting price for China-made Model 3 cars by 8% to CNY 249,900 (USD 36,805), making the giant more competitive among the passenger vehicle luxury brands in China. China-made Model 3 cars are equipped with CATL batteries whose supplier is one of the Chinese battery manufacturers that have now ranked among the top three players in this sector globally [7]. By contrast, take Toyota Mirai's FCV sales as an example; the sales price for Mirai is around CNY 400,000, which is 60% higher than

Tesla Model 3. Besides the purchase cost, the driving cost of FCVs is also higher than BVEs under the same mileage as the retail price for hydrogen is high now due to its immature supply chain [8].

Furthermore, the situation of low availability of battery charging infrastructure which heavily impacts customers' purchase intentions on BEVs has improved a lot in recent years. There were 0.45 million charging stations built by the end of 2019 in China. With intensive investments from the government, the number of new installations is planned to increase at an average ratio of 10,000 points per month in the following years [2]. Increasing public and shared charging stations provides more feasibility on battery charging to consumers, as BEVs can be easily refueled when people go outside for work and relaxation. Nowadays, as BEVs have been broadly recognized as a highly cost-effective product, more people turn to BEVs from fossil-fueled vehicles when they choose new vehicles.

In the case of FCVs, it should be noted that the global fuel cell market size is expected to reach USD 1059 million by 2024 from an estimated market size of USD 342 million in 2019 [8]. Consequently, business firms and governments at all levels are trying to increase the share of NEVs in China. For the sustained growth of FCVs, the development and growth of two important auxiliary sources of energy for an FCV, (i) batteries, and (ii) supercapacitors, are essential. For small (e.g., cars) and large applications of FCVs (e.g., busses and trains), various typologies comprising fuel cells, batteries, and supercapacitors are possible (for an excellent description and details of these typologies, please see [8]).

BYD, a Chinese brand ("Build Your Dream") in FCVs, is the leading firm with a market share of 52.4% as of the first quarter of 2021 [9]. However, the development and growth of FCVs in China face several challenges, including (i) the upstream and downstream supply chain of FCVs' lack of advanced technical competencies (ii), misperceptions about the safety and environmental friendliness of FCVs, and (iii) the cost of owning and maintaining an FCV. Therefore, the key objectives of this study are to (i) review the literature on NEV and FCV statuses in China, and (ii) identify the key factors in the development and adoption of NEVs in general and FCVs in particular. By focusing on the case of BYD, which has a strong sales network and the largest share of FCVs in China [7], this study assesses the perspectives of various stakeholders, including end-users, government officials, and industry experts in the value chain of the FCV industry [10]. By addressing the concerns of stakeholders regarding the adoption of FCVs, BYD can maintain and increase its share in FCVs and NEVs in China.

2. The Background: Challenges and Opportunities of FCVs in China

To better understand the development of the NEV industry and its role in environmental pollution reduction, potential energy savings, and the development of a more sustainable pathway for the development and growth of FCVs in China, we have reviewed the literature about (i) the status of the NEV industry, (ii) challenges and opportunities of BEV and FCV technologies, and (iii) a potential framework for the analysis of the possibilities and constraints for BYD in FCVs.

2.1. Development and Growth of NEVs in China

China has surpassed the United States as the world's largest automobile market since 2009. Benefiting from the rapid development of the automotive industry over the past decade, the emerging NEV industry in China has also made remarkable progress which attracts worldwide attention [10,11]. In China, BEVs, and PHEVs (Plug-in Hybrid Electric Vehicles) are categorized as electric vehicles with FCVs under the sector of NEVs, which can be further explained in Figure 1.

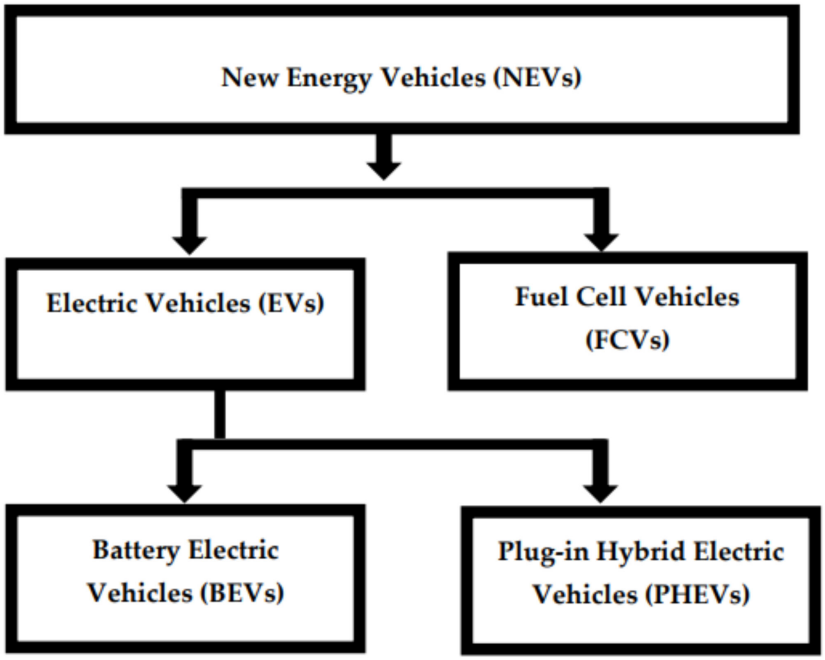

Figure 1. Key elements of NEVS (Source: [12]).

BEVs are full battery electric vehicles that can be powered solely by battery and must be charged by plugging them into a power outlet. FCVs rely on a fuel cell unit to generate electricity to power the motor; generally, compressed hydrogen is used for FCVs [12,13]. Although the current NEV market in China is dominated by BEVs and PHEVs, our study only focuses on BEVs and FCVs, as PHEVs, which still rely on fossil fuels, will be eliminated by the market from a long-term perspective.

Through the government's stimulation policies, such as purchase subsidies and tax exemption, 1.18 million NEVs with more than 100 diversified models were sold in China's local market in 2018 which maintained the country's standing as the largest NEV market globally [4,14]. BEVs accounted for 76.8% of the total sold volume, leaving the remainder for PHEVs. On the other hand, the commercialization of FCVs is still in progress. For instance, in terms of patent applications, the top enterprises are joint ventures, and most of the local enterprises in China do not rank in the top 10, as in Table 1 below [15]. Foreign brands from developed countries, such as Japan, the United States, Korea, and Germany, all have a patent layout in China. By applying for patents in China, they seek protection in the Chinese market, which also reflects the importance that other countries attach to China's market. These manufacturers not only have a large number of patents but also have high technical content. Most of the core technologies of hydrogen fuel cells have been mastered by them, which puts great pressure on the patent application in China. Moreover, the application of each country focuses on the hydrogen fuel cell and its manufacturing, and hydrogen storage fields, while China's patent covers only a few core fields, leading to the lack of dominance in the patented technology [16].

Although a huge investment has been made by multiple automotive markers, most FCVs are still concept cars; mass production is restricted by the high cost of the fuel cell unit. However, to meet the government's obligation on greenhouse gas emission reduction targets along with the vision of 'Made in China 2025' (which aims to elevate Chinese enterprises from world assembling centers to global innovation leaders [16,17]), the development of fuel technology and its commercialization needs to be accelerated.

Table 1. Preview of patent applicators.

Rank	Applicators	Number of Patients
1	Hyundai Motor Company	405
2	Honda Motor Co., Ltd.	322
3	Toyota Motor Corp.	164
4	Nissan Motor	139
5	Toyota Jidosha Kabushiki Kaisha	128
6	Kia Motors Corporation	70
7	Honda Motor CO5326	51
8	Renault SAS	51
9	Daimler AG	48
10	Suzuki Motor Corp.	39
11	Hyundai Motor Co., Ltd.	37
12	Nissan Motor Co., Ltd.	37
13	Hyundai Mobis Co., Ltd.	35
14	ERISCHE Motoren Werke Aktiengesellsch	34
15	Suzuki Motor Corporation	34
16	General Motors Corporation	32
17	Renault SA	30
18	GM GlobalTechnology Operations LLC.	26
19	Toyota Motor Co., Ltd.	25
20	Gen Motors Corp.	24

2.2. Dynamics of BEVs and FCVs in China: Challenges

With numerous local participants mass production of BEVs for several years, an integrated industrial chain has been built in China to deliver economies of scale. BEVs are not only adopted by private owners but also by commercial or public fleets, such as taxis, buses, and trucks [18]. BEVs, as commercialized and matured products, play a crucial part in reducing carbon emissions and alleviating the problem of oil dependency in China [13]. Through the government's stimulation policies, the sales volume of BEVs has been increasing significantly over the past five years. There were 0.96 million BEVs with more than 164 diversified models sold in China in 2019 which maintains the country's rank as the largest NEV market globally [2]. BEVs acquired a share of 80.1% in 2019 in the NEV market and have been widely accepted by Chinese customers. BEVs are not only adopted by private owners but by commercial or public fleets, such as taxis, buses, and trucks [18,19], Furthermore, BEVs play a crucial part in reducing carbon emissions and alleviating the problem of oil dependency in China.

Although BEVs' sales volume significantly increases year over year, its penetration rate was only 3.84% of the total sold passenger cars in 2018 [14]. Mileage limitations, long charging times, and the risk of spontaneous combustion have been recognized as the top three concerns regarding the adoption of BEVs from a customer perspective [19]. Although the rapid development from local battery manufacturers, such as BYD, and CATL, has helped the country to catch up with the leading-edge technology in this field [6], still a gap exists between manufacturing providers and marketing requirements on the performance of the battery.

By generating electricity from hydrogen in a clean, emission-free chemical process, fuel cells lead to a highly efficient powertrain with zero pollution. With its relatively small size, a fuel cell provides design flexibility in vehicles [20]. FCVs allow long driving range

and hydrogen refueling can be as simple as a conventional vehicle. Compared to BEVs, FCVs have been developed since the early 2000s due to their operational advantages and environmental privilege. However, there were only three models: Mirai from Toyota, Tucson ix35 Fuel Cell from Hyundai, and Clarity from Honda, available for sale worldwide in 2017, which indicates the slow progress of FCV commercialization [16]. It takes a long time for the automotive maker to realize mass production of FCVs. For example, Toyota had spent 25 years in the development cycle to make the Mirai model. Production cost is one of the major barriers to commercialization of FCVs. Further, the lack of a distinction between the policies for EVs and FCVs provides obstacles to the advancement of FCV-related technologies [11,17]. Besides the regulatory and cost issues, a mature supply chain of hydrogen can also determine the sustainability of the FCV industry. Due to its special chemical characteristics, hydrogen is difficult to store and distribute. The cost of building a hydrogen refueling station is much higher than a charging station for BEVs. Therefore, it is imperative to critically assess and analyze the issues faced by various stakeholders to promote FCV production and adoption in China.

3. Methods and Materials

To better understand the dynamics of NEVs and FCV development and account for the adoption of FCVs in China and FCV industry-specific data, in this exploratory study, mixed methods (e.g., application of Porter's Five Forces Model utilizing qualitative (i.e., literature and semi-structured interview data) and descriptive analysis (using questionnaire data) for demographics, cost, safety, and emissions variables associated with the adoption of FCV in China) are used in this research. Figure 2 describes the key steps of the methodology.

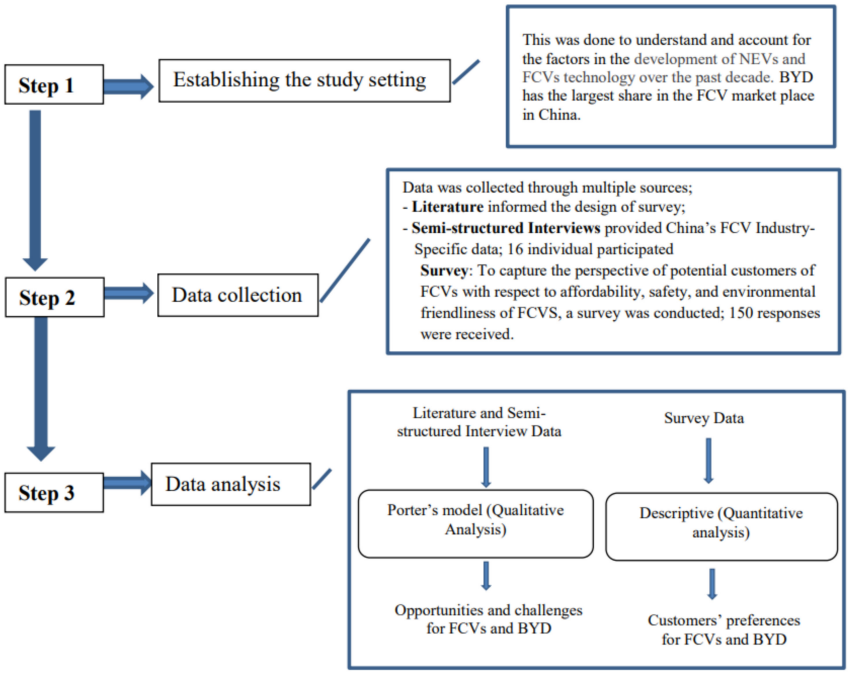

Figure 2. Key steps of methodology.

3.1. Establishing the Context

Using various resources (e.g., the online library of the university, web of knowledge, Frost and Sullivan, and Google Scholar), we conducted an in-depth literature review to gain knowledge about the development and growth of the FCVs industry in China. To properly capture the industry development trends, we also reviewed several industrial and technical reports. Critical factors in the adoption of technology were identified to form the basis of relevant data collection through semi-structured interviews and questionnaires.

3.2. Data Collection

In this exploratory study, we utilized multiple sources to obtain data regarding the dynamics of FCV adoption in China: (i) literature, (ii), semi-structured interviews, and (iii) questionnaire.

As the commercialization of FCVs in China is a work-in-progress, the literature review is the critical method of data collection about the basic knowledge, development, and perceptions of the FCVs industry. In a systematic review, we searched articles using the following keywords: "electric vehicles", "new energy vehicles", "battery electric vehicles", "fuel cell vehicles". Meanwhile, Boolean terms have been applied during the search; we used different combinations between those keywords and other terms that relate to this study, such as China, benefits, development, etc. This structured review informed the development of questions for semi-structured interviews and the questionnaire.

Individual semi-structured interviews were conducted to gain insights into the stakeholders' perceptions about the adoption of technologies, and the dynamics of the FCV value chain in China. Interviewee targets included R&D engineers and professionals in the FCVs industry. As relatively few people are working in the FCVs industry and strong network connections with the FCVs industry are not present, only limited interviewees (sixteen) were found. All team members attended the virtual interview via the most popular online chat tool in China "we chat." The interviews were recorded and transcribed, anonymously. The interview questions were prepared based on a literature review focusing on the following aspects: (i) strength in FCVs (selling points), (ii) upstream and downstream key factors in the adoption of FCVs, and (iii) key factors impacting the cost of FCVs in China.

A questionnaire was designed to collect potential Chinese users' perceptions about FCVs to identify their motivation for purchasing FCVs. Questionnaires were designed and distributed to respondents electronically using email. The majority of questions are designed to be closed-ended questions. The purpose of the questionnaire is to identify potential buyers of FCVs, the recognition of FCVs' costs, and related services. The key constructs covered are recognition of FCVs (e.g., the knowledge level of FCV technology principles, the environmental impact of adopting FCVs technology, acceptance of adopting FCVs technology), key factors in the decision about purchasing FCVs (e.g., expected purchase price and cost performance, safety assessment, government subsidies and other stimulating policies, FCVs' life cycle and maintenance cost, and feasibility and affordability of acquiring hydrogen), and respondents' demographic information (e.g., age and gender, occupation, annual income, car-owning status, and the frequency of using a car). A pilot study was carried out to refine the questionnaire. We administered 400 questionnaires in two megacities of China, Shanghai and Beijing. A total of 150 questionnaires (a response rate of 37.5%) were collected and included in our analysis.

3.3. Framework for the Analysis

Michael Porter's Five Forces Model [21] will be applied here to analyze the feasibility of BYD to adopt new technology for FCVs. This model allows a systematic assessment of a company's position in the competitive environment and can perform a cross-sectional scan of the profitability and attractiveness of industry [22,23]. Therefore, an application of Porter's model can help BYD assess FCVs' attractiveness, how the development of FCVs will affect current NEV competition, and how BYD can position itself for success.

In this analysis, the degree of matching between BYD's current resources and FCVs will be examined. Besides, there is no immutable market, and there is no one-model-fits-all strategy either. Strategy formulation is a dynamic process of constant feedback and constant adjustments. It is necessary to maintain a certain degree of strategic flexibility for BYD. As the role of people in BYD is expected to become more important, the design of an effective and diversified incentive system will also be analyzed by applying Porter's model. We will not only focus on parts of the macro analysis but also use the strategic analysis to figure out how to guide FCV adoption strategy via increasing competitive advantage. Additionally,

we will use Porter's Five Forces Model to analyze the fuel selection for electric vehicles in the Chinese market.

Overall, we applied both qualitative and quantitative tools to perform the data analysis. As this is an exploratory study, the main analysis of the development and adoption of FCVs in China is based on the application of Porter's Five Forces Model, a qualitative method. From a consumer perspective, the main factor which affects their purchase decision is FCVs' cost performance [24]. We conducted statistical descriptive analysis regarding variables such as purchasing cost and operation cost, background and motivational factors, and safety and environmental friendliness of FCVs.

4. Results and Discussions

For the development and growth of FCVs in China, here we analyze and discuss our results utilizing Porter's Five Forces framework.

4.1. Threats of New Entrants and Implications for BYD

After years of efforts, China's hydrogen fuel cell industry has been transformed from small-batch and foreign aid-dependent test launches in some cities, to local independent research and development for innovation and commercialization. However, according to the China Association of Automobile Manufacturers [25], in 2019, FCV production and sales reached 2,833 units and 2,737 units, reflecting 85.5% and 79.2% year-on-year increases, respectively [26]. Compared with the large potential market size in China, there is great potential for FCV market development in China. For BYD to introduce FCVs, it is both an opportunity and a challenge, which is the same as other current or potential new entrants.

Considering the opportunities, there will be many new entrants coming, who will threaten BYD's FCV transformation. One reason is that China's market never faces the difficulty of capital investment [5,24,27]. With the global economy under downward pressure due to the COVID-19 pandemic, China's economy remains the hope to boost world growth. The Chinese market has seen at least 49 investment, merger and acquisition deals announced in 2019 regarding hydrogen and fuel cell businesses. The total funding involved in these deals exceeded CNY 100bn, compared to an overall CNY 85bn investment in 2018 [28,29]. The growing investment is mainly supported by the local government's ambitious plans. Therefore, capital investment is not the biggest obstacle to new FCV entrants.

Domestic new entrants might come from current OEMs. Most current FCV players are local OEMs, such as BYD, as they have the advantage of local existing dealerships. Similarly, once the market and technology are well developed, other OEMs can also join in, because they all have the advantage of local dealerships. They are likely to compete with BYD in terms of channel penetration.

While new entrants from abroad will bring threats to BYD, China is capable of independent production of FCV technology. However, China's research on FCV technology is still in the initial stages, There are a few high and new technology enterprises committed to the R&D and production of dynamic hydrogen equipment in China. Currently, for small OEMs, the high cost of R&D and infrastructure investment and relatively low-profit margin (compared with BEVs) have led the potential new entrants to stay on the sidelines. Despite the Chinese government's provisions of fiscal subsidies, still there is a lack of economies of scale. The Chinese government is now shifting subsidies for FCVs from OEMs to hydrogen stations. Consequently, the competition would become severe.

In summary, threats to BYD include local new entrants' strong sale networks and patent protection from foreign new entrants.

4.2. The Threat of Substitutes for BYD

As mentioned above, the commercialization of FCVs is still in its early stage in China, in addition to the threats of the new entrants, the threats coming from the substitutes also bring a big challenge to BYD. However, the biggest threat to FCVs' substitution is no doubt, BEVs. As the mainstream technology of NEV currently, BEVs dominate the

NEV market globally. BEVs' mass production has also been realized for many years in China. The increasing popularity of BEVs has been recognized as the biggest threat to FCVs which also can restrain FCV adoption in the future. Compared to other global FCV players who have obtained leading-edge technology in this field, Chinese OEMs started later. Moreover, Chinese OEMs invested less in R&D, which is one of the major roadblocks to promoting FCVs in China. "Some domestic companies that make hydrogen fuel cell reactors claim to be large, but they rely on imports for all their raw materials". Wang Cheng, a professor at Tsinghua University's Institute of Nuclear Energy and New Energy Technology, said in an interview that domestic companies mainly buy membranes and catalyzers and reassemble them, with key technologies and raw materials monopolized by foreign countries. Therefore, it seems imperative that governments at various levels can help address these challenges to enable competitive development and growth of the FCV industry in China. Consequently, the adoption of FCVs will rise and will help firms, such as BYD, to overcome the challenge of substitutes, such as BEVs.

4.3. Bargaining Power of the Supply Chain of BYD

After analyzing the external factors caused by the new entrants and substitutes, the internal elements, such as the bargaining power of suppliers, should be taken into consideration by BYD as well. The supply chain of BYD can be divided into two groups. The first group is the current supplier base that can be shared among traditional fuel vehicles, BEVs, and the new FCVs, such as the suppliers for body, exterior, interior, and chassis. The technology and quality are stable and mature for these traditional components; therefore, it is hard for suppliers to differentiate their offerings. It means that OEMs have the freedom to choose from a variety of suppliers with relatively low switching costs. The other group consists of special suppliers which are dedicated to FCVs, most importantly fuel cell module suppliers. The rapid growth of those suppliers in recent years has led to a very high barrier to entry in terms of technology and capital investment. Especially those from Japan, which possesses the ability to vertically integrate its supply chain in fuel cell manufacturing. In this situation, the OEMs in China cannot find a way around them, and it empowers the supplier to have greater bargaining power over BYD.

4.3.1. Number of Suppliers

As mentioned above, Japan's fuel cell supply chain is relatively close to itself. Although there are several suppliers for key components in the industry, in the end, they all become internal subsidiaries of the Japanese OEMs through investment. However, the suppliers from Canada and North America, such as Ballard, Hydrogenies, and Plug, are relatively more open compared to the Japanese competitors [22,30]. They are currently the leading suppliers for the stacks in the world, willing to cooperate with the fuel cell module suppliers globally.

In China, the middle stream of fuel cell module suppliers is also developing very fast. In the 'List of New Energy Vehicles Recommended Models for Promotion and Application' issued by the Ministry of Industry and Information Technology from 2018 to 2019, a total of 93 fuel cell models from 21 OEMs are listed and eligible for subsidies, and 32 of them are supported by middle stream fuel cell module suppliers in China [23,31]. Among them, the top five companies of fuel cell modules with the most installation volume in China are Refire Group, Beijing Sinohytec, Horizon, Sunrise Power, and Vision Group (Zao et al. 2020). A large and strong FCV industry in China should enable BYD to grow its market share sustainably.

4.3.2. Unique Services

The core advantage of the global suppliers is that they have full capability of independent R&D and manufacturing of the upstream material for the stack, such as the proton exchange membrane, catalyzer, and gas diffusion layer, which contributes to more stable and controllable quality performance of the fuel cell module (as shown in Figure 3). On

the other hand, "the domestic fuel cell module suppliers have the lesser capability for the moment," said an FCV industry expert in the interview. For BYD, a systematic and balanced approach whereby smooth supplies (utilizing both domestic and foreign suppliers) can be ensured, appears to be the way forward.

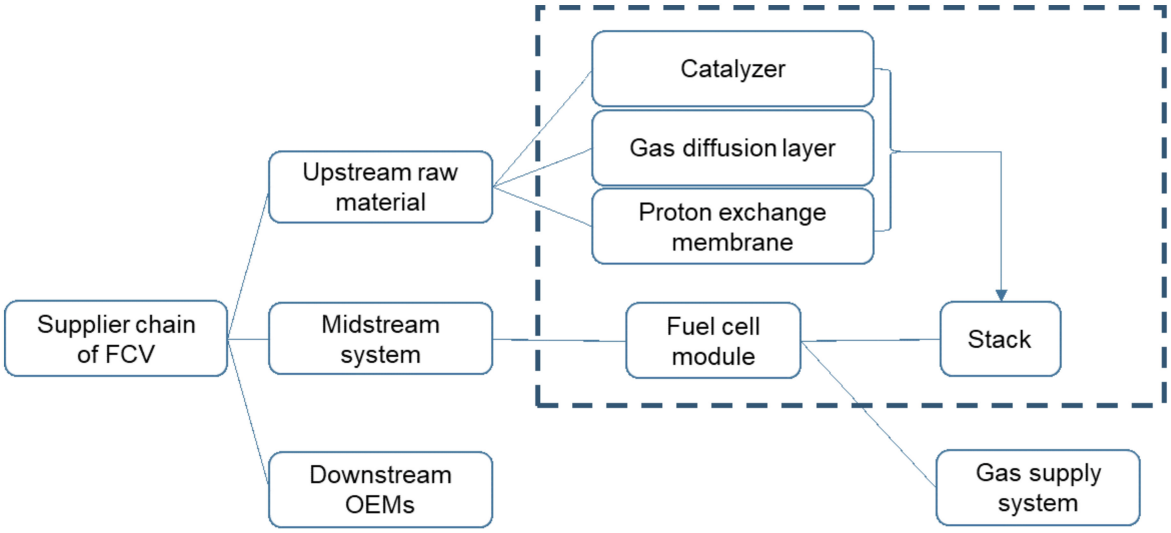

Figure 3. Supplier chain of FCV.

4.3.3. Size of Suppliers

As the supply chain for BYD, the local fuel cell module suppliers would be the first choice. In terms of the number of applied vehicles, the system suppliers that are far ahead in the amount of supporting downstream models are Beijing Sinohytec and Refire Group. The number of supporting modules reaches 20 and 14, respectively. Beijing Sinohytec provided a module for eight OEMs in the catalog, while Refire Group has supported six OEMs.

In terms of sales performance, Refire Group sold more than 1,000 fuel cell modules in 2017 and 2018, and the total sales revenue of fuel cell system products assembled in major auto plants by Refire Group exceeded CNY 300 million. In 2019, it ranked first place with an installation rate of 28%. Meanwhile, in 2019 Beijing Sinohytec sold 498 sets of fuel cell modules, achieving an income of CNY 542 million, and realizing an increase of 47.19% over the same period of the previous year [24,32]. Likewise, the increased capacity of the suppliers of auxiliary energy sources (batteries or supercapacitors) is likely to support the development and growth of BYD's supplier chain of FCV.

4.3.4. Cost of Changing

Take Refire Group as an example. In 2016, to introduce Ballard's technology, Refire Group paid USD 20 million for the technology transfer and established a joint venture with 90% of the shareholding. Refire Group also signed a contract with Ballard to purchase membrane electrodes with a minimum value of USD 150 million from Ballard in the next five years.

After the introduction of this technology, the stacks of Refire Group are mainly produced by its joint venture with Ballard. Refire Group has established the world's largest stack production line with an annual capacity of 20,000 units in Yunfu, Guangdong. The product life span is more than 15,000 h, which meets the requirements of commercial vehicles and realizes mass production. Refire Group sold about 3000 units in 2018, with more than 2000 units installed in the domestic market vehicle, quickly reaching 70% market share, and Refire Group become the biggest domestic electric stack supplier [24,33].

Therefore, if BYD adopted Refire group as its fuel cell supplier, then the cost of changing would be extremely high. This is because fire group can claim its advanced lump sum investment for introducing high technology from Ballard, ensuring its production

quality. In summary, the bargaining power of the suppliers is extremely strong based on the current situation. Therefore, overcoming the pain points in the supply chain, cost-effective supply of technologies (i.e., batteries and supercapacitors) for the auxiliary energy sources, and creating value through its dynamic capabilities will become the key factors to the success of BYD's future adoption of FCVs.

4.4. Bargaining Powers of Buyers and BYD

Affordability and preferences of buyers are key determinants of their NEV purchasing decision. Therefore, here we present an analysis of purchasing power of buyers and their major perceptions regarding the adoption and use of FCVs.

4.4.1. Analysis of Purchasing Power of Buyers

The analysis of potential buyers' purchasing power is highly important to market segment strategy. Based on the survey, two aspects of potential buyers' purchasing power are analyzed:

1. What cities have more annual household earnings?
2. What is the acceptable FCV price to respective respondents with different annual household earnings?

As shown in Figure 4, the annual household earnings are below CNY 30k, tier 1 cities 25%, tier 2 cities 54.16%, tier 3 cities 100%, and villages 71.38%. It appears that tier 2, 3, and villages have a higher percentage than tier 1. For the annual household earning above CNY 30k, tier 1 cities 75%, tier 2 cities 45.84%, tier 3 cities 0%, villages 28.57%. Tier 1 has a higher percentage than the others. Tier 1 cities have a far leading percentage of 40.52% if annual household earnings above CNY 50k are analyzed, while tier 2 has only 4.17% and the others are 0%. It does indicate that higher-tier cities have a higher percentage of higher annual household earnings.

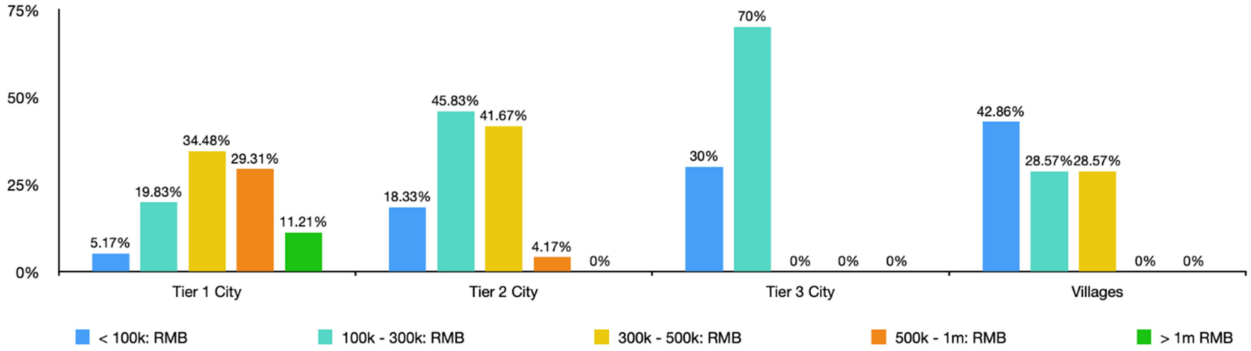

Figure 4. Status of respondents' residential city and annual household earning.

For the annual household earning below CNY 100k, they can mostly accept FCVs with a price range between CNY 100k–200k (92.86%), and only 7.14% can accept FCVs with a price range of 200k–300k, as shown in Figure 5. There is no acceptance of FCV prices above CNY 300k. It is quite challenging for a manufacturer to price FCVs at CNY 100k–200k by current technology and market share, even though the market share is high.

The percentage of acceptable FCVs priced 200k–300k grows and keeps a high percentage at 42.86%, 52.94%, and 48.57% for the respective annual household earnings of CNY 100k–200k, CNY 300k–500k, CNY 500k–1m. This market segment is still promising if the price of FCVs can be achievable at 200k–300k.

It is interesting to note that the percentage of acceptable FCV price at 300k–400k, as this percentage significantly rises to 75% for the annual household earnings above CNY 1m, while it is quite low for the rest of the categories of annual household earnings. It seems feasible to price FCVs at 300k–400k for a market segment with annual household earnings above CNY 1m; however, the percentage of this market segment is merely 7.79% according to the survey. It is quite a low figure for the percentage of acceptable FCVs priced 400k–500k

and above CNY 500k, for all annual household earnings. It is very few market shares if the FCV's price is high above CNY 400k.

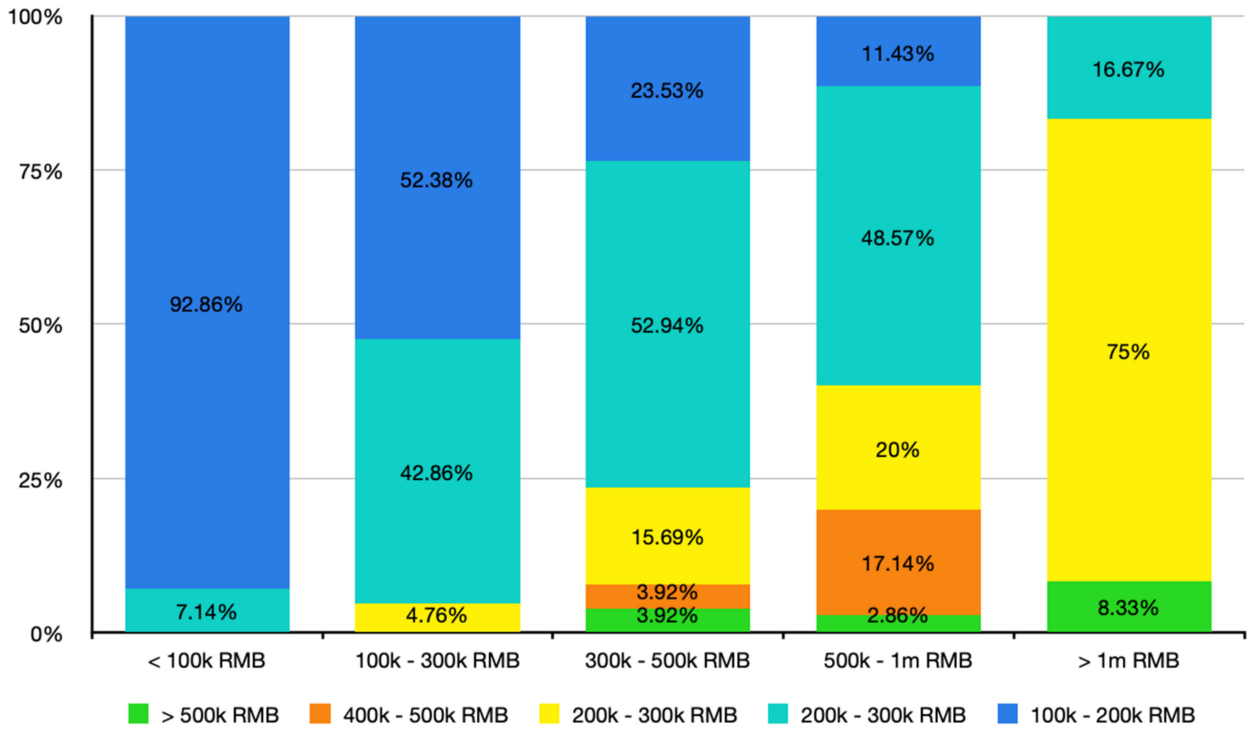

Figure 5. Annual household earning and acceptable FCVs price.

4.4.2. Analysis of Potential Buyers' Preference and Bias

In addition to the basic information of potential buyers, some preferences and biases are analyzed to gain insights into their take on FCVs and the technology features. As shown in Figure 6, 70.12% of the respondents accept an FCV's useful life span can be designed as long as 8 years for passenger cars, which is not a big challenge for FCVs with current technology, as the capability of FCVs today can reach 8 years.

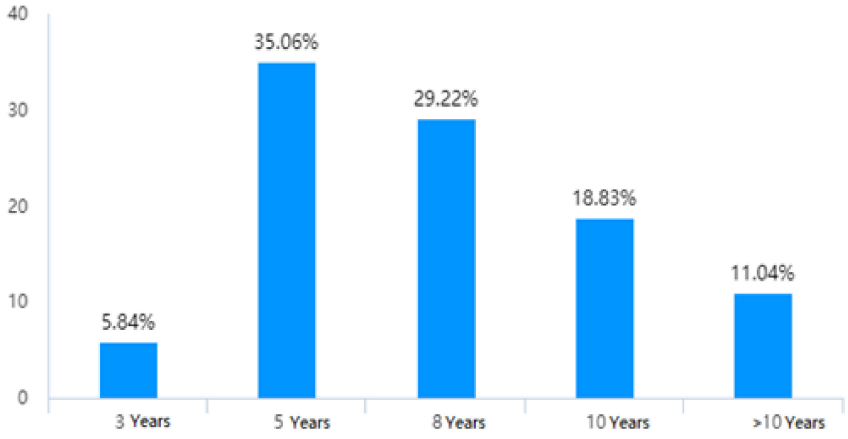

Figure 6. FCVs useful life.

A total of 66.23% of the respondents perceive that hydrogen fuel is cheaper than gas fuel, as shown in Figure 7. However, as the network of the hydrogen charging station is not widely spread, it creates a challenge for having cheaper hydrogen. Hence, the adoption of FCVs is very limited.

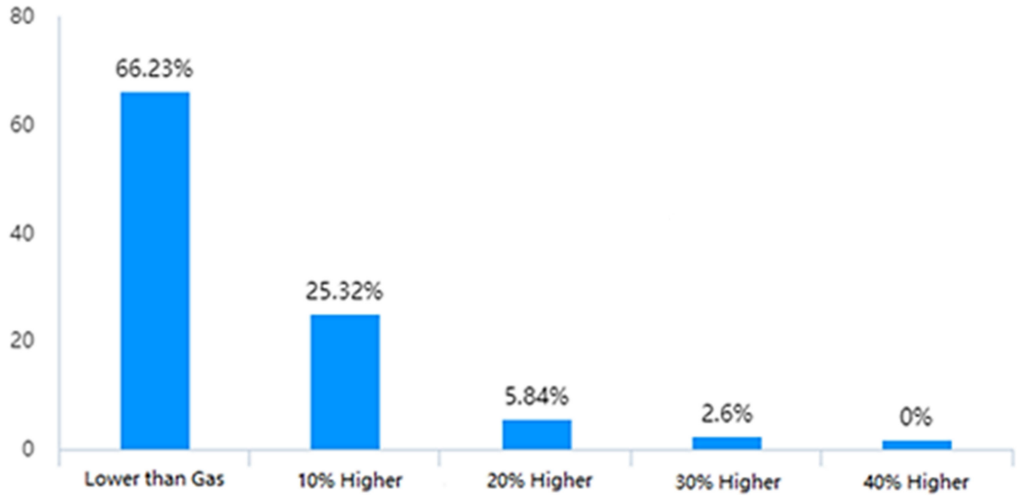

Figure 7. Acceptable hydrogen price.

Figure 8 shows that 79.87% of the respondents prefer the charging station should not be as far as 5km away from their home. The data indicate that potential buyers take the convenience of daily car usage as a priority.

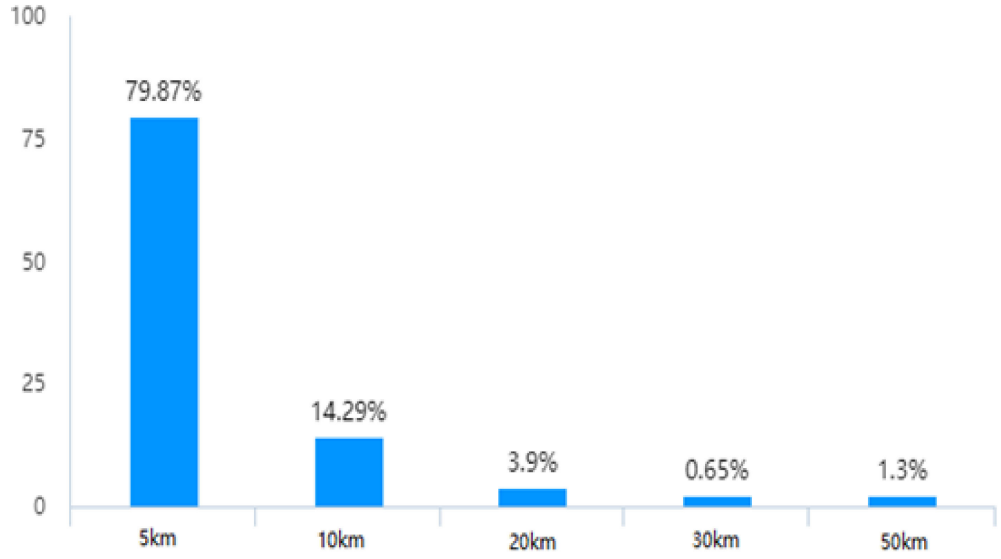

Figure 8. Acceptable hydrogen station distance.

A total of 64.28% of the respondents did not believe environmental protection is so important and a priority when they choose to buy passenger cars (see Figure 9). This can put the adoption of FCV technology initiatives in an awkward position as FCV adoption can support the goal of achieving zero-emission for environmental protection. Here, a government policy can play a critical role in the promotion of FCVs in the market with the hope of achieving targeted emissions levels for the country.

It is not surprising that over 88% of the respondents take safety as a high priority, as in Figure 10. On the other hand, people misperceive hydrogen-based solutions as dangerously explosive. These safety-related biases and misperceptions could be a factor in the low adoption of FCVs in China. Here, education and awareness about the usefulness of hydrogen-based solutions appear to help increase the adoption of FCVs.

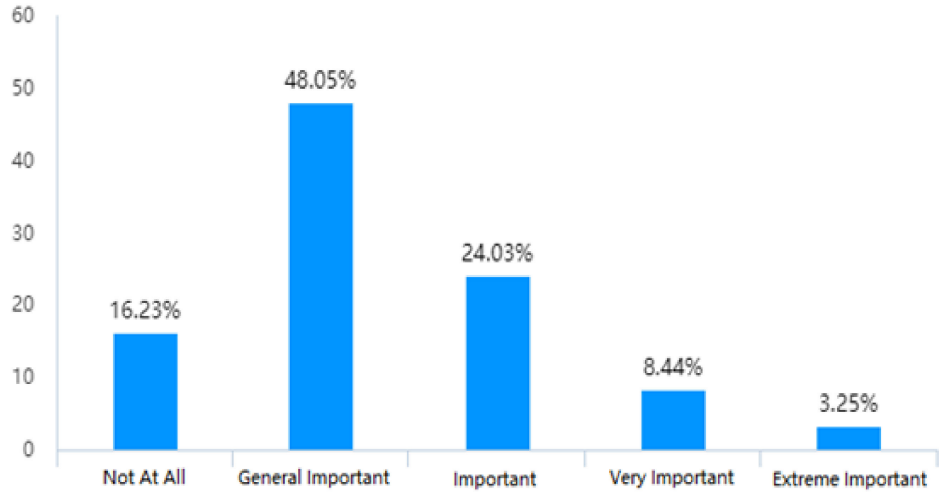

Figure 9. Perception of environmental protection.

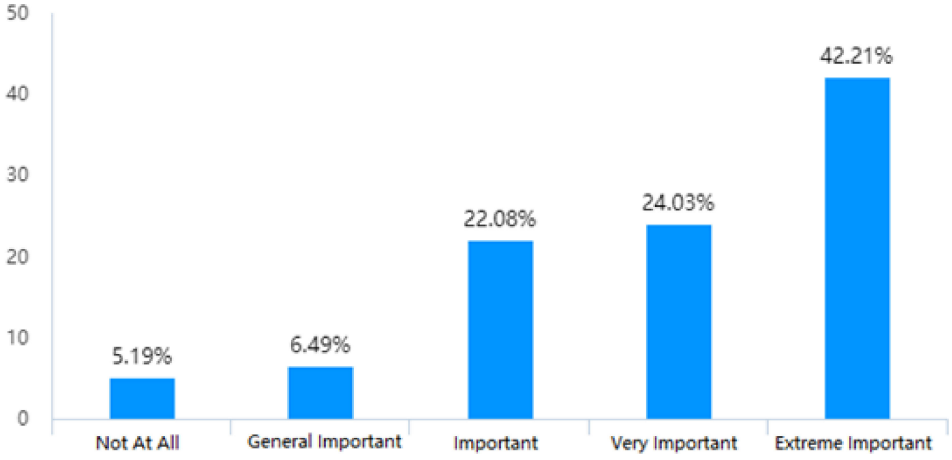

Figure 10. Perception of safety.

Figure 11 shows that the importance of the number plate to the buyers is spread in a normal distribution. It looks like there is no significant preference by the potential buyers according to the survey. However, when the need for a number plate is associated with the buyer's residential city, some interesting patterns emerge, as shown in Figure 12.

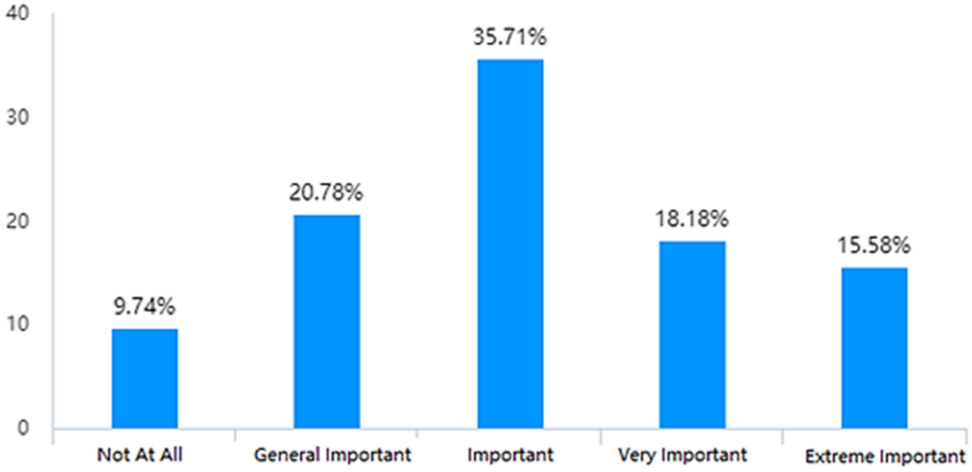

Figure 11. Perception of number plate.

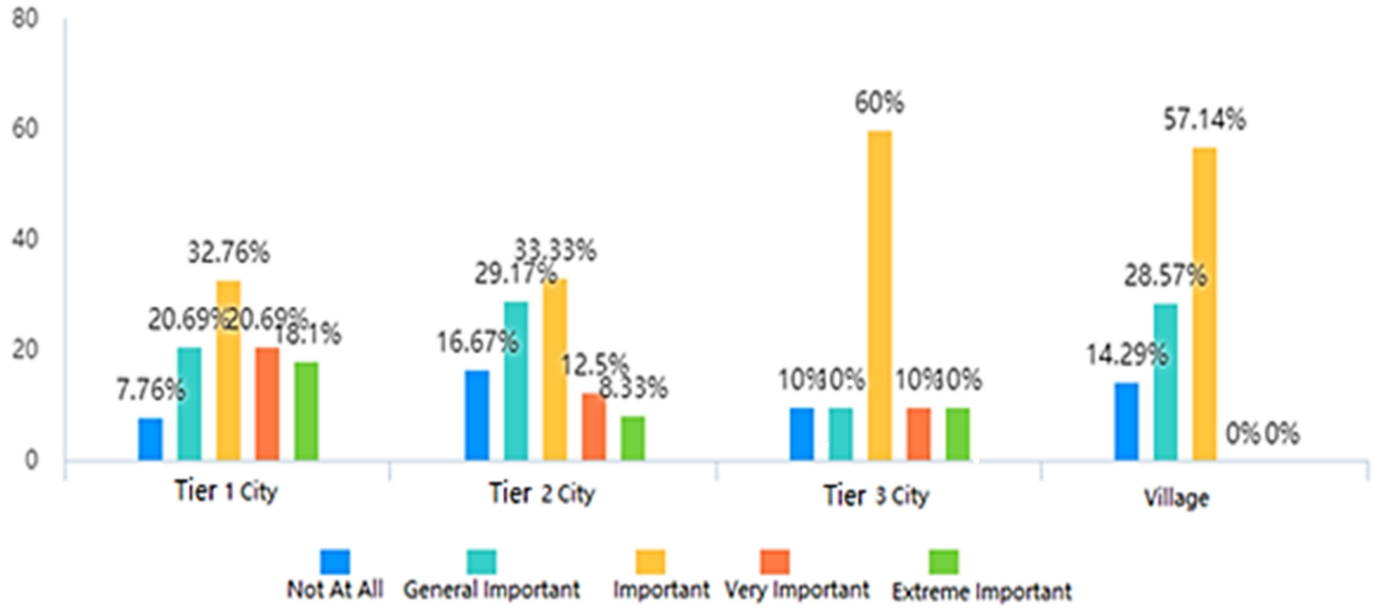

Figure 12. Residential city and perception of number plate.

For instance, when looking into the perception of very important and extremely important, the higher-level tier city takes more priority on number plates: 38.79% for tier 1 city, 20.83% for tier 2 city, 20% for tier 3, and 0% for villages.

By current transportation policy, there are more limitations in the higher-level city to obtain the number plates. Take the example of Shanghai, it takes at least CNY 80k to obtain a number plate for a gas car, and a lucky draw is conducted to distribute the paid number plates. To encourage BEV cars, the Shanghai government issues the number plates for free. Therefore, a number plate can be part of the cost to buy a car in first and second tier cities.

On average, 47.4% of the respondents recognize the BYD brand (see Figure 13). However, as shown in Figure 14, when looking into details categorized by acceptable FCV price, the brand recognition becomes lower when the acceptable price is higher: 56.86% for CNY 100k–200k, 45% for CNY 200k–300k, 38.46% for CNY 300k–400k, 25% for CNY 400k–500k, 0% for above CNY 500k.

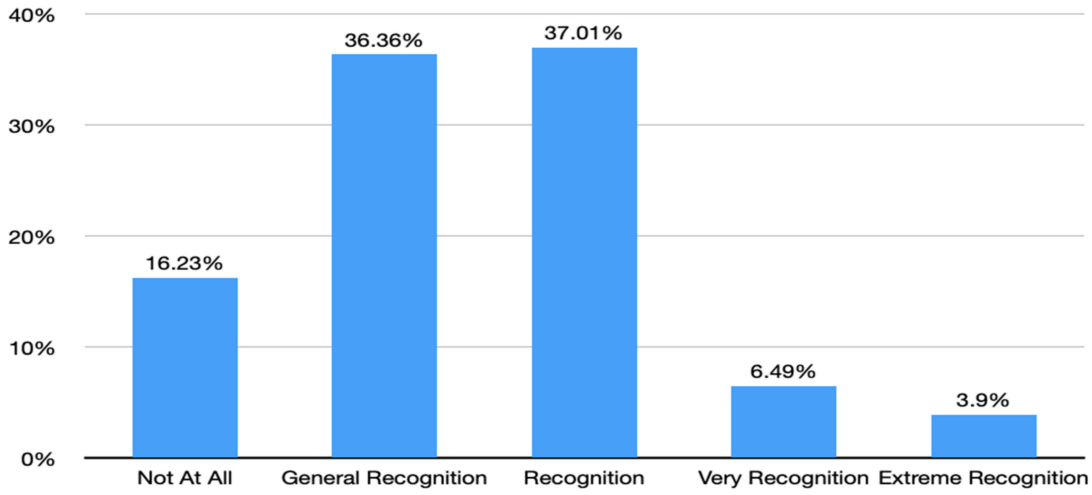

Figure 13. Recognition of BYD brand.

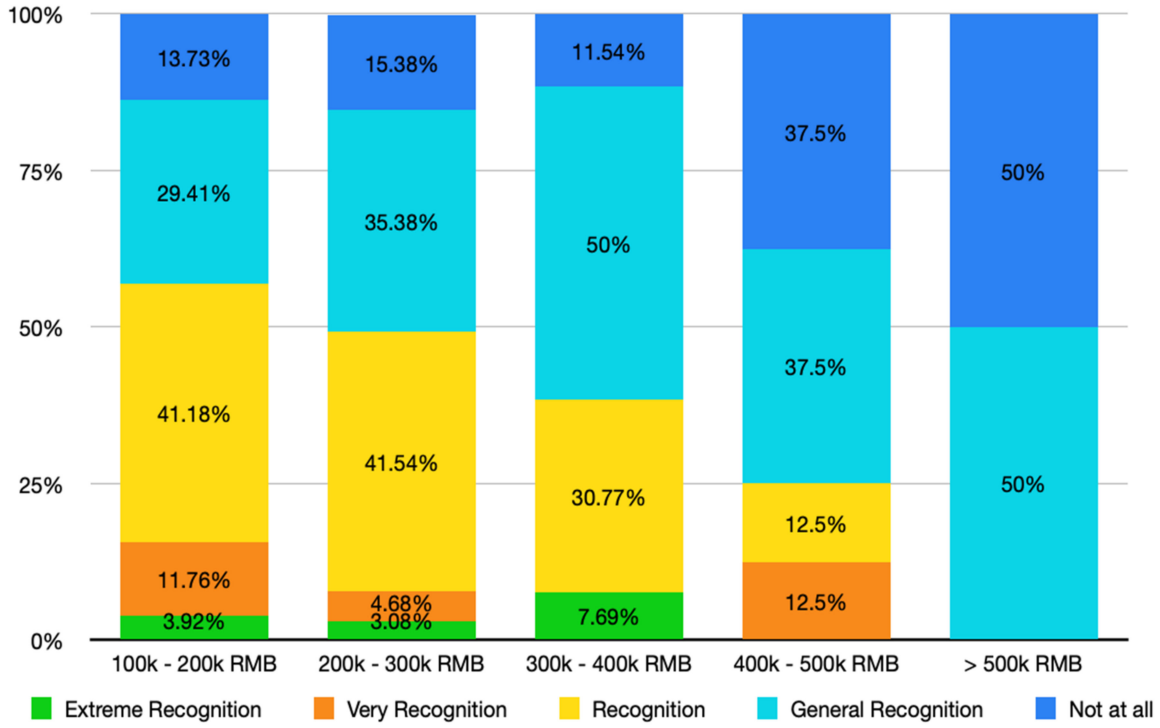

Figure 14. The Acceptable FCV Price.

The overall perceptions about various factors in buyers purchasing decisions are presented in Table 2.

Table 2. Buyer's bargaining power perceptions.

Key Factors	Buyer's Bargaining Power Perceptions
Cost	Strong: FCV prices are very high compared to BEVs and gas cars; hydrogen fuel price is higher than gasoline.
Quality	Weak: FCV quality and useful life are as good as BEVs
Hydrogen Charging Stations	Strong: No wide network of hydrogen gas stations.
Environment	Medium: Buyers do not care about the environment, even though FCVs are extremely eco-friendly.
Safety	Medium: FCVs are very safe but the bias of buyers should be addressed as they may perceive FCVs as unsafe.
Driving License	Medium: No free driving license for FCVs by the government yet.
Recognition of BYD	Strong: BYD is not well recognized.

4.5. Rivalry among Existing Competitors

4.5.1. Number of Competitors

In total, 28 listed companies manage the FCVs in China. These companies are the competitors of BYD. For instance, the fuel cell project of Shanghai Jetco Technology Co., LTD. (HongKong, China), a subsidiary of Shanghai Automotive Industry Corporation (SAIC), officially launched in Shanghai, aims to realize the production capacity of 12,000 fuel cell power reactors and systems by 2021. At the same time, Chery Automobile also made a new move in the field of hydrogen FCVs. The first phase of Shanghai Jetco's fuel cell project is set to go into production in August next year, and it is expected to reach CNY 1.2 billion by 2024. BYD has to pay close attention to this development.

4.5.2. Quality Difference

We consider the Shanghai Automotive Industry Corporation (SAIC) as a key competitor with BYD. Shanghai Automotive Industry Corporation's technology advanced degree has a wonderful bright spot. SAIC's R&D center is unique in the design of exterior and interior decoration. SAIC's products, whether for traditional cars or new energy vehicles, cannot be separated from the support received from global suppliers. SAIC also lacks research and development of core technologies, and many materials need to be sourced globally. In the current pandemic environment, BYD has more advantages. BYD has its R&D in battery technology, and BYD is developing and producing core components by itself. SAIC, on the other hand, can often obtain high-quality and mature subsystems from its global suppliers. Thus, the overall proportion of SAIC's research and development, and local production, is less than BYD. Therefore, BYD is well poised to grow its share.

4.5.3. Switching Cost

According to our survey, 42% of people would like to accept CNY 200K to 300K as the price of FCV, and 66% of people are willing to accept the price of fuel that is lower than the gas price. For the switching cost, the price of FCVs does not have too great a gap with the NEVs, while the daily fuel fee is a big concern for customers.

The high cost of fuel cell stacking is mainly due to the low output, high complexity of the fuel cell system, and high cost of materials. If we can scale it up and can make breakthroughs in technology, then the cost can reduce effectively and directly. The U.S. Department of Energy calculates that a tenfold increase in production would reduce vehicle costs by 23%. Meanwhile, with the breakthrough of electric reactor technology, the cost will fall by 23%. The combined cost reduction would be 45%, which can create another opportunity for BYD's growth.

4.5.4. Customer Loyalty

Customer loyalty refers to the tendency of customers to have a favorable impression of a product or service and they make repeated purchases. According to our survey, 45% of people recognize and accept the BYD brand. The BYD brand is reliable and innovative for customers. Furthermore, in 2016, BYD Auto Sales Co., Ltd (Xian, China) won the "2016 China Auto Service Golden Wrench Award – Customer Loyalty Award". Higher customer loyalty helps the firm keep the customers for repeat purchases. BYD can continue to invest in building higher brand recognition to solidify its market share in FCVs in China.

5. Conclusions

The key objective of this study was to assess the perspectives and perceptions of various stakeholders, including end-users, government officials, and experts in the NEVs industry in China, with a particular focus on the development and growth of FCVs. Using BYD as a case, our analysis provides us with some important conclusions and insights: (i) people in the 25–40 age category are more likely to accept new technology, (ii) about 76% of people with an annual household earning above CNY 300 can accept the price of FCVs in the range of CNY 200K–300K, (iii) about 70.12% of the respondents accept an FCV's useful life can be designed as long as 8 years for a passenger car, (iv) about 9.87% of the respondents think that the charging station should not be more than 5km away from home, (v) about 64.28% of the respondents do not consider environmental protection a priority, (vi) about 88.32% of the respondents take safety as a priority, and (vii) less than 45% of the respondents who accept FCV prices at CNY 200k–300k recognize the BYD brand, and the percentage of BYD recognition is even lower as the acceptable FCV price goes higher.

Among the various factors that affect their purchasing decisions, it is interesting to note that a majority of the people of new-technology-based vehicles do not consider the "environmentally friendliness of a car" as a key factor in their decision. To increase its market share, BYD should invest in building its brand and overcome the misperception of customers about FCV as a safe and reliable car.

Given the successful outcomes of government policies regarding BEVs in China, under similar favorable policies, the supply chain of FCVs can develop and grow and BYD's market share is expected to increase. Fuel cell companies in China that form alliances with high-quality downstream customers will benefit from the high-volume increase in downstream vehicles to achieve incremental cost reductions. Therefore, it is critical for China's fuel cell industry to further enhance the independent R&D and production capacity to support the growth and competitiveness of firms in the NEVs industry [30,34]. Local Chinese OEMs, such as BYD, are expected to play a major role in this sector to achieve technology transformation and seize the market share.

Overall, for the development and growth of FCV adoption and a low-carbon lifestyle in China, simultaneous support and strengthening initiatives for the upstream and downstream activities of the value chain of the FCV industry are required. With increased investments in its brand recognition, BYG has the potential to increase its market share and profitability.

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Informed Consent Statement: Informed consent (verbal) was obtained from all subjects involved in the study.

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