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Fuzzy set qualitative comparative analysis (fsQCA) applied to the adaptation of the automobile industry to meet the emission standards of climate change policies via the deployment of electric vehicles (EVs)

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ABSTRACT

Facing global climate change challenges entails a sustainable development of transportation. Governments and automobile manufacturers are highly aware of how a large-scale deployment of Electric Vehicles (EVs) can reduce greenhouse gas (GHG) emissions and mitigate global warming. This study aids the design of the adaptation strategies of the automotive industry to meet global goals on climate change by means of a fuzzy-set qualitative comparative analysis (fsQCA), which makes it possible to measure the level of actors' satisfaction. This allows identification of a combination of factors leading to the outcome while dealing with uncertain environments due to the heterogeneous nature of actors with conflicting of interests. The methodology has been successfully applied to a case study, thus providing greater transparency, fairness, social equity, and consensus among actors.

1. Introduction

Because of climate change challenges, several intergovernmental bodies have promoted decarbonization policies to avoid crossing the safety threshold of 1.5 °C or 2 °C (Intergovernmental Panel on Climate Change (IPCC) 2019). In this sense, transport is responsible for an important part of greenhouse gas (GHG) emissions and depletion of fossil fuels (Whitehead et al., 2018; Shin et al., 2019). Nowadays, transport as a whole is responsible for about a quarter of total carbon dioxide emissions from fuel combustion and road transport is responsible for a fifth (International Energy Agency 2019). In this sense, many countries are promoting the large-scale deployment of Electric Vehicles (EVs), which may play an important role in meeting those global goals on climate change (Zheng et al., 2018). This is because EVs are more efficient than conventional fossil-fueled vehicles, and hence, are responsible for considerably lower emissions over their lifetime (Moriarty and Wang 2017). However, EVs may also lead to human toxicity and environmental problems such as freshwater eco-toxicity or metal depletion impacts.

The repercussions of technological innovations to respond to climate change and greenhouse gas emissions has already been studied (Su et al. 2017; Lamperti et al., 2020). Yong and Park (2017) carried out a fuzzy-set qualitative comparative analysis (fsQCA) on factors affecting the deployment of EVs, which present a different penetration rate in each country because of a variety of economic, social, and technological barriers. They analyzed the causal conditions of EVs adoption and their relationship with policy decisions such as tax exemption and purchase subsidies to compensate for the higher costs of EVs manufacture. They concluded that no single policy tool is effective; instead, a policy mix should be applied for a successful deployment of EVs. The purchase of EVs was also analyzed by Deuten et al. (2020), who conclude that only strong incentives lead to large sales shares of zero emission vehicles. However, Sierzchula et al. (2014) suggest the key factor related to EVs adoption is the charging infrastructure, although they suggest that neither financial incentives nor charging infrastructure ensure high EVs adoption rates. Following this line of thinking, Tran et al. (2012) showed the importance of assessing EVs deployment from an integrated perspective, focusing on key interactions between technology and behavior across different scales.

As a result, recent government policies have established a set of strategic actions aimed at favoring the shift towards other more efficient means of transport. The policy related to EVs is mainly focused on

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technological and market development, which include reliability and durability of batteries, reducing battery weight and volume, safety, cost reduction, improved hybrid electric powertrains, electricity source, charging infrastructure and plug-in solutions.

However, there are major uncertainties about how these strategies should be implemented and about their results during the transition to EVs. Furthermore, the worldwide automotive industry has been facing severe difficulties in recent years, which have led to a strong pressure on manufacturers to restructure their operations, and several assembly plants have been closed with consequent job losses. In addition, the different companies in the automotive industry continue to face the medium- and long-term challenge to remain competitive (EU 2012).

This paper is intended to provide insight into the best adaptation strategies of the automotive industry for the transition from conventional gas-powered vehicles to EVs by performing an fsQCA (Ragin 2008). This problem represents a multi-criteria decision-making (MCDM) analysis that considers a wide range of factors including management, legal, financial, technological, and environmental factors. The findings of this paper provide insight into which configuration of factors leads to the outcome (i.e. actors' satisfaction). To the best of our knowledge, this is the first time that the fsQCA has been applied to the adaptation of the automobile industry to meet the emission standards of climate change policies via the implantation of EVs with such variety of antecedent conditions or factors and actors. The methodology has been applied to the automotive industry in Spain. The rest of the paper is structured as follows: Section 2 presents the methodology developed for the adaptation of the automotive industry in order to meet climate change targets; Section 3 applies the methodology to the case study of the automotive industry in Spain; finally, the conclusion section is provided.

2. Method

2.1. EVs as an adaptation strategy for meeting climate change targets

The automotive industry is of strategic importance for the European economy and its products and services have a daily impact on the lives of European citizens. The sector represents around 12 million direct and indirect jobs and a positive contribution to the EU trade balance (EU 2020). This is an important part of private spending on research and innovation and is an essential driver of technological innovation. It is a growth multiplier due to its important economic relations with many industrial sectors. These relationships are related to the previous levels of the market, such as the steel, chemical and textile sectors, as well as the subsequent levels (information and communications technologies, repair, and mobility services).

The industrial activity of the automotive industry in Spain (including the manufacturers of vehicles and components) represents employment for around 300,000 people. The European commitment to GHG emission reductions is between 80% and 95% by 2050, which for Spain entails reductions between 14 and 88 $MtCO_2$ (Amores et al., 2016). The investments that the Spanish economy would have to make until 2050 to implement the decarbonization policies are estimated at between EUR 330,000 million and EUR 385,000 million.

As a result, the automotive industry is forced into a gradual change towards the manufacture of EVs in order to meet the various objectives set by the Regulation (EU) 2019/631 to reduce CO_2 emissions for new passenger vehicles and light commercial vehicles. This decarbonization and energy policy of the EU entails several objectives for its vehicle fleet:

- Objective 1: As of 2020, an objective of 95 gr. CO_2/km as average emissions from new passenger cars and an objective at the EU park scale of 147 gr. of CO_2/km as average CO_2 emissions from new light commercial vehicles registered in the Union.
- Objective 2: From 2021 to 2024, additional measures are proposed for the reduction of 10 gr. of CO_2/km.
- Objective 3: Starting in 2025, an objective is set at the EU park scale equal to a reduction of 15% of the target in 2021 for the average emissions of both the new passenger car park and the new light commercial vehicle fleet. In addition, a reference index is applied for zero emission and low emission vehicles equal to a 15% share of the new passenger car park and the new light commercial vehicle fleet.
- Objective 4: In 2030, it is intended to achieve a reduction of more than 31% of the target set for 2021, in addition to a very close percentage (between 30% and 35%) for the quota provided for vehicles of zero emission and low emission.
- Objective 5: Ensure the transition to mobility without emissions in a socially acceptable and fair manner, highlighting measures in employment and investment. For this purpose, public and private investment is foreseen to achieve a greater supply of zero emission and low emission vehicles that make this product available to the population.
- Objective 6: Implement refueling and refueling infrastructures and integration in energy systems, as well as sustainable supply of materials and sustainable production, re-use and recycling of batteries in Europe.

These objectives set a clear path for reductions in CO_2 emissions from the road transport sector and contribute to meeting the binding objective of internal reduction of at least 40% of greenhouse gas emissions in the economy as a whole by 2030, achieving the transition to zero net emissions of GHG intended for 2050. In this way, it is intended to guarantee the reduction through the gradual implementation of zero emission or low emission vehicles, reaching a significant quota of the market before 2030 and reaching zero in 2050.

It is worthwhile mentioning that there are other techniques which have been developed in the literature to deal with a reduction in energy consumption (Valero et al., 2019; Rubio et al., 2020; Valera et al., 2021) or to analyze the viability of using wind turbines for electricity generation in EVs (Rubio and Llopis-Albert 2019).

2.2. Summary of fuzzy-set qualitative comparative analysis

The fsQCA is a configurational comparative methodology for obtaining linguistic summarizations from data that are associated with cases. It is based on set theory and fuzzy logic (Ragin 2008). An exhaustive explanation of the theoretical aspects of this methodology is presented by Mendel and Korjani (2012, 2013). It has been applied to complex qualitative comparative problems in a wide variety of research areas (e.g. Berbegal-Mirabent and Llopis-Albert 2015; Llopis-Albert and Palacios-Marqués 2016; Llopis-Albert et al., 2018; 2019).

The main goal of the methodology is to determine which combination of configurations or pathways (i.e., factors) is minimally necessary and/or sufficient to attain a certain outcome and to identify which groups of cases share a specific combination of conditions (Meyer et al., 1993). A configuration is made up of factors or conditions that can be positive, negative, or absent. A condition is necessary if a certain outcome cannot be attained without it. Contrary, a condition is sufficient if it leads to the outcome by itself without the need of other conditions (Ragin 2008). The method assumes complex causality and asymmetric relationships, which reveals configurations that are sufficient to lead to a certain outcome. There are conditions that are sufficient or necessary for all cases analyzed. Nevertheless, conditions may be sufficient and necessary when combined with other conditions, a situation called conjunctural causation). They also may describe only one alternative among others and which is applicable only to some cases, a situation that is called equifinal causation. Hence, the methodology considers that many configurations may lead to the same outcome.

In addition, the fsQCA overcomes the limitation of dealing with binary variables. In fact, it enables analysis of different levels of belongingness of cases to a particular set. This is carried out by defining the outcome and causal conditions as fuzzy sets, where membership functions (MFs) must be settled. Firstly, a calibration procedure must be performed, which entails converting data into measures of set membership via theoretical or substantial knowledge external to the empirical data. This allows the categorization of meaningful groupings of cases (Ragin 2008). Fuzzy values describe the degrees of membership in a specific set, which range from full membership (1) to non-membership (0), while the crossover point (0.5) represents neither in nor out of the set.

Secondly, a truth table must be constructed. The size of this matrix is made up of 2^k rows, where k is the number of antecedent conditions, and each column represents a condition. The number 2 represents both the causal condition and its complement. The truth table describes all logically possible combinations of causal conditions and classifies the cases in accordance with the logically possible combinations. Each empirical case corresponds to a configuration depending on which antecedent conditions the case meets (Fiss 2011).

Thirdly, the method tries to reduce the number of rows in the truth table through the Quine–McCluskey algorithm (Quine 1952). This algorithm uses Boolean algebra to attain a set of combinations of causal conditions, in which each combination is minimally sufficient to obtain the outcome. This procedure is based on a set of indicators, such as the consistency and the coverage (Ragin 2008). The consistency quantifies the degree to which instances sharing similar conditions lead to the same outcome (Ragin 2008). Hence, the consistency measures the degree to which membership in the solution (the set of solution terms) is a subset of membership in the outcome. The coverage represents the empirical relevance of a solution, and therefore it measures the proportion of memberships in the outcome explained by the complete solution. The raw coverage illustrates the share of the outcome that is explained by a certain configuration (i.e., solution). The unique coverage expresses the share of the outcome that is exclusively explained by a certain configuration.

3. Application to a case study

The fsQCA is applied to the automotive industry in Spain. The adaptation strategies to deal with the environmental targets are based on the following actions (EU 2012):

- Investing in advanced technologies and financing innovation by means of a range of regulatory initiatives and support for research and innovation.
- Improving market conditions via a stronger internal market and the consistent implementation of proper regulation.
- Enhancing competitiveness on global markets via an effective trade policy and the international alignment of vehicle regulations.
- Anticipating adaptation by investing in human capital and skills and smoothing the social impacts of restructuring.

The design of the best adaptation strategies of the automotive industry to make a successful transition towards EVs depends on a wide range of considerations, including management, legal, financial, and technological and innovation factors. Furthermore, a total of 51 subfactors are considered in this study. The worth of considering such a variety of factors has already been discussed in the literature (e.g., Llopis-Albert et al., 2018; 2019). These factors may justify or prevent the high initial investment in the short run for the transition from manufacturing conventional gas-powered vehicles to EVs.

Table 1 shows the five factors or conditions used in fsQCA that may lead to the actors' satisfaction when designing the best adaptation policies of the automotive industry to the GHG emission standards.

The antecedent conditions regarding the management and legal factors or antecedent conditions (C1) include 11 subfactors. They cover the feasibility of implementing the adaptation strategies to the deployment of EVs considering long payback periods and the implementation

Table 1
Factors or conditions considered in fsQCA. A set of factors is considered to define the optimal adaptation strategies. These are factors that may justify or prevent the high initial investment in the short run for the transition from manufacturing conventional gas-powered vehicles to EVs.

Factors or antecedent conditions (C)	Subfactors
Management and legal factors (C1)	C1.1: Feasibility of implementing the adaptation strategies: short implementation time. C1.2: Expected improvement in productivity and performance of manufacturers in the long run. C1.3: Adaptability to changes in order to achieve flexible manufacturing systems (e.g. to address possible fluctuations in demand and failures in the production line, restriction of machines, number of workers, number of shifts, need to manufacture different products or provide services, avoid strikes or litigations, etc. C1.4: Possible dependency on third-party battery manufacturers. C1.5: Short time to gain market share from conventional combustion engine vehicles (i.e., expectations of increasing EVs sales, which entails a rapid market penetration from the actual vehicle fleet in Spain mainly based on conventional combustion engines). C1.6: Enhancing competitiveness on global markets: improve trade policy (tariff barriers) and international alignment of vehicle regulations. C1.7: Social equity, fairness, transparency, consensus, accessibility to all social strata. C1.8: Quality of products / services. C1.9: Deployment of EVs will not lead to layoffs, strikes or litigations. C1.10: Job creation. C1.11: fulfillment of environmental regulations and existing legal framework.
Financial factors (C2)	C2.1: Feasibility of implementing the adaptation strategies regarding investment costs: equipment acquisition, installation, development of new technologies, patents, etc. C2.2: Customer's willingness to pay for the initial cost overrun of EVs. The development of the technology to lower the price may take a while. C2.3: Lower maintenance and charging costs of EVs if compared with gas-powered vehicles. C2.4: Other costs such as payback periods, transportation, operation, energy and maintenance costs, depreciation, workers' dismissals and training, equipment, and battery costs. C2.5: Invest in human capital and skills to avoid the layoffs (implementation may lead to layoffs). C2.6: Long amortization period because of the transition from conventional combustion engines to EVs. C2.7: Uncertainty about the possibility of receiving government subsidies and/or tax incentives to boost demand. C2.8: Short-term expectations of lowering EVs costs because future technological advancements (e.g., due to mass production of batteries). C2.9: Expectations of lower price of electricity for the consumer and higher energy generation efficiency in the future. Avoiding the persistent increase in oil prices due to scarcity. Reduce the dependency on oil. C2.10: Invest in research, development, and innovation because of the difficulties in developing the required technologies for the transition.
Technological & Innovation factors (C3)	Customer's reluctance to acquire EVs because of technical issues such as: C3.1: Autonomy (driving range and speed). C3.2: Battery recharge times. C3.3: Availability of recharge points. C3.4: Repair, maintenance, and replacement of batteries.

(continued on next page)

Table 1 (*continued*)

Factors or antecedent conditions (C)	Subfactors
	C3.5: Energy cost and efficiency. C3.6: Availability of tax incentives. C3.7: Existence of specific parking areas. C3.8: Problems in cities facing shortage of electricity supply. C3.9: Lack of noise sensation. C3.10: Implementation of own charging networks carried out by automobile manufacturers. C3.11: Rely on a third-party for the implementation of charging networks. C3.12: Eco-friendly technology for the fulfillment of climate change targets: reduction in dioxide carbon emissions, and lower energy consumption. C3.13: Safer to drive (in case an accident occurs, electricity supply is cut from battery). C3.14: Smoother transition by means of hybrid electric vehicles (HEVs). C3.15: Other technical considerations such as ease of use and better ergonomics.
Environmental regulations (C4)	C4.1: Achievement of environmental targets: Greenhouse Gas Emissions (GHE). C4.2: Use of renewable energy sources and sustainability policies. C4.3: Restrictive standards defining acceptable limits for exhaust emissions of new fuel vehicles. C4.4: Deadline to achieve a complete fleet of EVs. C4.5: Repercussions of worldwide climate change. C4.6: Carbon footprint of manufacturing EVs compared to internal combustion engine vehicles. C4.7: Reduction in noise pollution.
New services / business (C5)	C5.1: Boosting of electricity generation companies. C5.2: Businesses related to the production and technology of batteries. C5.3: Battery replacement services (removing, refurbishment, upgrades, etc.). C5.4: Construction of charging stations and their whole ecosystem. C5.5: Production of charging tools for EVs. C5.6: Developing of software for EVs. C5.7: Installing home solar systems with EVs chargers. C5.8: Supply of raw materials needed in the production of EVs.
Output	Actors' satisfaction

time. Other subfactors that may lead to the actors' satisfaction are an expected improvement in productivity and performance of manufacturers in the long run, or in the quality of products or services. The adaptability to changes is also considered in order to achieve flexible manufacturing systems (e.g. to address possible fluctuations in demand and failures in the production line, restriction of machines, number of workers, number of shifts, need to manufacture different products or provide services, etc.). More subfactors considered are to deal with possible conflicts, litigations or strikes with labor unions, or the training of non-qualified workers, the possible dependency on third-party battery manufacturers or a short time to gain market share from conventional combustion engine vehicles (i.e., expectations of increasing EVs sales, which entails a rapid market penetration from the actual vehicle fleet in Spain mainly based on conventional combustion engines). Also considered is how actors value an enhancement in competitiveness on global markets by improving trade policy (tariff barriers) and international alignment of vehicle regulations, or the achievement of social equity, fairness, transparency, consensus, and accessibility to all social strata. Finally, job creation or the fulfillment of environmental regulations and existing legal framework is also considered.

The financial factors (C2) encompass 16 subfactors. We consider the feasibility of implementing the adaptation strategies regarding investment costs, such as equipment acquisition, installation, development of new technologies, patents, etc. The customer's willingness to pay for the initial cost overrun of EVs is also considered, together with possible reduction of prices due to technology developments and the lower maintenance and charging costs of EVs compared with gas-powered vehicles. Lower cost may arise, for instance, due to mass production of batteries or future technological developments. The possible investment in research, development, and innovation is considered because of the difficulties in developing the required technologies for the transition; also, investment in human capital and skills to avoid layoffs.

Another subfactor is the uncertainty about the possibility of receiving government subsidies or tax incentives for buying EVs to boost demand. This may play a major role in gaining market share from conventional combustion engine vehicles (i.e., expectations of increasing sales of EVs, which entails a rapid market penetration from the actual vehicle fleet in Spain mainly based on conventional combustion engines). Moreover, we take into account the diversification of energy sources, the reduction in the dependence on fossil fuels and its persistent price increase due to scarcity.

On the other hand, the technological and Innovation factors (C3) cover 16 subfactors. The customer's reluctance to acquire EVs is considered because of technical issues such as battery autonomy, high battery recharge time, availability of recharge points, short driving range and speed, lack of noise sensation, the existence of specific parking areas, the need to replace the battery after several years, and that EVs are not suitable for cities facing shortages in electricity supply. An additional issue that should be addressed is regarding the decision to be taken by the automotive industry about implementing its own charging network and battery manufacture, or relying on third-parties to provide that. However, the latter case would lead to dangerous dependencies in the future for vehicle manufacturers. A key issue is that EVs represent an eco-friendly technology that helps to fulfill climate change targets (i.e., a reduction in dioxide carbon emissions and noise pollution, and lower energy consumption).

We also deal with the fact that EVs are safer to drive, since in case of an accident, electricity supply is cut from battery; EVs also provide ease of use and better ergonomics. In addition, a smoother transition can be achieved by means of hybrid electric vehicles (HEVs).

The environmental regulations factors (C4) comprises 7 subfactors, which cover the achievement of environmental targets regarding Greenhouse Gas Emissions (GHE), use of renewable energy sources, a deadline to achieve a complete fleet of EVs, worldwide climate change agreements repercussions, the carbon footprint of manufacturing EVs compared to internal combustion engine vehicles and a reduction in noise pollution.

The last factor considered entails the creation of new businesses or the boosting of existing ones (C5), which consists of 8 subfactors: the boost of electricity generation companies, businesses related to the production and technology of batteries, battery replacement services (removing, refurbishment, upgrades, etc.), the construction of charging stations and their whole ecosystem, the production of charging tools for EVs, the installment of home solar systems with EV chargers or supply of raw materials needed in the production of EVs.

To consider all these factors, the fsQCA technique is applied to provide insight into the adaptation of the automotive industry to meet global goals on climate change. It has the advantage of dealing with uncertain environments due to the heterogeneous nature of the stakeholders involved and the wide variety of factors leading to their satisfaction. This approach also allows us to consider the actors' level of participation and their degree of influence on the decision-making process in designing the adaptation strategies. The outcome of the multi-criteria decision-making problem is the actors' satisfaction.

The information used in this study is based on government reports, public domain information, meetings, personal interviews, surveys, mass media information, and expert opinions. Data comprises information from a wide range of actors including automobile manufacturers, managers, labor unions, workers, governments, and customers (e.g., car buyers or service clients). Furthermore, the study considers large companies from the automotive industry in Spain, but also small and medium-sized enterprises (SMEs) producing vehicle components.

The criterion used to choose the actors is based on considering all groups who will be affected in some way by the implementation of the strategies. This comprises those who have some interest in the benefits of its implementation and those who are likely to suffer the consequences. Eventually, three levels of participation are taken into account: information level, in which actors are only informed; consultation level, in which actors express their opinions during the decision-making process; and active involvement level, in which actors are engaged in seeking solutions and have the authority to co-decide. Certainly, the level of participation and degree of influence is not the same for all types of business entities (which cover corporations, cooperatives, partnerships, sole traders, limited liability companies, and others), types of customers (regarding their purchasing power and environmental awareness), size of the corporation (SMEs and large or multinational companies), and different legal systems. In this regard, this methodology can be adapted to different realities and countries.

It is worthwhile mentioning that the active involvement of actors in management decisions has positive effects on productivity performance, since it leads to greater transparency, fairness, social equity, and consensus. This can be explained by the fact of the synergies created because of the different values of the actors, their levels of knowledge, resources, interests, and perceptions about the problem and the diversity of strategies adopted. Additionally, the stakeholders' engagement brings together a variety of points of view and interests; it leads to better use of information and management, increases the legitimacy of final decisions, reinforces democratic practices, and increases workers' confidence in their managers. An important issue to bear in mind when conducting a study of this scope is the heterogeneity of the stakeholders, which leads to a conflict of interests among them, and therefore hinders the problem.

The actors' degree of preference or acceptance about the different factors is analyzed using a continuous fuzzy set. The values range from 0 (i.e., low degree of acceptance or agreement) to 1 (i.e., high degree of acceptance or agreement). The calibration procedure is performed to transform the actors' preferences about the antecedent conditions into fuzzy variables, while matching or conforming to external standards. Note that fuzzy sets can tackle both quantitative and qualitative measurements, thus overcoming some of the limitations of both. Moreover, fuzzy sets enable adequate treatment of multiple data sources, as is the problem when designing the best adaptation strategies of the automobile industry to meet climate change targets.

The calibration procedure is carried out using all the available information collected from actors, which is organized using variables on a Likert scale or interval scale. These psychometric scales are broadly used for scaling information. They are representations of numerical values, such as the budget each actor is willing to devote to a certain measure. An underlying concept, such as the investment required by manufacturers to perform the conversion from the internal combustion engine vehicles to EVs, can be structured and labeled in set theoretic terms, for instance, ''degree of membership in the set of those willing to invest more than a certain quantity'', which could be based on the firm's turnover. Hence, the actor's degree of agreement about a certain statement could be categorized using a five-level Likert scale, for instance: "strongly disagree", "disagree", "neither agree nor disagree", "agree", and "strongly agree". The conversion between these verbal labels and fuzzy scores is performed by means of three qualitative anchors that structure fuzzy sets, i.e., they represent the degrees of membership to a set. Specifically, we have used the threshold of the 5th percentile (which represents full non-membership, i.e., a low degree of acceptance or agreement regarding a certain factor), the 50th percentile (the crossover point dividing "more in" from "more out" with regard to a specific statement, i.e., it represents the actors' maximum ambiguity about their membership in the set), and the 95th percentile (which displays full membership, i.e., high degree of acceptance or agreement).

During the calibration procedure, the fuzzy scores must also consider the actors' level of participation (i.e., information only, consultation, or active involvement), the degree of influence on the final decisions to be implemented, and the different companies of the automotive industry and their financial situation. In addition, this study uses the size (number of employees) and turnover of the company to homogenize the results, i.e. these values are used to make results comparable across different companies and realities. Obviously, shareholders and management have more influence than labor unions or workers. Therefore, appropriate fuzzy-set membership scores are assigned to actors with more influence and a greater level of participation. Actors with a greater influence and level of participation are therefore considered to be more difficult to satisfy.

The aggregate final score for each factor is obtained by means of the arithmetic average of the fuzzy scores for each subfactor. In short, during the calibration of fuzzy sets, the verbal labels of the scales should be converted into metrics without any loss of information. In this way, it is possible to scale the degree of membership while considering qualitative differences among actors and conditions. After several rounds of analyses, the calibration procedure provides a truth table that is evaluated by means of fsQCA software (Ragin 2008).

Since there are five factors, the matrix dimensions are (2^5) rows and 5 columns. The matrix is firstly tested for necessary conditions for the outcome and for the negation of those conditions, designated by the tilde (~) sign in Table 2.

A condition is considered necessary when its consistency score exceeds the threshold value of 0.9 (Schneider et al. 2010). Table 2 shows the consistency and coverage values for all factors. Only one out of five factors presents a consistency above this threshold, thus being a necessary condition leading to the outcome. Therefore, the technological and innovation subfactors need to be present in order to achieve the actors' satisfaction.

The truth table is minimized using Boolean algebra. It returns a set of combinations of causal conditions, where each combination is minimally sufficient to lead to the outcome. The minimization procedure is performed using the coverage and consistency values.

This approach allows consideration of uncertainty in data and results, thus enhancing the level of confidence in the results. To do that, the reliability and validity of the results is assessed via robust tests, which are based on several parameters of fit such as consistency, raw coverage, and unique coverage. On the one hand, Tables 2 and 3 depict the results of those tests, which shows satisfactory levels of confidence for the different solution terms as defined by Ragin (2008). On the other hand, for the non-necessary conditions, the results are imprecise. Despite the presence of those conditions in several configurations, their absence is relevant in other recipes. Note that the presence or absence of those conditions in a certain configuration is due to the actors' heterogeneity.

Table 3 shows the seven solutions or configurations that are found by the algorithm with acceptable consistency indices (≤ 0.80). In addition,

Table 2
Analysis of necessary conditions. Following the nomenclature, the symbol (~) represents the negation of the characteristic.

Conditions (C) tested	Consistency	Coverage
C1	0.718	0.670
~ C1	0.632	0.513
C2	0.791	0.726
~ C2	0.445	0.401
C3	0.836	0.689
~ C3	0.623	0.645
C4	0.693	0.622
~ C4	0.482	0.698
C5	0.651	0.404
~ C5	0.452	0.512

Table 3
Sufficient configurations of antecedent conditions for actors' satisfaction. Note: Based on Fiss's (2011) notation, the symbol 'x̂' means absence of the condition and '●' means presence of the condition. Blank cells represent ambiguous conditions.

Actors' satisfaction Antecedent Conditions (C)	Configuration (CF) Number						
	CF1	CF2	CF3	CF4	CF5	CF6	CF7
C1	●		○	●	○		●
C2		●	●	○	●	●	
C3	●	●		●	●	●	●
C4	○	●	●		●	●	○
C5	●		○	●		○	
Raw coverage	0.072	0.132	0.036	0.289	0.218	0.345	0.028
Unique coverage	0.032	0.008	0.005	0.008	0.193	0.053	0.015
Consistency	0.881	0.987	0.835	0.969	0.801	0.879	0.816
Solution coverage	0.698						
Solution consistency	0.894						

the raw coverage values range from 0.03 to 0.35. Following Ragin's (2009) recommendation, this paper presents the intermediate solution. Additionally, in accordance with the notation of Ragin and Fiss (2008), black circles (●) indicate the presence of a factor, white circles (O) represent its absence, and blank cells denote ambiguous factors. The diversity of these configurations suggests that they are sufficient but not necessary. Consequently, no unifying configuration explains the actors' satisfaction.

The results show that, aside from the necessary conditions, there are other factors that are present in several configurations, for example, the financial factors (Table 3). In this sense, subfactors such as government subsidies and tax incentives play a major role in attaining the actors' satisfaction. This proves that actors' satisfaction depends on a wide range of factors because of the high heterogeneity of actors with conflicting interests. Therefore, results indicate that all factors are closely related and without the achievement of one of them maybe the outcome will not be reached. Then if all actors move in the same direction the transition to EVs will be attained faster and more smoothly. In this sense, if customers are willing to buy EVs despite the initial cost overrun compared to gas-powered vehicles, manufacturers will find the necessary financial investment, which could be boosted by government tax incentives or subsidies, to provide EVs that are attractive in terms of technological factors (such as low recharge time batteries and availability of recharge points) while meeting the environmental regulations.

As for the management and legal factors, results are imprecise. Although the presence of this condition appears in two configurations, its absence is relevant in two other respects. The underlying rationale behind this result may owed to the fact that if the other factors are present manufacturers will find a way to overcome all management and legal issues.

The causal paths presented in Table 3 illustrate that environmental factors are also important in the achievement of actors' satisfaction, due to the restrictive GHG emissions regulations and the social environmental awareness. Results suggest that new businesses and the boosting of existing ones play a discrete role in the attainment of the outcome, since it is only present in two configurations.

It is worthwhile mentioning that some of the actors may lack appropriate knowledge about certain subfactors. This can be solved by explaining to them the key management, legal, financial, and technical concepts during the different rounds of the fsQCA. This is possible because the results are easily understandable for non-experts in the matter. Furthermore, with this approach, actors will achieve a deeper understanding of the design difficulties in defining the best adaptation strategies and, as a result, there will be more consensus (Mandell, 2001). It is worthwhile mentioning that different mechanisms have been used to engage stakeholders, such as meetings, workshops, conferences, expert panels, web-based communication technologies, consultation of industry associations and labor unions, and surveys.

As a rule, for the achievement of good outcomes actors must be engaged in the early stages and should be provided with clear goals, information, and organization (e.g., a suitable agenda and mechanisms to engage them, and appropriate steps for the whole process). This is especially true for actors with less power in the decision-making process, since they are less likely to hinder decisions and more likely to support them. Furthermore, satisfied actors are less prone to delay the implementation of the adaptation strategies through their opposition, for instance, by litigation (Berry et al., 1993).

4. Conclusions

The transition from fossil-fueled road transport towards EVs plays a key role to meet the climate change targets of reducing GHG emissions progressively up to 2050. The results of the fsQCA can help in defining the best adaptation strategies to be followed by the automotive industry. This is reinforced by the fact that this study comprises a wide range of actors and factors.

Results have shown that because of the high heterogeneity among actors the transition requires the involvement of governments as well as companies and customers. In this sense, for the case of Spain, the achievement of the environmental objectives will require a change in consumption patterns, which are mainly dominated by combustion engine vehicles.

GHG emissions targets are influencing the innovation of climate-related technologies, so that the most influential subfactors for a successful implementation of adaptation strategies to EVs are: to increase the battery autonomy and the availability of charge stations; to reduce the battery recharge time; the possibility of receiving government subsidies and/or tax incentives to boost demand; and the fulfillment of climate change targets. Then actors pay more attention to technological factors, which together with financial subfactors, such as governmental subsidies and tax incentives, are responsible for making EVs attractive for customers. These conditions will lead to a faster and smoother transition and deployment of EVs, which is a win-win situation for all actors. However, results suggest that all factors are closely related and without the presence of one of them the outcome is not likely to be reached, since all factors appear in several configurations. Therefore, management, legal and environmental subfactors are also key to achieve the actors' satisfaction, although to a minor extent.

However, automotive manufacturers focus more on profits, while governments focus on the fulfillment of environmental standards, and customers on the price of the vehicle, the recharge time and the availability of recharge stations. This is because these conditions presumably favor all actors.

Actively involving stakeholders with conflicting interests in management decisions has positive effects on firms' performance. It provides higher levels of transparency, fairness, social equity, and consensus. Moreover, the methodology leads to a greater understanding of the problem for all actors and reduces the possibility of delays in implementing the measures due to labor union strikes or litigation. This approach can also be easily adjusted to different realities and countries. The achievement of successful results is hampered by the existence of uncertainty due to imperfect and/or unknown information, and scarce or inappropriate actor participation. On this subject, the methodology may help automotive manufacturers remain competitive under conditions of uncertainty in the market and high heterogeneity among actors. Then the fsQCA can be used as a decision support system in decision-making processes under complex environments.

With regard to the limitations and further research, since automotive is a worldwide industry, regional and cross-country comparisons should be carried out to confront the results obtained in this case study.

Likewise, it would be desirable to assess if the causal configurations remain unchanged over time, to consider other core factors, such as the confidence in the management team, and to evaluate whether the reliability and validity of results are similar when applied to other industrial sectors.

Also, the adaptation of the automobile industry to fulfill the emission standards as imposed by climate change policies via the implantation of EVs should consider the appropriate mechanisms to overcome faster the severe economic slowdown due to the COVID-19 pandemic. This should be empirically corroborated in future studies about this topic.

Author statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the Technological Forecasting & Social Change.

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