How Drivers Decide Whether to Get a Fuel Cell Vehicle: An Ethnographic Decision Model

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ABSTRACT

This article develops and tests an ethnographic decision model (EDM) of hydrogen fuel cell vehicle (FCV) adoption using interviews with California residents that either actually adopted an FCV or "seriously considered" doing so before deciding against it. We developed an initial model from 25 semi-structured interviews in which respondents self-described their decision-making processes. We iteratively tested and refined the model in a second round of 53 structured interviews. The final model consists of a first stage that assesses FCV adoption feasibility and a second stage that compares FCVs to other vehicle types. The model ultimately correctly predicts 86.8% of cases in the sample. In the first stage, respondents preferred to satisfy their need for a primary refueling station near home but a substantial number were willing to rely on a station near or on the way to work or other destination. Most drivers required a convenient backup station and a means of managing long-distance trips. Vehicle size options eliminated a few respondents. None rejected FCV adoption due to insufficient driving range. In the second stage, nearly all drivers engaged in some kind of cost comparison, though the factors considered varied greatly. Most opted for what they viewed as the less costly option, although a few FCV adopters and non-adopters were willing to pay more for their more preferred option. EDM is a promising qualitative research method for generating insights into how people navigate the decision whether or not to get an alternative-fuel vehicle.

Keywords: Hydrogen Fuel Cell Vehicle, Ethnographic Decision Model, Early Adopters, Decision Tree, Battery Electric Vehicle

1.1 INTRODUCTION

As of November 2020, twelve US states had formally adopted California's zero-emission vehicle (ZEV) mandate [1], although only California (43 stations), South Carolina and Connecticut (1 station each) had retail hydrogen stations open to the general public to support hydrogen fuel cell vehicle (FCV) adoption and travel [2]. This sparse infrastructure remains a long-acknowledged challenge for greater FCV diffusion: Melendez [3]conducted a comprehensive review of the primary barriers to early FCV adoption, identifying the availability and cost of refueling infrastructure as the greatest inhibitor to widespread adoption, along with availability and cost of vehicles, and inconsistent public policy and leadership. Until vehicle manufacturers brought FCVs to market in 2015, however, studies of FCV adoption had to be hypothetical in nature. Since then, surveys and interviews of early FCV adopters have corroborated most of the barriers identified by Melendez, with new ones emerging such as reliability of refueling stations and the driver's suitability for dealing with a dearth of infrastructure [4–6]. Surveys of prospective FCV adopters who ultimately did not get one found the lack of home refueling ability and concerns about sustainable hydrogen production to be primary barriers [7]. These recent works highlight factors that assist or hinder FCV adoption, but lack a consistent baseline of respondents who all began with an initial serious interest in FCVs and ended up in one of two groups: those who ultimately did and those who ultimately did not adopt one. An analysis of the decision-making process that leads to these outcomes is a pressing research need that has yet to be addressed. Our research question then is: how does a group of prospective FCV adopters move through the decision-making process that ultimately leads them to adopt one or not?

To address this question, we employ ethnographic decision modeling (EDM) to identify the primary shared factors that groups of people evaluate when making a particular decision. EDM is an established method that structures these factors into a decision tree model that predicts the behaviors resulting from people's decision-making processes [8]. EDM differs from much social science research: instead of considering the sampled population's intentions to behave, EDM uses the sampled population's already-settled decisions. The decision tree structure grounded in the real-world decision makes this method particularly useful for understanding what factors most impact a group's decision and how stakeholders or policymakers can influence key factors in the decision-making process.

This paper therefore has two goals. The first is to introduce this established method to the alternative fuels and vehicles literature which offers potential to gain new insight on alternative-fuel vehicle adoption generally. The second goal is to apply the EDM method to better understand how potential early FCV adopters navigate this complex and costly decision.

2.1 LITERATURE REVIEW

Several scholars have reviewed the literature on consumer adoption of AFVs to better understand how to encourage their diffusion, focusing on topics including: market modeling studies [9,10]; consumer preferences affecting adoption [11–13]; demographics and attitudes [14,15]; financial incentives [16]; and combined models for market diffusion and refueling infrastructure [17]. The majority of these reviews have covered hybrid and plug-in electric vehicle adoption, though there have been some specific to [18,19]FCVs .

A mixture of research methods have evaluated AFV adoption. Stated preference survey results are typically analyzed with discrete choice models that evaluate preferences for hypothetical vehicle alternatives given specifications of the vehicles and refueling availability and respondent characteristics [20,21]. Other surveys aimed to quantify the willingness to pay

(WTP) for a cleaner vehicle [22] and the predictive ability of attitudinal and symbolic factors on electric vehicle (EV) adoption [23,24]. Brey, Brey, and Carazo [25] included both revealed-preference questions about current refueling behavior and stated-preference questions about their willingness to adopt an AFV given a hypothetical network of stations. In the absence of empirical data on known AFV adopters, some studies have used agent-based modeling and diffusion analysis to simulate future adoption [26]. Demographic analysis of actual early adopters in California [27] can "reality test" the analysis of demographic factors in stated-preference surveys [28]. Qualitative methods, including focus groups and in-depth interviews, can uncover factors missed by survey instruments or quantitative modeling [7,29]. Each of these studies included either groups of adopters or non-adopters, but not both.

Some researchers have attempted to model how prospective AFV adopters navigate the decision process in some way. Noblet, Teisl, and Rubin [30] found that some "clean car" consumers first determine the type of car they want, and then choose a particular brand and model, which is when eco-labeling becomes important. Klockner [31] reported that drivers whose first car purchase was an EV expected to drive more, while those who replaced a traditional vehicle or added an EV to their household expected to drive less. These may apply to some extent to FCVs, but there are unique considerations that limit transferability.

Few have used ethnography as a means of studying FCV adoption. Ethnographic methods study how people behave in a socio-cultural setting and how group members interpret their own behavior in their own words. Vehicle selection clearly involves social, cultural, economic, geographic, and psychological factors, along with other heterogeneous individual preferences and tastes; ethnography can help us understand how people think and feel about these factors when selecting a vehicle. Content analysis is one of the more popular ethnographic methods used in transportation studies, and has been used to study AFV adoption. Caparello and Kurani [29] analyzed drivers' narratives about a 4-6 week trial period with a plug-in hybrid electric vehicle (PHEV), which uncovered themes such as confusion, recharging etiquette, payback analysis, and future expectations. Using an ethnographic approach known as "semiotic maps," Heffner et al. [32] found that intelligence, ethics, and uniqueness emerge as important symbolic meanings attached to early hybrid electric vehicle (HEV) adoption.

In a precursor to this study, Lopez-Jaramillo et al. [6] analyzed the content of hour-long interviews with 12 FCV adopters in the LA metropolitan area that informed our initial EDM design. They identified three broad categories of important factors shared by these known early FCV adopters: driver characteristics, vehicle characteristics, and refueling infrastructure. Adopters were concerned about the environment and willing to promote FCV technology, often soliciting help from other members of the FCV community for feedback on vehicles and stations. They found the available FCVs suitable to their travel needs and a fit with their lifestyle, and viewed them favorably to battery electric vehicles (BEVs). These 12 adopters found the refueling infrastructure sufficient for their driving patterns, although station reliability issues further impacted their driving and refueling habits. These characteristics, which were shared across a group of known adopters, suggest there were similarities in these adopters' decision-making process, though how they compare to those who considered but ultimately did not adopt an FCV is unclear.

Of importance to this point, Liao, Molin, and van Wee [13] categorized the literature findings on AFV adoption into two overarching sets: factors that consumers generally considered, and factors associated with heterogeneous responses to those factors. The common consumer considerations were further subdivided into financial, technical, policy incentives, and infrastructure factors. The causes of heterogeneity were subdivided into driver-specific sociodemographic, psychological, mobility conditions, social influencing, and experience factors. Their finding that prospective AFV adopters evaluate both shared and idiosyncratic factors when deciding whether or not to purchase or lease supports our application of the EDM method, which is capable of identifying and structuring the shared parts of the decision process within which individual drivers consider the heterogeneous factors specific to themselves.

Ethnographic decision tree models have successfully predicted a wide range of behaviors across many cultures, but they have yet to be applied to the study of AFV adoption. Researchers have built EDMs to understand and predict daily life decisions such as what fresh produce to buy [33], which crops to plant [8] or where to fish [34]; health decisions such as treatment options for various illnesses [35–37] and needle sharing among intravenous drug users [38]; and emergency decisions such as hurricane evacuations . Most relevant to this paper, Murtaugh and Gladwin [39] used EDM to model the type of automobiles people purchased and found that interior car size was the most constraining factor amongst buyers they interviewed. This method, then, offers a novel way to evaluate the shared decision-making process that prospective early adopters navigate when deciding whether or not to adopt one.

3.1 METHODS AND DATA

The EDM methodology was initially developed and described by Christina Gladwin [8]. Based on her process, building the model involves: selecting the behavioral decision to model; determining the decision criteria or constraints through an initial sample of respondents; and building the model based on these initial interviews. Testing the model involves: developing a structured interview protocol to collect information on each decision criterion; interviewing a second sample; calculating the success rate of the model; and adjusting the model based on errors. Ryan and Bernard [40] suggest an additional step: collect qualitative data from respondents in the form of self-reported motivations for actions. Figure 1 demonstrates our method.

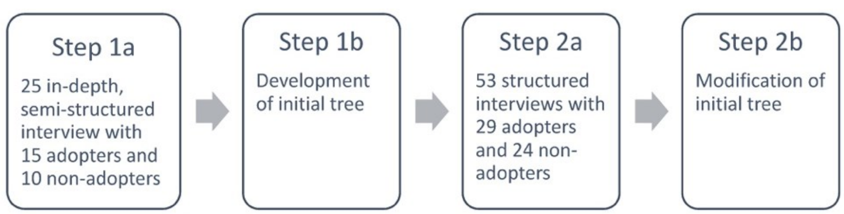

Figure 1. Methodology

3.2 Step 1: Building the Model

To build the initial model, we recruited respondents in the Los Angeles and San Francisco metropolitan areas who had seriously considered purchasing an FCV. Participants were recruited via social media groups and forums designed for drivers and others interested in FCVs, BEVs, PHEVs, and HEVs. The websites included various Facebook groups, InsideEVs, PriusChat, MyChevyBolt, MyNissanLeaf, and Reddit. As these websites constitute shared virtual public space, this non-probabilistic, purposive sampling strategy is appropriate for data collection with the goal of capturing shared cultural knowledge [41]. Snowball sampling attempts through respondents only resulted in one additional respondent.

For the initial round, we conducted 25 interviews with 15 respondents who decided to purchase an FCV and 10 who did not. This sample size exceeds the minimum suggested for reaching data saturation in qualitative research [42,43] and comports with other EDM research which typically relies on samples of 20-60 people. In the initial round, we recruited residents of the Los Angeles and San Francisco areas due to these locations having the highest concentrations of FCV drivers in the US. Interviews—typically an hour in duration—were conducted face-to-face and audio-recorded in June-August, 2018 in a location of the respondents' choosing. Respondents received compensation in the form of $35 gift cards. The Arizona State University Institutional Review Board approved all study materials and incentives. We pre-tested the interview protocol with AFV drivers in Phoenix, Arizona to ensure that all questions were understandable and appropriate [44]. Each interview began with the same prompt: "Thinking back to when you were thinking about purchasing/leasing a hydrogen fuel cell vehicle, walk me through your decision-making process. Why were you initially considering a fuel cell vehicle and what things did you consider when deciding whether or not to adopt this type of car?" We then allowed respondents to provide their own description of their decision-making process, occasionally probing to ensure we had adequate information about the process, that all aspects of the process were discussed, and that the respondent remained focused on the time frame *before* the actual purchase decision. The first 12 transcribed interviews formed the basis of the initial model that we then iteratively refined, as recommended by [8], by comparing the remaining 13 interviews to it, then modifying it to improve accuracy. Ultimately, the model predicted all but three of these 25 decisions correctly (88% accuracy).

3.3 Step 2: Testing the Model

We tested the initial model via a structured interview protocol with close-ended questions focused on each of the criteria and open-ended questions to understand how respondents prioritized criteria, and to elicit any new criteria not addressed by the initial model. We tested the model with 53 respondents from across California: 29 respondents who had decided to adopt an FCV and 24 respondents who decided not to. Sample sizes for testing the model are typically in a similar range to the initial sample: 20-60 per [40]. In our analysis, data collection continued until we achieved data saturation—when no new insights or issues emerge [45].

Table 1 shows the geographic and demographic characteristics of our sample. Adopters' characteristics reflect the appropriateness of our purposive sampling design in terms of consistency with other studies of early FCV adopters. For example, our sample was fairly similar to the characteristics of FCV adopters in the 2018 and 2019 California Air Resources Board (ARB) annual hydrogen evaluation reports [27]. In our sample, Los Angeles is slightly underrepresented, the percentage with graduate degrees is 50%, similar to the ARB findings, and our adopters' household incomes are lower (59% over $100K vs. 68% for ARB). The somewhat lower incomes in our sample, however, are consistent with the observation in the 2018 report that the income distribution may continue to shift downward as "influenced by the availability of CVRP rebates as well as auto manufacturer-supplied fuel cost incentives."

We also note the consistency in characteristics between adopters and non adopters in our sample, with the exception of one characteristic: gender. Women were underrepresented in our "Did Not Adopt" group. However, in the interviews, no gender specific issues such as car size/fit or household labor expectations were mentioned by respondents.

Table 1. Characteristics of Respondents

Category		Adopted (n=29)	Did Not Adopt (n=24)
Location	Los Angeles	12	11
	San Francisco	13	11

	San Diego	3	2
	Sacramento	1	0
Gender	Man	20	23
	Woman	8	1
Race/Ethnicity	White	17	12
	Hispanic	9	10
	Asian	1	0
	Other	1	1
	Prefer not to answer/missing	2	1
Age	25-29	2	1
	30-34	1	0
	35-39	2	4
	40-44	1	7
	45-49	7	4
	50-54	1	0
	55-59	7	5
	60-64	4	1
	65-69	2	1
	70-74	1	1
Number of People in HH	1	4	3
	2	10	9
	3	6	3
	4	4	8
	5	5	1
Children under age 18 in house	Yes	10	12
	No	18	12
Education	High School Diploma	3	0
	Bachelor's Degree	10	12
	Graduate Degree	15	12
Income	< $49.9K	0	0
	$50K - $74.9K	1	0
	$75K - $99.9K	5	2
	$100K - $149.9K	5	5
	$150K - $199.9K	6	5
	>$200K	8	7
	Prefer not to answer/missing	4	5
Vehicle Purchased	Toyota Mirai	22	-
	Honda Clarity	7	-
	BEV	-	11

	PHEV	-	8
	HV	-	2
	ICE	-	2
Political Leanings	Very Conservative	0	1
	Conservative	4	1
	Moderate	13	8
	Liberal	6	9
	Very Liberal	4	3
	No Opinion/Preferred not to answer/Missing	2	2
Occupation	Architecture and Engineering	6	9
	Arts and Design	0	1
	Business and Financial	6	5
	Computer and Information Technology	7	5
	Education, Training, and Library	1	1
	Entertainment and Sports	0	1
	Healthcare	2	1
	Life, Physical, and Social Science	0	1
	Office and Administrative Support	2	0
	Sales	2	0
	Retired/Missing	3	0
Reasons for Initial Interest in HFCV[1]	Environmental Concern	20	17
	Cost	13	14
	Technological Interest	11	5
	HOV Access	9	4
	Ending Gas Dependence	4	7
	Previous AFV Ownership	12	8

We recruited respondents using the same strategy as in Step 1. Second-round interviews were conducted via Skype from February 2019 to April 2020. Interviews were typically a half hour in length and respondents were compensated with $15 gift cards. We then adjusted the initial model using insights gleaned from the second round of interviews.

[1] These reasons were thematically coded based on responses to the question "Why were you initially interested in an FCV?" The codes are broadly based on codes developed for Lopez et al. [6]

3.4 Nota bene: Errors in the Model

A decision tree model that perfectly predicts respondent behavior is either too simplistic or too complex for practical use; in both cases the model becomes tautological. Erroneous predictions reflect idiosyncrasies in human decision-making processes. Gladwin [8,46] suggests that if the reasons for the errors do not suggest an unaccounted pattern of behavior, an accuracy rate of 85-90% indicates a well-constructed EDM.

4. RESULTS

4.1 Overview

Our method resulted in a two-stage EDM. The first stage represents the criteria participants considered when determining whether or not an FCV was a feasible option. The second stage represents the decision process that remaining participants went through after determining an FCV was feasible, wherein they compared FCVs to other vehicle options, focusing first on other AFV options and then entering into a cost comparison between other potential vehicles and the FCV.

Non-adopter respondents drop out of the EDM whenever their decision paths terminate in failure to acquire an FCV for any reason. Achieving a final decision to adopt an FCV requires percolation through both stages without any single factor causing a do-not-adopt decision.

In this first section of the results, we walk the reader through the tree from top to bottom. We explain the general structure, the exit branches, and the incorrect predictions. At the end of this section, we summarize the correct and incorrect predictions, both for those who adopted and those who did not.

4.2 First Stage Model: Feasibility.

All 53 respondents were evaluated in the Stage 1 model (Figure 2). Two participants dropped out of the model at the first criterion because the physical sizes of the available FCVs did not suit their needs and they did not have a second vehicle or other means of dealing with this limitation; they are counted as correct predictions because they ultimately did not get an FCV. A third participant indicated that no available FCVs met their size needs but still decided to get an FCV; the model thus incorrectly predicted this respondent's choice. Six respondents dropped out as they lacked a refueling station near or on the way to home, work, or some other regular destination. Four additional, correctly predicted respondents dropped out due to a lack of a backup station. Two of these respondents (on the left side of Figure 2) had a primary station near home but no backup station near home or near/on-the-way to work or other destination. Two other respondents (right side of Figure 2) lacked any stations near home and had only one near work or on the way, which met their primary need but not their backup requirement. One final, correctly predicted respondent dropped out of the Stage 1 model due to an inability to make long-distance trips. This process resulted in 39 respondents moving on to Stage 2, indicating that they considered the FCV to be feasible. Ultimately, Stage 1 correctly predicted the decisions of 52 out of the 53 respondents (98% accuracy).

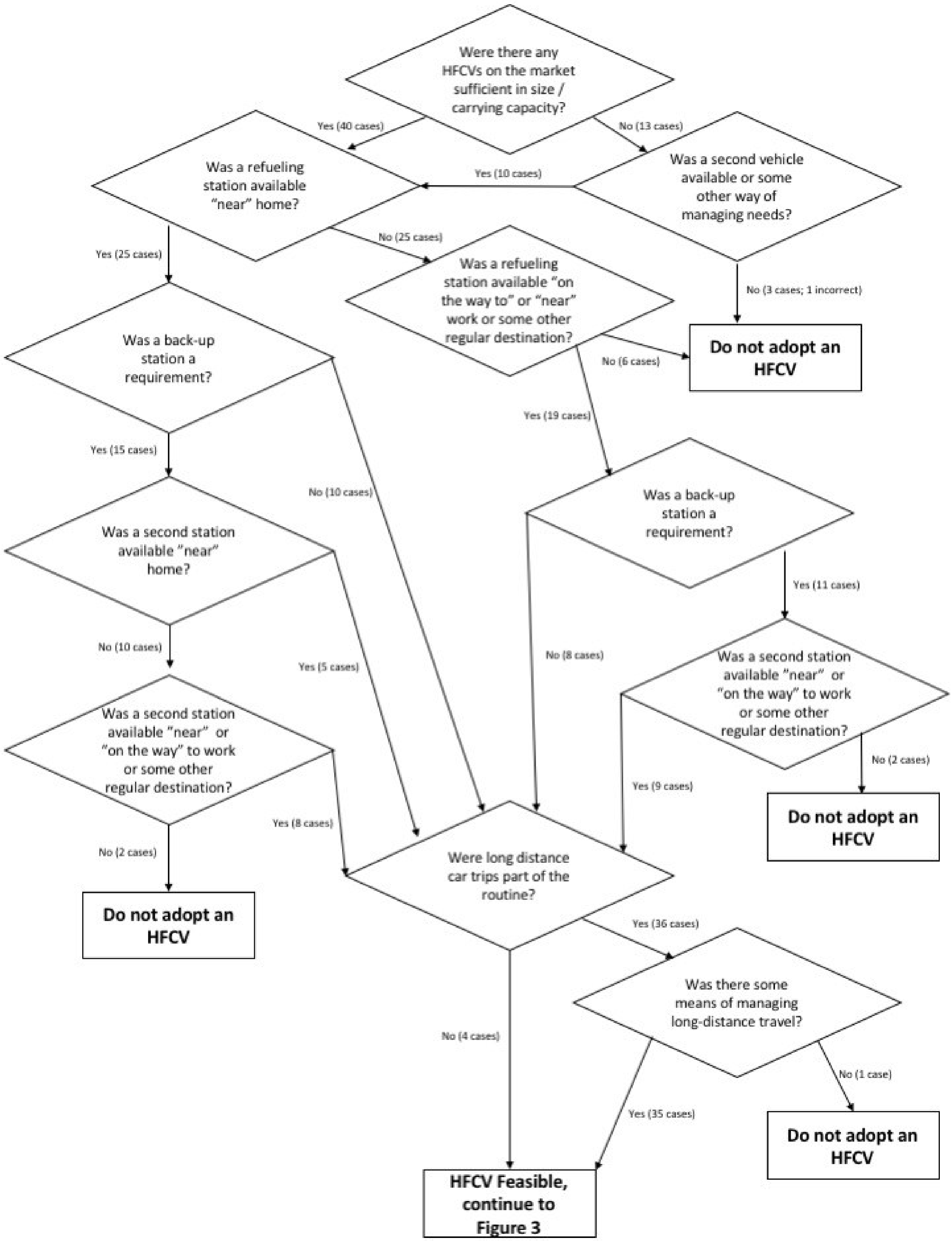

Figure 2. Stage 1 Model. Process to determine FCV feasibility.

4.3 Second Stage Model: Comparison to Other Vehicles.

Of the 39 respondents that continued to the Stage 2 model (Figure 3), nine did not consider purchasing or leasing any other vehicles, and we correctly predicted that they would adopt an FCV. Eight of the remaining 30 respondents exclusively considered ZEVs, either for environmental reasons or HOV lane access. Of those eight, two identified no acceptable BEVs due to their limited range, long recharging time, or lack of home recharging infrastructure; we correctly predicted that both would purchase an FCV. The remaining six who only considered ZEVs and the 22 respondents who considered non-ZEV options then entered into a cost comparison between the FCV and any alternative vehicle(s) they considered. Eleven considered the cost of the FCV to be greater than that of an alternative vehicle. The decision tree predicted that these respondents would not adopt an FCV, however three ultimately did, due to a strong preference for FCVs. The remaining 17 respondents considered the price of an FCV to be equal to or less than the other vehicle(s) they were considering. We predicted that all 17 respondents would purchase an FCV; three did not, opting for a BEV, PHEV, and one that operates with an internal combustion engine (ICE) instead.

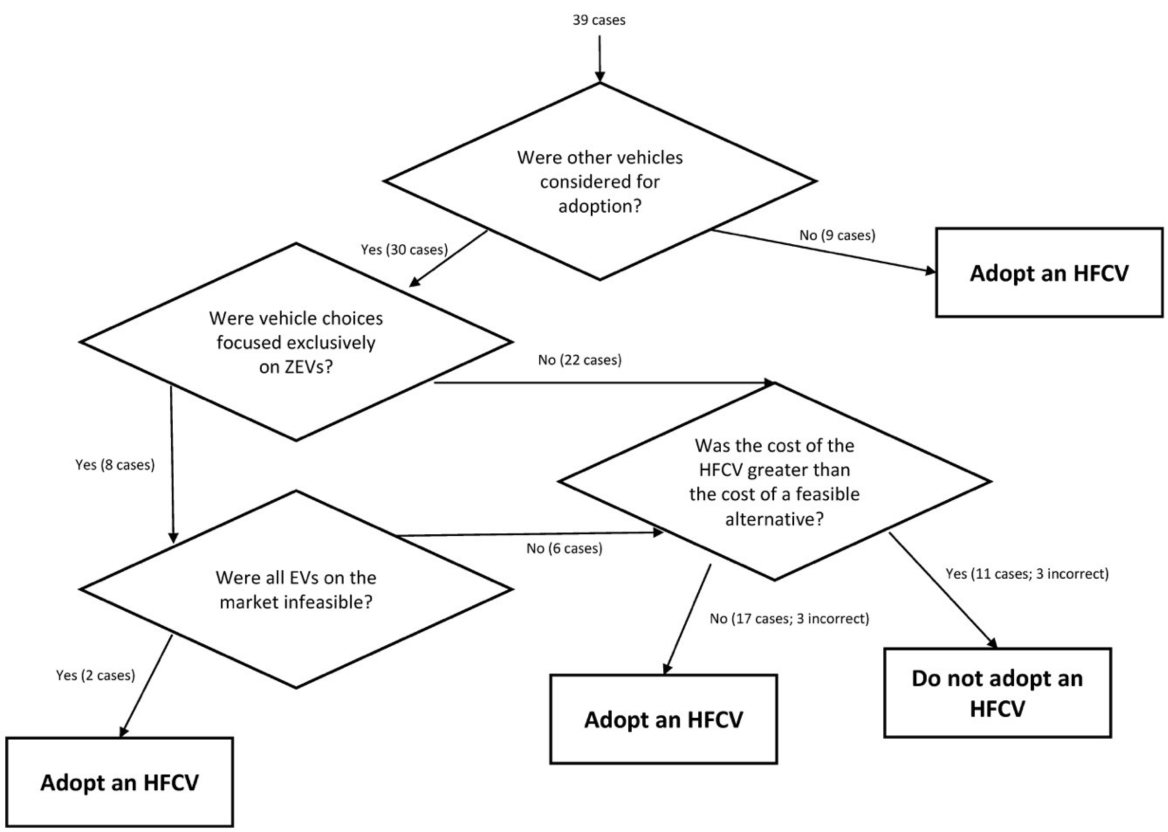

Figure 3. Stage 2 Model. Process to compare FCV to other options.

4.3 Final Decisions and EDM Accuracy.

The overall accuracy of the EDM was 86.8% (Table 2), with seven errors out of 53 respondents; this accuracy rate falls within the established acceptable range [8,46].

	Decided to Adopt	Decided Not to Adopt	Total
Correct	28 (52.8%)	18 (34%)	46 (86.8%)
Incorrect	3 (5.7%)	4 (7.5%)	7 (13.2%)
Total	31 (58.5%)	22 (41.5%)	

Table 2. EDM Results (n = 53)

4.4 Decision Factors in the EDM

When creating the EDM, several factors stood out as key based on the literature on FCV adoption and the EDM itself. The following section presents each of these findings.

4.5 Range

In the initial model, we included driving range as one of the criteria in Stage 1. We omitted this criterion after the second round of interviews to simplify the model. Given that range was sufficient for the vast majority of respondents and that FCVs on the market have a similar range to ICE vehicles and some Teslas, we removed this criterion from the final model. Only one respondent indicated concern with driving range. This respondent noted that in their research, the vehicle would not get the advertised range, stating that the FCV could only "reliably get 100-150 miles because it burned more or couldn't fill it up all the way." This range did not meet the respondent's stated need traveling 40 miles a day, along with a desire to travel from their home to Sacramento and back (approximately 210 miles) without refueling. With the removal of the range criterion from the EDM, this respondent dropped out of the tree due to a lack of a backup station.

Other drivers—speaking about their experience *after* adopting an FCV—estimated their typical driving range around 250-280 miles, lower than manufacturer-advertised ranges. In summary, we do not consider range to be a vital consideration in people's decision-making process regarding whether an FCV is a feasible option, at least among those who have reached the point of seriously considering an FCV.

4.6 Refueling Infrastructure

The location of refueling stations was critical to most respondents. Of the 15 respondents who dropped out of the model in Stage 1, ten did so based on perceived issues with local refueling infrastructure. Two distinct decision pathways emerged for satisfying drivers' regular local travel needs in this part of the tree. Most respondents first determined whether a station was near enough to home for them to meet their primary refueling needs; we made this criterion the first branching point of this part of the tree. Half indicated they had no station near home. This observation demonstrates that lack of near-home refueling is not an outright barrier to FCV ownership, though it forces prospective adopters to evaluate refueling station convenience in other ways. For those 25 respondents without a station subjectively near home, 19 stated that there was an available station on the way or near to work or some other regular local destination and 17 ultimately concluded that an FCV would be feasible for them. We grouped near work, near other regular local destination, and on the way together in the tree because there was no clear second-place type of station location evident in the way respondents discussed this.

In total, six of 25 respondents decided not to adopt an FCV due to not having a station available within their regular travel pattern. Three lived in the Los Angeles area, and all noted that the closest station was about a 40-60-minute detour. Two lived in the Bay Area and balked because their closest stations were 3-5 miles or 15-20-minutes out of the way. One San Diego respondent said the only station in the area was in the opposite direction from their commute. Other respondents, however, did not perceive similar deviations as prohibitive to FCV adoption, consistent with the wide variability of willingness to detour in [47]. Thus, while these two ways of satisfying the need for a convenient primary station emerged clearly from the interviews, respondents varied considerably in their personal thresholds for a station to be considered sufficiently near or on the way.

Twenty-six respondents required one or more "backup" stations prior to FCV adoption. While half of the respondents (25/50) percolating down the tree had a primary station near home, only fifteen required a backup station. Only a third of this group (5/15) also had a backup station near home, forcing two-thirds to rely on other types of station locations for backup refueling. In all, 17 of 21 drivers who said they required a backup station but lacked one near home were able to satisfy this need via a station near or on the way to work or other regular destination, and nine of 11 relied on alternative locations for *both* their primary and backup stations. This finding, while based on a small sample, raises questions about the primary justification for the strategy of "clustering" multiple stations in a single targeted neighborhood.

For three respondents in the Bay Area and one in San Diego, the lack of a backup station was responsible for them deciding not to adopt an FCV. The similarity in quantity of drivers who rejected FCV ownership for lack of a backup station and who did so for lack of a primary station (four and six, respectively) demonstrates the importance of backup stations to early adopters. Respondents typically cited information from dealerships and other drivers (primarily through social media, but also through personal connections and the California Fuel Cell Partnership's hydrogen refueling app) as sources for knowing that a backup station was necessary. Most respondents reported concern regarding stations running out of fuel or shutting down due to mechanical errors. One respondent focused on their experience of deciding against FCV adoption during the northern California fuel shortage in 2019 and another respondent described range anxiety resulting from prior EV experience. Some respondents indicated that a single backup station was insufficient and that they required at least 2-3 backup stations to support FCV adoption. Respondents' focus on station reliability in addition to location supports the growing body of literature that identifies station reliability as a critical consideration of early adopters (4,5).

4.7 Long-Distance Travel

Although we omitted vehicle range consideration from the model, respondents indicated concerns regarding occasional long-distance travel. Respondents self-defined "long-distance" and most discussed travel that extended beyond the range of the vehicle, although a few respondents considered "long-distance" to be as low as 40 miles. Of the respondents remaining in the model at the long-distance section, most (36/40) indicated that they make long-distance trips either solely within California (19/36) or to neighboring states that lack refueling stations (17/36). We identified multiple distinct decision pathways for achieving occasional long-distance travel unsupported by refueling stations (Table 3); we simplified these in the EDM to a single criterion that the respondent managed travel by "some means." Specifically, 28 respondents cited non-local refueling infrastructure, 21 mentioned a second vehicle in the household, 11 discussed the dealership rental offer, and four cited company cars, airlines, or traveling in a companion's car. Only one respondent, who traveled frequently between northern and southern California, indicated that the inability to make long-distance trips was a key criterion in deciding not to adopt an FCV.

Ways in which long-distance travel was feasible*	**Respondents who only traveled in state (n= 19)**	**Respondents who traveled in and out of state (n = 17)**
Supported by refueling Infrastructure	13	15
Second vehicle in the household	6	15
Rental car program	5	6
Company car/rental	0	2
Fly	0	1
Travel with someone else	0	1

Table 3. Ways in which respondents indicated long-distance travel was possible.
*Only respondents still in the model at the long-distance criterion are included here.

4.8 Cost Comparison

The issue of comparing costs between an FCV and another vehicle option was both common practice and complicated, primarily because different respondents considered different alternative vehicles and quantified costs differently. Of the 39 respondents for whom an FCV was feasible, nine did not consider any non-FCVs. Eight narrowed their search to a ZEV and two eliminated BEVs due to range, home-charging ability, or charging time. The remaining 28 respondents compared the cost of an FCV to an alternative. Of these, 20 chose an FCV, six a BEV, two a PHEV, one an HEV and two an ICE.

Some respondents, when asked “How did the cost of the FCV you were considering compare to other vehicles?” focused solely on the vehicle’s sticker price. Of these, some considered the price high for the amenities provided while others considered it low given the technology. Other respondents focused more broadly on operational costs, including the free fuel, free maintenance, and tax credits. Some respondents even focused more broadly on issues such as resale value and time saved due to HOV access.

We ran 25 respondents through the cost comparison in Stage 2 of the model. Regardless of how each respondent quantified the cost of the FCV and other vehicle options, 61% considered the FCV’s cost to be less than or equal to that of the other option(s). Given the equal or lesser costs, we predicted that all of these respondents would adopt the FCV, however three of the 17 respondents ultimately chose not to adopt the FCV. Two of these respondents actually considered the FCV cost less than that of their alternatives while the third considered the cost to be equal. One respondent felt the Mirai was “heavy” and “sluggish.” The second respondent compared the Honda Clarity FCV and PHEV and while they felt the FCV was cheaper, the long waitlist made the PHEV more feasible. The third respondent felt the FCV lacked “cool tech” and the customer was being asked to “finance the research.”

We predicted that the remaining 11 respondents who considered the FCV more expensive than other options would not adopt an FCV. For eight of the 11, this was correct. Two incorrectly predicted respondents were willing to pay more to support fuel cell technology, one of whom said, “someone needs to be the guinea pig.” All three highlighted HOV access and the features and drivability of the FCV, one calling the Mirai a “fun, sporty car to drive” and another feeling they got “a hell of a lot more car for the price.”

The fact that 61% of respondents considered FCVs to be cheaper than competing vehicles, while only three respondents were willing to pay more for an FCV and an equal number were willing to pay more for a non-FCV, raises concerns about future adoption of FCVs by consumers after federal, state, and manufacturer incentives end.

4.9 Multiple Reasons for Not Adopting

During Step 2 interviews, we addressed all criteria with every respondent regardless of whether they had already dropped from the EDM per prior responses. We thus identified which criteria respondents frequently cited in combination with others, and if any respondent had only one factor that made the vehicle infeasible. In Stage 1, none of the 13 respondents who we correctly predicted would drop out of the model had only one reason why the FCV was infeasible. Two dropped out at the first criterion regarding the vehicle size, although both noted other issues that led to their decision against FCV adoption. One expressed concerns about both making longer trips without a second car in the household and the inefficiency of hydrogen production. The other also cited a lack of stations near home and the FCV's lack of "wow factor." The five most common reasons for FCV unsuitability—beyond the criterion where they first dropped out of the model—were concerns about long distance travel (six respondents), perceived convenience of EV charging at home or work (five), concerns about the cost or environmental friendliness of hydrogen production (four), a desire to purchase rather than lease a vehicle (three), and perceptions that the FCV was a more expensive option (three).

In Stage 2 of the model, six of the eight respondents who considered the FCV to be more expensive and thus decided against FCV adoption noted other reasons that supported their decision. While each of these respondents had previously indicated that the refueling network was sufficient to consider the FCV to be feasible, five of them noted that it was still more inconvenient than they would have liked, and they had concerns about station failure. Another was concerned with the fossil fuel source of hydrogen. Only two respondents decided against FCV adoption due to a single criterion—cost.

5. 1 DISCUSSION AND LIMITATIONS

Our target population for sampling consisted of adults in California who "seriously considered" purchasing or leasing an FCV, regardless of the outcome of their decision. Our study was limited to California respondents because it is the only viable FCV market in the United States, but we recognize there may be limits to generalizing these results to other geographic areas and that future work should expand the focus to consider adoption factors in other populations. Additionally, we identified representative sampling frames for FCV adopters more easily than for non-adopters. Various social media forums exist for FCV adopters; no social media sites exist for people who considered adopting an FCV and decided against it. We reached out to non-adopters via forums for EV, PHEV, and hybrid drivers, surmising that some might have considered FCVs. This recruitment method did not sample drivers who are not active on online forums; we acknowledge that consumers who eschew online forums might approach the adoption decision process differently. Our results require confirmation from a broader sampling frame.

The difficulty of sampling individuals who seriously considered but ultimately did not get an FCV limited our sample size to only 53 individuals in Round 2. We emphasize, however, that this is not a significant limitation per EDM best practices. Ryan and Bernard's (36) seminal article places an *n* of 53 at the high end of the typical range of 20-60 Round 2 participants. We furthermore observed diminishing marginal returns in new information generated by later interviews, which confirmed that the decision processes described by respondents were similar, even if details varied.

Given that one purpose of this paper is to introduce an established but lesser-known ethnographic method that has not been used previously in the AFV literature, we would like to share some of our experiences that may prove helpful to future EDM studies on AFV adoption. First, there is no single correct way to generate a decision tree from the same set of interviews. The final decision tree structure was simplified substantially from earlier versions. We originally included additional branches to account for more idiosyncratic cases, but the result was a nearly tautological tree with very few incorrect predictions. For instance, we omitted a decision point after cost comparison asking if the respondent was willing to pay more for their more expensive option, which would have eliminated six of the seven total errors.

We also omitted a "Stage 0" in the EDM that accounted for several different reasons for initially considering an FCV. Stemming from them, we considered generating sub-trees specific to consumers who initially considered FCV adoption due to their (a) high-tech appeal, (b) environmental benefits, or (c) costs and incentives. Based on the standards of this method, however, we reduced the EDM to its most generalizable form without sacrificing any key factors that were commonly considered *and* that empirically and logically impacted respondents' final decisions. The goal is to create an EDM that is as simple as possible that captures the shared decision making process. We acknowledge that our final tree is what made the most sense to us based on what we repeatedly observed in interviews.

Second, a decision tree by definition is structured from a starting point to terminal branches and is evaluated sequentially. Respondents who reach a branch that drops them out of the EDM are eliminated at that point, without ever reaching later criteria that might represent more important factors to their decision-making. We did not attempt to determine the critical elimination factor for non-adopters, instead eliminating them at the first non-compliant factor. Thus, 14 respondents were eliminated in Stage 1 without reaching the comparison to other vehicles. This does not mean that these 14 individuals did not compare costs—nearly everyone mentioned costs in their interviews, and some spoke of weighing numerous factors contemporaneously. Some drivers discussed trade-offs, e.g., if the price had been lower, they would have been more willing to tolerate refueling hassles. The order we chose, however, was simpler and more consistent with what we heard from respondents. In Step 1 interviews, respondents tended to consider the feasibility factors as more straightforward to assess and did not get into the finer details of comparing costs until determining an FCV would be feasible. While some drivers may eliminate a BEV or FCV because it was too costly *before* determining if they could adapt to the vehicle's body type and refueling infrastructure, these drivers were likely missed in our sampling due to our requirement that respondents needed to have seriously considered the vehicle. Nevertheless, the order of factors is an inherent limitation of decision-tree models.

Finally, while the interviewer followed a series of defined prompts, semi-structured interviews sometimes veered in different directions, and we asked some respondents questions that we did not ask everyone. We did not, for instance, ask every respondent for a full inventory of vehicles in their household, although some volunteered this information. We thus did not pull this out as a separate factor in the long-distance section of the EDM but bundled it with other methods of managing long-distance travel.

6. CONCLUSIONS

This paper introduces an ethnographic method to the alternative fuels and vehicles literature to evaluate how potential FCV adopters typically navigate the decision to adopt one. The EDM produced in this study is based on two rounds of in-depth interviews of 78 respondents who either acquired an FCV or seriously considered doing so but did not. The tree consists of two stages: feasibility of the vehicle and infrastructure, and comparison to other vehicles. It identifies a number of critical decision points that either allow continued interest in FCVs or function as “deal-breakers” that lead someone to choose another vehicle. These findings are of importance to manufacturers and policy makers who are promoting FCV adoption, offering clear indicators on where to focus efforts on marketing and messaging. The tree could even be included in training material for salespeople working within FCV sales to show where potential adopters may be stuck in their decision process.

One-quarter of the respondents who ultimately rejected FCV adoption cited a lack of refueling stations convenient to home, work, or regular travel routes: this has long been considered the primary barrier to AFV adoption. The lack of nearby, convenient backup stations is the next most frequent reason a respondent does not get an FCV in the feasibility-assessment stage, and is a clear signal that unreliable stations do more than inconvenience early adopters: they can dissuade prospective adopters from ever getting an FCV in the first place. While respondents preferred to satisfy their needs for primary and backup refueling with a station near home, a majority of respondents were willing to rely on a station near or on the way to other locations. This finding supports other evidence that FCV drivers knowingly plan to rely on a set of stations that satisfy various geographic criteria. It suggests that manufacturers and policy makers should focus on developing a network of reliable stations in which as many individual stations as possible offer reasonable convenience not only to nearby residents but also to those who regularly travel to nearby locations for work or other reasons, or pass through the area on the way to somewhere else..

That the FCV range was sufficient for the vast majority of respondents—including those who ultimately did not get one—is notable. All prospective adopters felt they could complete their regular, daily travel using an FCV given the vehicle’s range. Long-distance travel, a prominent consideration of the general public, only eliminated one respondent from FCV consideration. Most respondents either used their FCVs to conduct their long-distance trips or found a diversity of other ways to do so, such as a secondary vehicle or a rental car. Given the lack of range concern amongst the respondents, we suggest that the focus on range in advertising does not need to be as prominent.

Of the respondents who concluded that an FCV was feasible, roughly a quarter were exclusively focused on FCVs. The majority compared the FCV to another vehicle option, with almost a quarter narrowing their choices to FCV vs. BEV and the remainder considering PHEV, HEV, or ICE. Of these, most chose what they viewed as the cheaper option, although a few were willing to pay more for their preferred option, whether it was an FCV or BEV. There was great diversity, however, on which costs and incentives respondents included. Additionally, when asked about initial interest in FCVs, several respondents stated that they first learned of FCVs by researching vehicles eligible for tax incentives. Several other respondents indicated that they first began looking at AFVs as a way to reduce maintenance and gas costs. Thus, it is clear that the total cost, as well as rebates and incentives, are still key factors that influence the decisions of whether or not to adopt AFVs.

Finally, the ethnographic decision method appears to be an insightful way of extracting and representing the shared decision processes for FCV purchasing. When asked to “take us through your decision process,” common pathways emerge quickly in the first round and can be refined and confirmed in a second round. Despite a relatively small sample size, a simplified decision tree is able to predict nearly 90% of decisions correctly. Future work incorporating the EDM method in AFV adoption research offers a number of promising opportunities, including determining what criteria are key in the adoption of a broader range of eco-friendly vehicles, as well as issues such as station choice, purchasing vs. leasing, and many other AFV-related decisions. Additionally, replication of this study outside of the California context will be valuable to see what factors may be specific to this population.

REFERENCES

[1] Zero Emission Vehicles | Department of Environmental Conservation n.d. https://dec.vermont.gov/air-quality/mobile-sources/zev (accessed December 4, 2020).

[2] Office of Energy Efficiency and Renewable Energy. Alternative Fuels Data Center. Altern Fuels Data Cent n.d. https://www.afdc.energy.gov/data/10304 (accessed July 30, 2020).

[3] Melendez M. Transitioning to a hydrogen future: Learning from the alternative fuels experience. Golden, CO: National Renewable Energy Laboratory; 2006.

[4] Hardman S, Chandan A, Shiu E, Steinberger-Wilckens R. Consumer attitudes to fuel cell vehicles post trial in the United Kingdom. Int J Hydrog Energy 2016;41:6171–9. https://doi.org/10.1016/j.ijhydene.2016.02.067.

[5] Ramea K. An integrated quantitative-qualitative study to monitor the utilization and assess the perception of hydrogen fueling stations. Int J Hydrog Energy 2019. https://doi.org/10.1016/j.ijhydene.2019.05.053.

[6] Lopez Jaramillo OG, Stotts R, Kelley S, Kuby M. Content Analysis of Interviews with Hydrogen Fuel Cell Drivers in Los Angeles. Transp Res Rec 2019;2673:377–88. doi: 10.1177/0361198119845355.

[7] Hardman S, Shiu E, Steinberger-Wilckens R, Turrentine T. Barriers to the adoption of fuel cell vehicles: A qualitative investigation into early adopters' attitudes. Transp Res Part Policy Pract 2017;95:166–82. https://doi.org/10.1016/j.tra.2016.11.012.

[8] Gladwin CH. Ethnographic decision tree modeling. vol. 19. Los Angeles: Sage; 1989.

[9] Al-Alawi BM, Bradley TH. Review of hybrid, plug-in hybrid, and electric vehicle market modeling studies. Renew Sustain Energy Rev 2013;21:190–203. http://dx.doi.org/10.1016/j.rser.2012.12.048

[10] Greene DL, Lin Z, Dong J. Analyzing the sensitivity of hydrogen vehicle sales to consumers' preferences. Int J Hydrog Energy 2013;38:15857–67. https://doi.org/10.1016/j.ijhydene.2013.08.099.

[11] Rezvani Z, Jansson J, Bodin J. Advances in consumer electric vehicle adoption research: A review and research agenda. Transp Res Part Transp Environ 2015;34:122–36. https://doi.org/10.1016/j.trd.2014.10.010.

[12] Coffman M, Bernstein P, Wee S. Electric vehicles revisited: A review of factors that affect adoption. Transp Rev 2016;37:79–93. https://doi.org/10.1080/01441647.2016.1217282.

[13] Liao F, Molin E, Wee B van. Consumer preferences for electric vehicles: a literature review. Transp Rev 2017;37:252–75. https://doi.org/10.1080/01441647.2016.1230794.

[14] Hjorthol R. Attitudes, ownership and use of Electric Vehicles – a review of literature. Institute of Transport Economics; 2013.

[15] Turcksin L, Mairesse O, Macharis C. Private household demand for vehicles on alternative fuels and drive trains: a review. Eur Transp Res Rev 2013;5:149–64. https://doi.org/10.1007/s12544-013-0095-z.

[16] Hardman S, Chandan A, Tal G, Turrentine T. The effectiveness of financial purchase incentives for battery electric vehicles–A review of the evidence. Renew Sustain Energy Rev 2017;80:1100–11. doi: 10.1016/j.rser.2017.05.255.

[17] Gnann T, Plötz P. A review of combined models for market diffusion of alternative fuel vehicles and their refueling infrastructure. Renew Sustain Energy Rev 2015;47:783–93. https://doi.org/10.1016/j.rser.2015.03.022.

[18] Hardman S, Tal G. Who are the early adopters of fuel cell vehicles? Int J Hydrog Energy 2018;43:17857–66. https://doi.org/10.1016/j.ijhydene.2018.08.006.

[19] Roche MY, Mourato S, Fischedick M, Pietzner K, Viebahn P. Public attitudes towards and demand for hydrogen and fuel cell vehicles: A review of the evidence and methodological implications. Energy Policy 2010;38:5301–10. doi:10.1016/j.enpol.2009.03.029.

[20] Hoen A, Koetse MJ. A choice experiment on alternative fuel vehicle preferences of private car owners in the Netherlands. Transp Res Part Policy Pract 2014;61:199–215. http://dx.doi.org/10.1016/j.tra.2014.01.008.

[21] Fan J-L, Wang Q, Yang L, Zhang H, Zhang X. Determinant changes of consumer preference for NEVs in China: A comparison between 2012 and 2017. Int J Hydrog Energy 2020;45:23557–75. https://doi.org/10.1016/j.ijhydene.2020.06.002.

[22] Hackbarth A, Madlener R. Willingness-to-pay for alternative fuel vehicle characteristics: A stated choice study for Germany. Transp Res Part Policy Pract 2016;85:89–111. https://doi.org/10.1016/j.tra.2015.12.005.

[23] Morton C, Anable J, Nelson JD. Assessing the importance of car meanings and attitudes in consumer evaluations of electric vehicles. Energy Effic 2016;9:495–509. https://doi.org/10.1007/s12053-015-9376-9.

[24] Egbue O, Long S. Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. Energy Policy 2012;48:717–29. http://dx.doi.org/10.1016/j.enpol.2012.06.009.

[25] Brey JJ, Brey R, Carazo AF. Eliciting preferences on the design of hydrogen refueling infrastructure. Int J Hydrog Energy 2017;42:13382–8. https://doi.org/10.1016/j.ijhydene.2017.02.135.

[26] Eppstein MJ, Grover DK, Marshall JS, Rizzo DM. An agent-based model to study market penetration of plug-in hybrid electric vehicles. Energy Policy 2011;39:3789–802. https://doi.org/10.1016/j.enpol.2011.04.007.

[27] California Air Resources Board. Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development n.d. https://ww2.arb.ca.gov/resources/documents/annual-hydrogen-evaluation (accessed September 5, 2020).

[28] Ziegler A. Individual characteristics and stated preferences for alternative energy sources and propulsion technologies in vehicles: A discrete choice analysis for Germany. Transp Res Part Policy Pract 2012;46:1372–85. https://doi.org/10.1016/j.tra.2012.05.016.

[29] Caperello ND, Kurani KS. Households' stories of their encounters with a plug-in hybrid electric vehicle. Environ Behav 2012;44:493–508. doi: 10.1177/0013916511402057.

[30] Noblet CL, Teisl MF, Rubin J. Factors affecting consumer assessment of eco-labeled vehicles. Transp Res Part Transp Environ 2006;11:422–31. https://doi.org/10.1016/j.trd.2006.08.002.

[31] Klöckner CA. The dynamics of purchasing an electric vehicle – A prospective longitudinal study of the decision-making process. Transp Res Part F Traffic Psychol Behav 2014;24:103–16. https://doi.org/10.1016/j.trf.2014.04.015.
[32] Heffner RR, Kurani KS, Turrentine TS. Symbolism in California's early market for hybrid electric vehicles. Transp Res Part Transp Environ 2007;12:396–413. doi:10.1016/j.trd.2007.04.003.
[33] Plattner S. Economic decision making of marketplace merchants: an ethnographic model. Hum Organ 1984;43:252–264. https://doi.org/10.17730/humo.43.3.50502002868g67v7.
[34] Gatewood JB. Deciding where to fish: The skipper's dilemma in Southeast Alaskan salmon seining. Coast Zone Manag J 1983;10:347–67. https://doi.org/10.1080/08920758309361928.
[35] Montbriand MJ. Decision tree model describing alternate health care choices made by oncology patients. Cancer Nurs 1995;18:104–17.
[36] Ryan GW, Martínez H. Can We Predict What Mothers Do? Modeling Childhood Diarrhea in Rural Mexico. Hum Organ 1996;55:47–57. doi: 10.17730/humo.55.1.p0n23832j8q34743.
[37] Weller SC, Ruebush TRI, Klein RE. Predicting Treatment ‐ Seeking Behavior in Guatemala: A Comparison of the Health Services Research and Decision‐Theoretic Approaches. Med Anthropol Q 1997;11:131‐267. doi: 10.1525/maq.1997.11.2.224.
[38] Johnson J, Williams ML. A Preliminary Ethnographic Decision Tree Model of Injection Drug Users' (IDUs) Needle Sharing. Int J Addict 1993;28:997–1014. doi: 10.3109/10826089309062179.
[39] Murtaugh M, Gladwin H. A hierarchical decision-process model for forecasting automobile type-choice. Transp Res Part Gen 1980;14:337–47. doi: 10.1016/0191-2607(80)90053-9.
[40] Ryan GW, Bernard HR. Testing an ethnographic decision tree model on a national sample: Recycling beverage cans. Hum Organ 2006;65:103–14. doi: 10.17730/humo.65.1.884p8d1a2hxxnk79.
[41] Handwerker WP, Wozniak DF. Sampling Strategies for the Collection of Cultural Data: An Extension of Boas's Answer to Galton's Problem. Curr Anthropol 1997;38:869–75. https://doi.org/10.1086/204675.
[42] Guest G, Bunce A, Johnson L. How Many Interviews Are Enough?: An Experiment with Data Saturation and Variability. Field Methods 2006;18:59–82. https://doi.org/10.1177/1525822X05279903.
[43] Hagaman AK, Wutich A. How Many Interviews Are Enough to Identify Metathemes in Multisited and Cross-cultural Research? Another Perspective on Guest, Bunce, and Johnson's (2006) Landmark Study. Field Methods 2017;29:23–41. https://doi.org/10.1177/1525822X16640447.
[44] DeMaio TJ, Rothgeb JM. Cognitive interviewing techniques: In the lab and in the field. Answering Quest. Methodol. Determining Cogn. Commun. Process. Surv. Res., N. Schwarz & S. Sudman (Eds.) San Francisco: Jossey-Bass; 1996, p. 177–95.
[45] Corbin JM. Basics of qualitative research: techniques and procedures for developing grounded theory. 3rd ed. Los Angeles, Calif: Sage Publications, Inc; 2008.
[46] Gladwin CH. A theory of real-life choice: Applications to agricultural decisions. Agricultural Decision Making: Anthropological Contributions to Rural Development. P. Bartlett (Ed.), New York: Academic Press; 1980, p. 45–85. https://doi.org/10.1016/B978-0-12-078882-8.50008-8.

[47] Kelley S, Krafft A, Kuby M, Lopez O, Stotts R, Liu J. How early hydrogen fuel cell vehicle adopters geographically evaluate a network of refueling stations in California. J Transp Geogr 2020;89:102897. https://doi.org/10.1016/j.jtrangeo.2020.102897.