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# Real-world insights into user acceptance of e-fuels for passenger vehicles in Germany

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**Abstract**

E-fuels can provide a temporary replacement of fossil fuels until fleets are converted to zero-emission vehicles. To ensure a broad use of these fuels, their acceptance by car owners is critical. In late 2020 we conducted a survey on user acceptance of renewable fuels in Germany with more than 500 participants including a stated choice experiment and a willingness-to-pay analysis. During 2021, the participants of the first study were contacted again to gain knowledge about the everyday use of their vehicles. In the context of this paper, the results of the different surveys were combined to obtain real-world insights into the acceptance of e-fuels by different user groups. We found that usage behavior, gender, and environmental behavior have an influence on fuel choice. In particular, differences in vehicle use were reflected in the willingness-to-pay analysis.



*Keywords:* User acceptance; Survey; Stated preference; Trip diary; Renewable and low-carbon fuels; Renewable energy

## 1. Introduction

Germany’s road transportation saw reductions in greenhouse gas emission of around 6% in 2021 compared to 1990 due to the effects of the COVID-19 pandemic (German Environment Agency, 2022). Before the pandemic, emissions were about 3% higher than emissions in 1990 (German Environment Agency, 2022). Only due to reduced travel during the pandemic were the sectoral target for 2020 achieved (KSG, 2019). In order to reduce fossil fuel usage and thus greenhouse gas emissions, alternative fuels are being developed that allow continued usage of existing vehicles and infrastructure.

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There are many different terms for these kinds of fuels (e.g., alternative fuels, renewable fuels, synthetic fuels, $CO_2$ or carbon neutral fuels, biofuels). In the case of $CO_2$-neutral fuels, a distinction is generally made between two production paths. $CO_2$-neutral fuels can be produced from electrical energy, water and $CO_2$ (i.e., e-fuels) or from biomass (i.e., biofuels). In this paper alternative fuels are general $CO_2$-neutral fuels, e-fuels are from renewable electricity, water and $CO_2$ and biofuels as fuels are from biomass. Our focus lies on e-fuels.

E-fuels offer one solution to decarbonize the transportation sector. In addition to battery electric vehicles, e-fuels are a promising option for substituting fossil fuels. Existing internal combustion engine vehicles can be operated using e-fuels and have a neutral greenhouse gas footprint. Furthermore, e-fuels allow for fast refueling just like conventional vehicles. In addition, the current fuel supply and distribution infrastructure can be maintained. Currently, e-fuels are in their early stage of development (National Platform Future of Mobility, Working group 2, 2021).

Given the present low availability of e-fuels, there is limited research on user acceptance of e-fuels. Therefore, we carried out a survey of user acceptance of e-fuels using a stated preference survey and a driving and fueling logbook. The objective of the present paper is to identify the needs of different user groups and evaluate drivers and barriers to the adaptation of e-fuels for daily use from individual car owners.

In the following section we provide an overview of the research literature on this topic. Then we present the methodology for our analysis. This is followed by the study results and a discussion of the findings. Finally, we present an outlook for future research and the limitations of the current study.

## 2. Literature Review

User acceptance of e-fuels plays an important role in the adoption of these technologies. In recent years, a number of studies have explored the importance of individual acceptance of such fuels using different methods. Huh et al. (2014) examined Korean customers' preferences of a renewable fuel standard. Increased fuel price was found to be the most influential attribute on the acceptance level, whereas other attributes such as reduced emissions and fuel efficiency had little impact on individual acceptance.

These results were supported by Linzenich et al. (2019) who studied the preferences of German car drivers towards alternative fuels. They found that the most important factor was fuel cost, whereas emission reductions were irrelevant for fuel preference. A market simulation of diesel and alternative fuels revealed that a large majority of users would prefer conventional fossil fuel options, indicating a low consumer demand for such fuels at the present.

Since price seems to be the largest driver for acceptance, Shin and Hwang (2017) examined consumer preferences and willingness-to-pay for potential biofuels. Consumers were generally willing to accept increased costs of such fuels to a certain extent. However, willingness-to-pay depended on income levels, and higher income levels were associated with a higher willingness-to-pay.

Arning et al. (2021) identified different acceptance profiles for carbon capture and utilization and e-fuels in Germany on a representative sample in Germany ($n = 343$). $CO_2$ storage and reduced fossil resource use were the main drivers for acceptance. Based on a latent class analysis they defined three general acceptance profiles: "green motives," "financial motives" and "profitability and participation-sensitivity." Environmental benefits were the most acceptance-relevant factors for "green motive" respondents, whereas profitability was more relevant for "financial motives" respondents. For the third group, profitability and public participation in the deployment process, but not environmental benefits, were the most important factors.

In another recent study, Offermann-van Heek et al. (2018) evaluated the acceptance of e- fuels using conjoint analysis. Here, laypersons evaluated life-cycle scenarios consisting of diverse options regarding $CO_2$ capture, transport and production infrastructure. The authors found that end products had higher acceptance than intermediate products of $CO_2$-based fuels. The most acceptance-relevant factors were the capture and transport of $CO_2$. Preferences were influenced by information about environmental impact and energy demand. However, results from Teoh and Khoo (2021) suggest that user perceptions are also highly influenced by a variety of other factors (e.g., government policy, market value of vehicles, convenience and accessibility, environmental and technological concerns, influence of family, friends, and colleagues).

While acceptance of alternative fuels has been studied for several years, previous studies have not insufficiently considered different fuels. In addition, the usage patterns of passenger vehicle users have not been sufficiently considered. Thus, we address these missing areas of research in this study.

## 3. Methods

The empirical approach of this study can be divided into two main parts: an online survey, including a stated preference survey, and driving and refueling logbooks. In order to examine user preference of fuel choice in more detail, the results of the driving and refueling logbooks were included in the stated preference evaluation. The samples for both parts were drawn from the MovingLab participants' pool: an existing pool of participants for transportation studies with the German Aerospace Center.

### *3.1. Online survey*

The aim of the survey was to assess the adoption of e-fuels by German car users. The online survey was hosted on the platform Survey Engine. From the MovingLab participants' pool 1,255 German car owners who possess at least one vehicle for private purposes were chosen and contacted via email. The survey was conducted in three waves between September and October 2020. In total 805 replies were received. Before evaluation, a data pre-processing was performed to clean the dataset of faulty replies that contain incomplete or duplicate answers as well as inconclusive and contradicting answers. The final dataset contained 545 valid replies (16% return).

The online survey consisted of two parts. First, a general part included questions about socio-demographic aspects, environmental behavior, acceptance of e-fuels as well as experience with alternative fuels and powertrains. Second, a stated preference part was used to model hypothetic decision making for choosing a certain e-fuel depending on the certain fuel characteristics. Further data like information on the sex, age groups and type of residence area according to RegioStaR2 were taken from the MovingLab database (Federal Ministry of Transport and Digital Infrastructure, 2020).

In the stated choice experiment, participants were given a choice between four different refueling options out of four e-fuels and their characteristics (Table 1). The names of the fuels were not visible to the participants. Each refueling option also differs in the characteristics physical state (gaseous or liquid), nitrogen oxide emissions (compared to the other fuels), $CO_2$ emissions (compared to the other fuels), fuel price (price per 100 km), range (with a full tank) and resource consumption (energy and water consumption during production). The assumptions on the characteristics of the e-fuels are based on investigated fuel production paths within the BEniVer project (see Acknowledgements). The following question was asked:

> *Imagine you need to refuel your vehicle. For this purpose, all the alternatives for refueling given below are available to you. The information on the physical state, nitrogen oxide emissions, $CO_2$ emissions, fuel price, range and resource consumption differ depending on the fuel.*

Table 1: Fuel alternatives and their characteristics considered in stated choice experiment (the names in brackets were not shown in the survey)

| Property | Format | A (CNG) | B (Petrol) | C (Methanol) | D (Diesel) |
|---|---|---|---|---|---|
| Physical state | categorical | gaseous | liquid | liquid | liquid |
| Nitrogen oxide emissions | ordinal | low \| medium | low \| medium | very low | high \| very high |
| $CO_2$-Emissions | ordinal | very low | low \| medium | medium \| high \| very high | low \| medium |
| Fuel price | € per 100 km | 10 \| 14 \| 17 | 17 \| 23 \| 29 | 13 \| 17 \| 22 | 17 \| 23 \| 29 |
| Range | km per tank filling | 230 \| 310 \| 390 | 420 \| 565 \| 710 | 210 \| 285 \| 360 | 430 \| 585 \| 740 |
| Resource consumption | ordinal | very low | medium \| high \| very high | very low \| low | medium \| high \| very high |

Two choice sets, each with six decision situations, were created using the Ngene software (ChoiceMetrics, 2018) and a pre-test was completed. For the model estimation, a multinomial logistic regression approach was used according to Dios Ortúzar and Willumsen (2011).Only fully completed surveys were considered. To build the final model, the influence of different information from the base online questionnaire was analyzed. Using an iterative approach, explanatory variables were identified and included in the final model.

### *3.1.1. Driving and refueling logbooks*

In the spring of 2021, 1,255 German car owners from the MovingLab participants' pool were asked to take part in the online survey. In addition to socio-demographic information, people were asked to provide information about their vehicles and behavior-related aspects (e.g., trip purpose, frequency of use).

In the logbook, all trips were recorded within a reference week as well as all refueling processes over eight weeks. Among other things, the persons had to enter information in the logbook about the purpose of the journey, the route or arrival and departure times. A final total of 297 people took part in the online.

Both logbooks enabled the collection of real-world data on driving and refueling behavior that can be connected to the user acceptance of potential e-fuels in the near future. Therefore, the results of both methods enable a detailed analysis of acceptance, preferences, and opportunities to improve the adaption of e-fuels into the private transportation sector.

## *3.2. Connecting the data*

To enable more in-depth analyses of the stated preference survey, information from the participants pool, from the general part of the online survey and from the driving and refueling logbooks were also included. Sex, age and residence urban structure were obtained from the participants pool. Household composition, environmental behavior, innovativeness and prior experience with alternative fuels and drives were obtained from the general survey. Furthermore, three different groups were identified from the driving and refueling logbooks. The intersection of participants who took part in both the online survey and the driving and refueling logbooks was relatively small (n=185).

Three different groups were formed from the results of both survey books. Group 1 (logbook) consists of the number of trips made during the reference week. Group 2 (logbook) contains the average kilometers during the reporting week, and Group 3 (fuel log) contains the number of refueling events within the eight weeks.

For the imputation, we evaluated each group with regard to the age distribution and the general frequency of car use (Table 2). Age was divided into three groups (under 30 years, 30 to 49 years and 50 years and older). The frequency of car use consists of 2 categories (almost daily use and regular to irregular use). Due to the small sample, the categories were combined and all people who did not report daily were placed in the second category (1-3 days per week).

Table 2: Frequency distribution as a basis for imputation

| | | **Group 1** | | **Group 2** | | **Group 3** | |
|---|---|---|---|---|---|---|---|
| age | car use | below-average number of trips | above-average number of trips | below-average kilometers travelled | above-average kilometers travelled | below-average number of refueling processes | above-average number of refueling processes |
| < 30 years | (almost) daily use | 53% | 47% | 29% | 71% | 47% | 53% |
| | regular to infrequent use | 69% | 31% | 44% | 56% | 56% | 44% |
| 30-49 years | (almost) daily use | 30% | 70% | 59% | 41% | 35% | 65% |
| | regular to infrequent use | 74% | 26% | 44% | 56% | 54% | 46% |
| 50 and over | (almost) daily use | 31% | 69% | 46% | 54% | 44% | 56% |
| | regular to infrequent use | 83% | 18% | 53% | 48% | 60% | 40% |

Table 2 shows the frequency distribution that serves as the basis for the imputation. It can be seen that the distribution of the groups differs in terms of age and car use. People who generally use the car almost every day also covered an above average number of journeys and kilometers within one week in the reporting week and also refueled more frequently in eight weeks. Age also has an influence. The percentage of people who stated that they do not use the car every day and also made a below average number of journeys within the reference week increases the higher the age group.

## 4. Results and Discussion

The general frequency of car use gives a first impression of how intensively people use their car. In contrast, the number of trips within the reference week shows the actual use of the car. People who made a large number of trips also ticked the almost daily use in the online questionnaire. During the reporting week, an average of 12.6 journeys per car were made with an average distance of 23.5 kilometers. In addition to the way home (35%), the car was primarily used to get to work (19%), for shopping (17%) and for leisure trips (11%). Looking at the number of trips made and the average kilometers differentiated according to socio-demographic information, it is observed that men are more represented than women in the categories "above-average number of trips". In the age categories, the 30 to 49 year-olds made a higher proportion of journeys in the reporting week than the under 30 year-olds or over 50 year-olds. This could be due to the fact that this age range has a high proportion of employed people and the main purpose of travel is to get to work. In the eight-week reporting period, a car was refueled 4.6 times on average and an average of 32.6 liters per refueling. A large part of the refueling processes was combined with other travel purposes (e.g., shopping). People who covered an above-average number of journeys and kilometers during the reporting week also had an above-average number of refueling events.

In Table 3 the results of the final multinomial logit model are presented. Overall, the estimated coefficients show the expected signs and plausible values. In Fig. 1 aspects from Table 3 are visualized in a normalized form to illustrate the assessment by the different user groups.

Table 3: Estimated regression coefficients and model fit from multinomial regression

| **Coefficient** | **Est. Value $\beta$** | **Std. error** | **t-test** |
|---|---|---|---|
| ASC Petrol | 1.03 | 0.138 | 7.49 |
| ASC Diesel | 0.879 | 0.16 | 5.49 |
| ASC Methanol | 0.426 | 0.133 | 3.2 |
| $\beta$ co2 negative environmental behavior | -0.365 | 0.0421 | -8.67 |
| $\beta$ co2 positive environmental behavior | -0.432 | 0.0436 | -9.9 |
| $\beta$ nox | -0.2 | 0.0412 | -4.87 |
| $\beta$ price more trips | -0.0787 | 0.00536 | -14.7 |
| $\beta$ price less trips | -0.0948 | 0.00611 | -15.5 |
| $\beta$ range female | 0.00332 | 0.000228 | 14.6 |
| $\beta$ range male | 0.0031 | 0.00022 | 14.1 |
| $\beta$ resources positive environmental | -0.322 | 0.0344 | -9.38 |
| $\beta$ resources positive environmental | -0.53 | 0.0369 | -14.3 |
| **Model fit** | | | |
| Log-Likelihood (0): | | | -4,458 |
| Log-Likelihood (final): | | | -3,731 |
| Corrected MCFadden $\bar{\rho}^2$ | | | 0.161 |
| Estimated coefficients: | | | 12 |
| Observations | | | 3,216 |

ASC: alternative specific constant  $\beta$: estimated regression coefficients

Environmental characteristics such as $CO_2$ emissions and resource consumption are given greater consideration by car owners with strong environmental awareness. We also found that there was a greater difference between the groups with higher and lower environmental awareness in the assessment of resource consumption than in the assessment of $CO_2$ emissions (Fig. 1). Nevertheless, compared with the other environmental aspects, $NO_x$ emissions play a minor role in decision-making. No correlation with environmental awareness was found here either. Furthermore, a correlation between the evaluation of the fuel price and the car use of Group 1 was identified. For people who use their vehicle more frequently, price is less relevant in the decision-making process (Fig. 1). Another difference in the evaluation of fuel characteristics could be identified with regard to the range with a full tank. The range with a full tank has a slightly higher relevance for women than for men (Fig. 1).

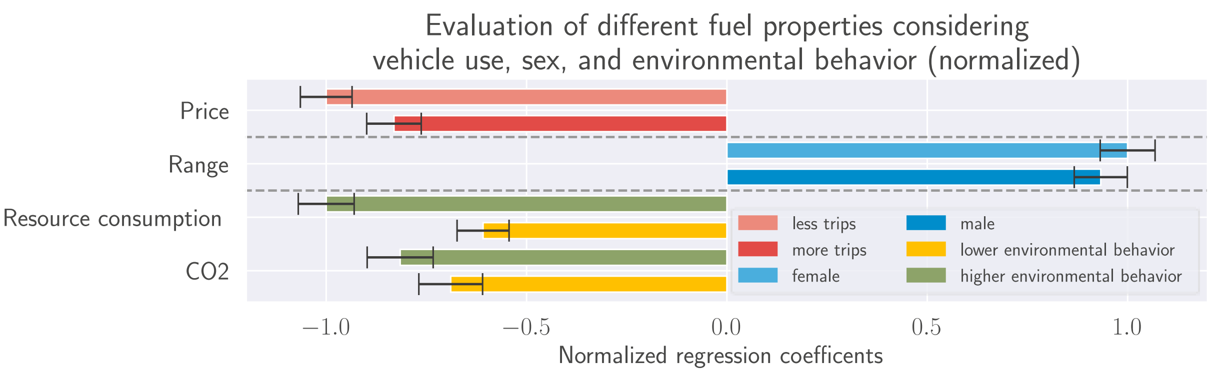


Fig. 1: Normalized evaluation of different fuel properties considering vehicle use, gender, and environmental behavior.

The results of the models from Table 3 can be used to evaluate and compare the willingness-to-pay for additional range with a full tank. In Fig. 2, the results of this analysis are presented. The figure shows that users of Group1 who are more frequent drivers are willing to pay an additional premium for a higher range and therefore a fuel with higher energy density (see upper bars). A similar effect can also be observed between the sexes. Women tend to be more willing to pay a higher premium for additional reach than men (see dark and light blue bars).

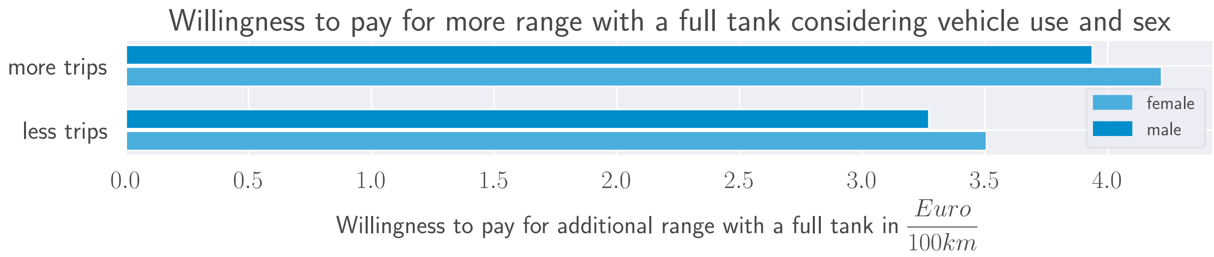


Fig. 2: Willingness-to-pay for additional range with a full tank considering vehicle use and sex

The results show that the acceptance of e-fuels highly depend on the user group. We found that usage behavior, gender, and environmental behavior have an influence on fuel choice. In particular, differences in vehicle use were reflected in the willingness-to-pay analysis. In particular, there were significant differences in the willingness-to-pay analysis for different vehicle user groups. Users who use their vehicle more frequently tend to be willing to pay more for additional range. Since it can be assumed that more trips also mean higher mileage, this result appears counterintuitive at first. However, the analyses of the driving and fuel logbooks show that people who use their car less frequently usually drive longer distances and therefore may have a different relation to fuel prices. However, this fact indicates that the actual target group for alternative fuels might be more price-sensitive.

## 5. Conclusion

In this paper the quantitative method of conducting multiple surveys was chosen for acquiring insights into the driving and refueling behavior, preferences, and acceptance of German car owners towards e-fuels.

The scope of this research is limited to vehicle users in Germany who are also members of the sample. Since the invitations were sent by e-mail, only participants with an e-mail address were considered. In order to put the findings into context, it is important to consider current developments in the transport sector and the limitations of the study. New alternatives are increasingly opening up for individual motorized transport in particular. How alternative drivetrains will affect the acceptance of e-fuels can hardly be estimated. Moreover, it is not yet clear when and to what extent e-fuels will be available. Therefore, the results found should be understood as a directional guide and a basis for further investigation.

Future research topics arising from the results should include further studies on user acceptance of user groups whose needs cannot be satisfied by alternative drivetrains. Specifically considering their price sensitivity compared to alternative drivetrains. In addition, it should be investigated whether and to what extent e-fuels should be used for the transition between vehicles with internal combustion engines and alternative drivetrains in motorized private transport. A clear policy direction on this topic would also be desirable in order to provide investment security for suppliers and users. The results further show that the production of e-fuels can be a strong barrier to acceptance, especially for environmentally conscious people. In the past, for example, there were major acceptance problems with the introduction of a gasoline-ethanol mixture in Germany (E10). Therefore, it is important in a public debate to ensure sufficient transparency regarding the origin of the fuels, the amount of renewable electricity needed for production, and the competition for use in the region of production.

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