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Who will buy electric cars? An empirical study in Germany

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ABSTRACT

This study forecasts the market potential of electric vehicles by looking at 14 categories of vehicle. It weighs the individual priorities against social preferences and a selection process is used to analyse priorities and barriers to allow individuals considered potential electric vehicle buyers to be identified.

1. Introduction

In 2009, of 3.8 million new car registrations in Germany, only 162 were electric vehicles (EVs). Nevertheless, almost all major manufacturers are demonstrating interest in them and small, micro, and city cars are being developed. In addition to technical considerations, particularly regarding power storage, a lack of knowledge about future market opportunities is inhibiting many manufacturers.[1] This paper helps to clarify the situation and, in a survey among German consumers, purchase-relevant vehicle criteria of two categories (type and use) are prioritized and iteratively consolidated to identify barriers of consumers' buying intention in the EV market and, by using this information, to identify vehicle categories that may exhibit a promising market potential for EVs.

2. The methodology

Stated preference methods are widely used in marketing and have been extensively applied to problems of consumer choice and market forecasting when preference data is either unavailable or not easily obtainable, as with the case of EVs (Chiu and Tzeng, 1999). To design a stated preference experiment, the hypothetical product types and criteria included are initially identified and selected (Louviere et al., 2000).

2.1. Vehicle uses and types

Official classifications of vehicle categories by governmental or semi-governmental institutions – such as ISO 3833, fueleconomy.gov for the United States; VFACTS Motor Vehicle Classifications for Australia; and EU car classification for Europe – are not identical and generally vary regarding vehicle sizes and uses. Here, we break down vehicles features to yield eight types (Table 1).

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[1] For example, according to public press releases, 50% of the population can imagine purchasing an electrically powered vehicle. J.D. Power and Associates (2010), for instance, explicitly scrutinizes the omnipresent enthusiasm regarding EV market growth, but at a very abstract level without considering what types of EVs have the real market potential.

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Table 1
Vehicle types.

No.	Type	Examples	Price range
1	Micro car, city car	Smart Fortwo, Fiat 500, Peugeot 107	€8000–15,000
2	Compact car, small family car	Ford Focus, Opel Astra, Toyota Auris, Volkswagen Golf, BMW 1 Series, Mercedes A-Class	€12,000–24,000
3	Midsize car	Ford Mondeo, Mercedes C-Class, Audi A4, BMW 3 Series, Honda Accord, Opel Insignia, Volkswagen Passat	€17,000–30,000
4	Van	Renault Espace, VW Sharan, Ford Galaxy, Citroen C8	€18,000–35,000
5	Executive car	Ford Crown Victoria, Holden Commodore, Toyota Crown, Chrysler 300C, Lexus GS, BMW 5 Series, Jaguar XF, Audi A6	€25,000–60,000
6	SUV	Land-/Range Rover, Ford Explorer, Jeep Grand Cherokee, Volkswagen Touareg, Cadillac Escalade, Chevrolet Suburban, Toyota Land Cruiser	€40,000–100,000
7	Luxury car	Audi A8, Jaguar XJ, Maserati Quattroporte, Mercedes S-Class, BMW 7 Series, Volkswagen Phaeton	€50,000–
8	Sports car	Chevrolet Corvette, Porsche 911, Ferrari 458 Italia, Nissan Z-car, Audi R8, Mercedes SL	€40,000–

A separate classification for use is developed because there are differences between vehicle types and their operation purposes; uses may play an important role in the purchase decision process for EVs because of their limited cruising range. These categories are:

1. First vehicle for all-day use; short- and long-distance operations.
2. Secondary car basically for occasional and short-distance operations.
3. Family car for transporting several passengers.
4. Commercial vehicles (e.g., taxis).
5. Leisure car to operate during time off.
6. Off-roaders.

The criteria considered here with regard to conventional vehicles and EVs purchases are price, maximum cruising range, environmental impact, performance, durability, and convenience.

A survey was conducted online with 1152 individuals (35.9% female, average age 39.9 years). The qualities of web surveys vary widely (Couper, 2000). The disadvantage of inappropriate answers by the subjects due to loose control of the sampling process can counteract the advantage the ability to collect large data sets at small cost. The e-mail addresses were thus selected carefully. They were obtained from a pool of 130,000 members of a German service provider who were recruited from e-commerce customers of various suppliers of everyday commodities, furniture, and electronics. All 1152 participants made a choice of their preferred car by use and type. A comparison of the overall percentages for each type with actual new registrations in the German market in 2007 and 2008 shows a reasonable congruence. Thus, the consistency of the data and representativeness of the study can be assumed.

Regarding uses and types, participants were asked to be selected the type of vehicle with an electric motor they would prefer (Table 2). The selection procedure is presented in Fig. 1. Individual preferences regarding the six purchase criteria are sampled. These preferences are aggregated to social preferences. In another step, participants were asked to rank the criteria according to their individual priority. Both the social preferences and the individual priorities are combined into individual barriers. Preferences, priorities, and barriers will be analyzed in the selection process to obtain quantitative predictions of potential EV buyers.

Table 2
Choice of preferred vehicle by use and type.

	Micro	Compact	Mid Size	Van	Executive	SUV	Luxury	Sport	Total
First	74	319	287	90	56	65	8	23	922
Secondary	32	14	13	1	0	2	0	5	67
Commercial	2	4	9	9	1	1	0	0	26
Family	0	6	14	61	2	24	1	0	108
Leisure	0	1	4	1	0	0	0	17	23
Off-road	1	0	0	1	0	4	0	0	6
Total	109	344	327	163	59	96	9	45	1152
% of type	9.5	29.9	28.4	14.1	5.1	8.3	0.8	3.9	100.0
% of new German registrations 2007/2008[a]	45.5[b]		26.0	13.3	5.6	8.2	0.7	6.9	[c]

[a] Source: Pkw-Neuzulassungen (new registrations of passenger cars). Numbers for 2009 have not been reported because of a cash-for-clunkers campaign by the German government.
[b] Because micro/city and compact cars are classified differently in this study, the numbers have been added for both types.
[c] Omitted because of crossovers.

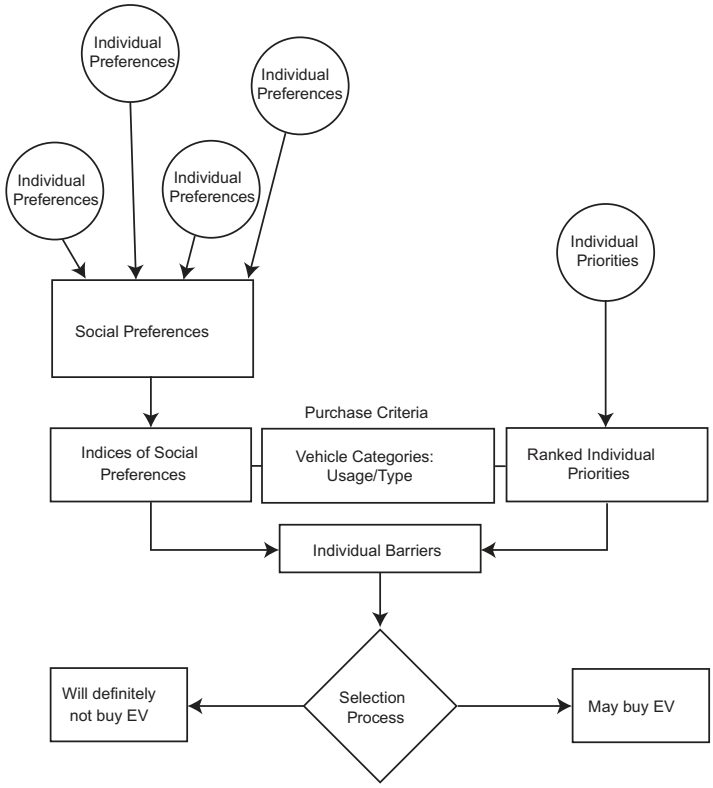

Fig. 1. Overview of the procedure.

2.2. Social preferences

The price, range, performance, environment, durability, and convenience criteria were presented to participants who were asked to mark those perceived as important for the vehicle uses and types. The answers were aggregated and divided by the number of participants to produce 14 percentage-indices representing the importance of each criterion.

Prices, as expected, are important for nearly all uses and types, except for sports cars where performance is most important. The more vehicles will be used for all-day operation, essentially the first car, the more important is the cruising range from the participants' point of view. For micro cars and secondary cars there is less interest in this characteristic.

To explore the underlying structures in the data, correspondence analyses is applied (Greenacre and Blasius, 2006), allowing each vehicle use and type and the six criteria can be represented in a single factor space. This analysis uses the χ^2 dis-

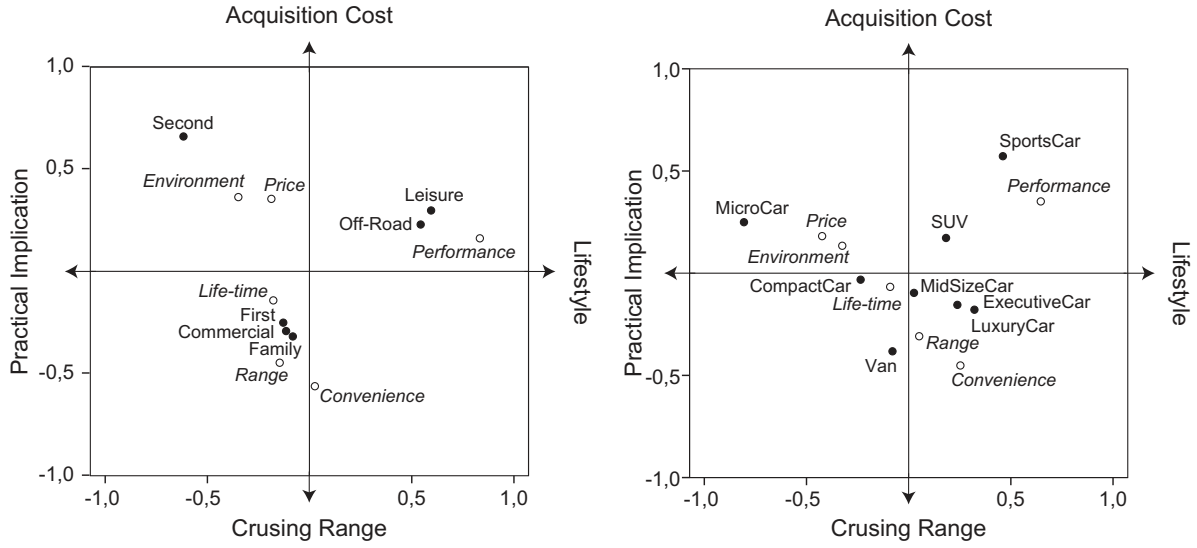

Fig. 2. Correspondence analyses; vehicle use (left) vehicle types (right). Note: χ^2 values and declared parts of the inertias per dimension: left: $\chi^2 = 377.301$, $p < .001$, $\lambda_1 = 55.7\%$, $\lambda_2 = 41.7\%$; right: $\chi^2 = 308.193$, $p < .001$, $\lambda_1 = 73.7\%$, $\lambda_2 = 22.2\%$.

tances between expected and observed values to calculate the center of gravity distributions about the center point of the coordinates – the centroid.

Both parts of Fig. 2 show a consistent distribution of the six criteria in two-dimensional space. It is stretched across the horizontal axis, which can be interpreted as the differential between practical implications and lifestyles, and the vertical axis, which represents more price-sensitivity in the upper part and range-sensitivity in the lower.

The closer the values are to each other, the more they are related to each other. The distances to the centroid are not important, but the angles between the slopes that connect the items with the center are. The larger these angles, the more different items are with opposites at 180°. Micro cars, which are often used as secondary vehicles, are the most price-sensitive, while their range is less important. In contrast, range, convenience, and durability are important criteria for most vehicles. This suggests that the vehicles furthest removed from the range characteristic – the greatest limiting factor for EVs – are best-suited for use as micro/city cars, SUVs/off-roaders, and sports/leisure cars.

Individual priorities may deviate from the average, e.g., executive cars are classified by the majority as preferable for longer trips (Fig. 2). These vehicles often serve as company cars and are used for long business trips. Who use their executive car for daily commuting from their homes to their offices, have a lower range priority. Thus, after the identification and analysis of overall society preferences, individual priorities have to be identified.

As the first step, participants were asked to choose the vehicle they would next purchase with regard to the vehicle type and its use. In a second step, they were asked to rank the six criteria in a descending order, with six points for the top priority and one point for the lowest regarding the car, once selected in a conventional vehicle and once in an electric version. To determine differences in average priorities with regard to the transition from conventional to electric vehicles, the means of the aggregated individual priorities are compared (Fig. 3).

Price is the top priority for both conventional and the electric vehicles with range ranked second. Range is a significantly increasing priority for EVs. The other criteria-performance, durability, environment, and convenience – are given less priority. In addition, both performance and durability are a significantly decreasing priority for EVs.

Given these results, we focus on price and range as the essential criteria to examine further.

2.3. Individual barriers to EV purchase

The individual price and range barriers are calculated by multiplying the indices of social preferences regarding the specific vehicle category with the individual priorities regarding electric vehicles.

$$\text{Individual barrier}_{x,y} = \text{Index of social preference}_{x,y} \cdot \text{Individual priority}_{y} \quad (1)$$

where $x \in$ {first, second, family, commercial, leisure, off-road, micro, compact, midsize, van, executive, SUV, luxury, sports car} and $y \in$ {price, range}.

Separated into use and type categories, the barriers are normalized from 0 to 100. The average price barriers are 81.80 for use and 75.93 for type, and average range barriers are 42.38 for use and 35.14 for types. The medians of the price barriers are 100 for use and 85 for type and of the range barriers are 47 for use and 39 for type.

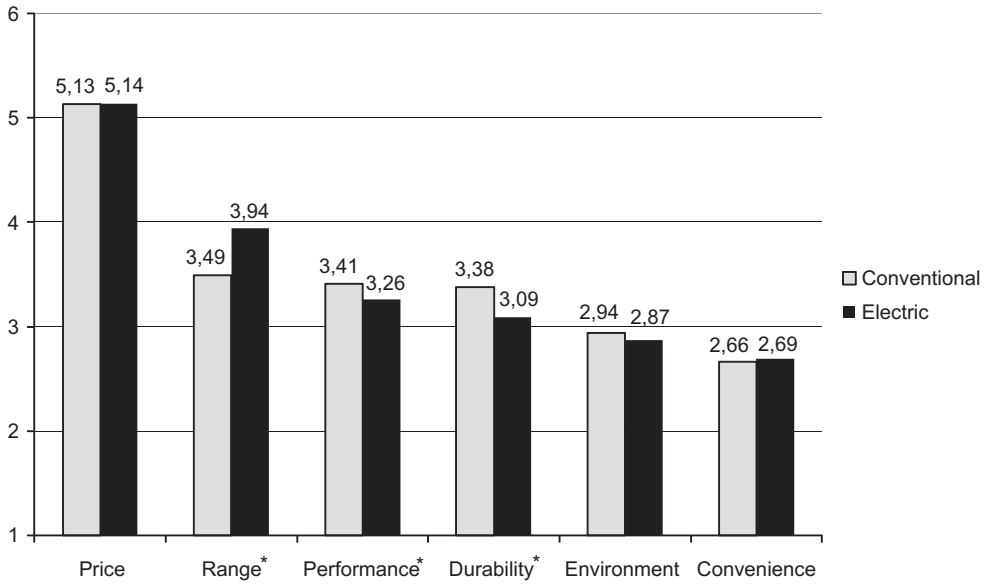

Fig. 3. Means of priorities of the six criteria for conventional and electric vehicles. *Significance of t-test: $p < .001$, $N = 1152$.

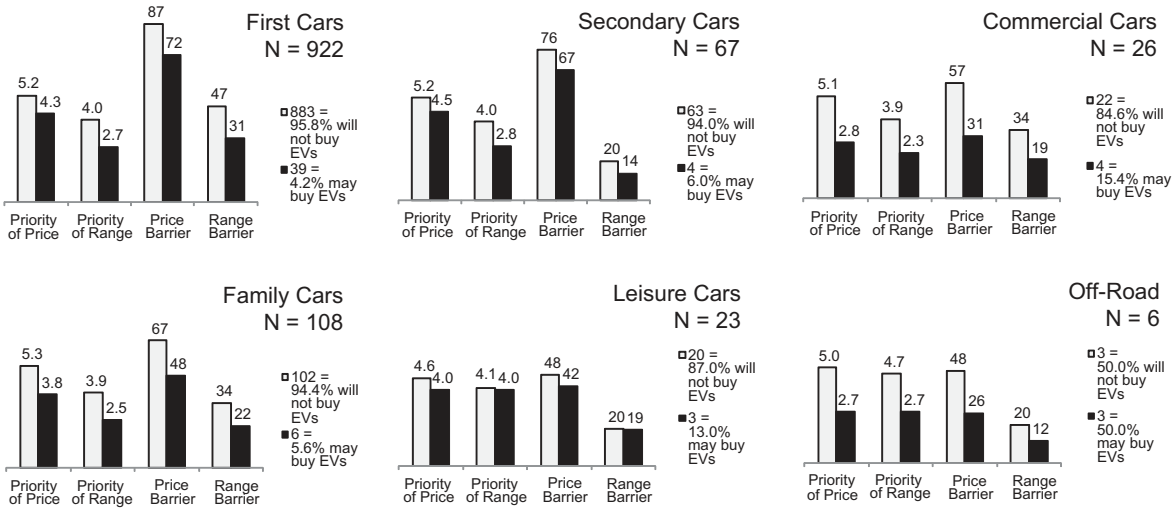

Fig. 4. Priorities and barriers regarding vehicle uses for individuals who will not buy EVs and those who may. Priorities from 6 = top priority to 1 = least priority; barriers from 0 = lowest to 100 = highest. *N* = number of subjects who had chosen the specific use for their next vehicle purchase.

Individuals are identified by the following selection rules:

(a) Individuals' barriers are below the median.
(b) Individuals do not generally refuse to buy an EV.
(c) Individuals did not mention price or range as being important regarding their individual preferences.
(d) Price is not individual's top priority, i.e., its highest rank could be at a maximum of five.
(e) Range is the less than the individual's second priority, i.e., its highest rank could be at a maximum of four.

Because of criteria (d) and (e), criterion other than the price and range criteria could have top priority.

3. Results

Regarding the use category, for 387 participants' price and range barriers were below the medians, and of these, 14 refused to buy an EV. Among the remaining 373 individuals, 97 did not mention price or range as being important for their specific use. Additionally, those 59 participants with a price priority below six and range priority below five showed significantly lower barriers for price (62 versus 83) and range (27 versus 43) than participants who were not selected.

In the type category, 340 participants' price and range barriers were below the medians and 25 refused to buy an EV. Of the remaining 315 individuals, 91 did not mention price or range as being important. Of those, 66 exhibited price priorities below six and range priorities below five; they had significantly lower price (56 versus 77) and range (25 versus 36) barriers.

3.1. Discussion

Fig. 4 shows the use category for selected and non-selected participants. Although the number of subjects selected in the group of first cars purchases (39) may seem high, this is attributable to the size of this group. Of 922 participants, 4.2% are selected as potential EV buyers. They rated the priority of price and range lower than non-EV potential buyers, and therefore their barriers are lower than those of the other subjects.

Six percent of subjects in the category of secondary cars show an extremely low range barrier of 14, but with price barriers that are the second highest of all use categories. The very high price-sensitivity for this vehicle use could undo the advantage of secondary cars regarding their low range-sensitivity.

Only 26 individuals chose a commercial car as their preferred vehicle and four of them show a low priority for the criteria price and range, implying that two to three other criteria are perceived as more important. A closer look to the sampled shows one participant giving price the second highest priority of five, one ranked it at four, and two perceived it as the least important criterion. Three ranked range as the next to last priority for EVs, and one gave it a three. Clearly, there is a quite low sensitivity to these criteria, with individual priorities for range the lowest in all vehicle categories.[2]

[2] This does not necessarily mean that commercial cars do not operate for long distances and many businesses have a car pool that would enable interchange of vehicles during recharging periods. Accordingly, one target group could be taxi businesses. A New York taxi driver covers 130–200 miles per shift (Taxicab Fact Book, 2006), a range that is met by electric vehicles equipped with lithium ion technology.

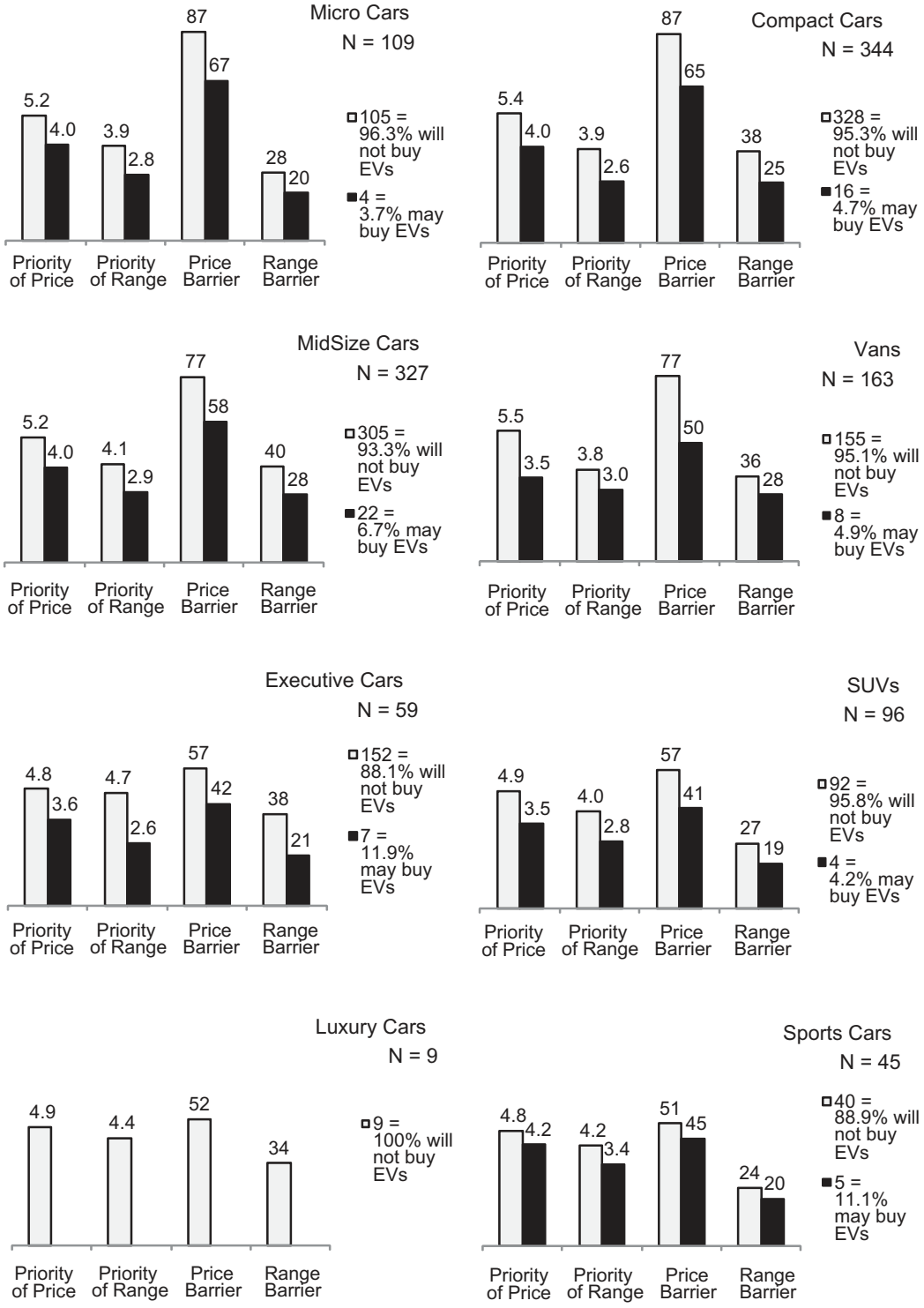

Fig. 5. Comparison of the priorities and barriers regarding vehicle types for those subjects who will not buy EVs and those who may buy EVs. Priorities from 6 = top priority to 1 = least priority; barriers from 0 = lowest to 100 = highest. *N* = number of subjects who had chosen the specific type for their next vehicle purchase.

Six out of 108 individuals emerge as potential EV buyers of family cars. Price and range barriers are in the midrange, and it seems feasible that there are some family cars used for commuting, rather than for long vacation trips, thus making EVs an option. Since leisure cars and off-roaders are generally used during the owners' free time, range barriers are not high and there is a lower price barrier making EV versions acceptable in some cases (Fig. 5).

Micro/city cars show response patterns similar to that of secondary cars. Range barriers are relatively low, but price barriers are the highest of all vehicle categories. This makes the consideration of an EV purchase unlikely. This is interesting in light of the multitude of micro cars forecast to come into the market in the near future.

The high price barriers for micro/city cars result from the proportion of the vehicle prices regarding conventional vehicles and EVs. In this category, EVs may be up to three times more expensive than the same vehicle with a conventional motor. This proportion declines with more expensive conventional versions. Accordingly, price barriers are lower for compact and midsize cars, particularly executive cars. These categories seem to have more potential for EVs than for micro cars. Not all of these vehicles are used for long-distance trips, and as the price proportion is lower, there will be a higher probability for EV purchases (up to 11.9% in the executive class).

However, this is not the case for luxury cars. Six out of nine participants who chose this type gave price as the top priority, and five individuals ranked range at the top or as the second priority. Although social opinion does not perceive price and range as very important for luxury cars (indices are 46 and 33 compared with 70 and 42 for compact cars) potential luxury car buyers have added attitude to these criteria.

Family cars show similar results as vans. Their price barriers are similar (48 and 50) and the percentage of potential EV buyers is 5.6% for family cars and 4.9% for vans. Obviously, the acceptability of EVs depends on the intended operation of vans with regard to the cruising range.

Similar considerations can be made for sports utility vehicles (SUVs). If they are operated as sports cars, range is not a high priority. However, as a utility vehicle, range may be much more important. The four subjects selected (4.2%) with the second lowest range barrier of all vehicle types (19) seemingly belong to the group that operates SUVs as sports cars.

The correspondence analyses (Fig. 2) show that performance is important to off-roaders, leisure, and sports cars. Among sports cars as their preferred vehicle, 20.0% (9 out of 45) of the subjects ranked performance as their top priority compared with only 5.9% on average. Regarding those participants who have been selected, three out of five (60.0%) ranked performance as the most important. Although individuals in this group do not have the lowest individual priorities for price and range (4.20 and 3.40, respectively), 11% can be considered potential buyers of electric sports cars.

3.2. Evaluation of the procedure

By comparing several vehicle categories, it can be seen how the procedure allows for social preferences to correct individual priorities. Individual price and range priorities are nearly equal for first and secondary cars (Fig. 4). As Kurani et al. (1996) and others argue, survey participants overestimate their aversion to limited range in the individual preference rankings. In this analysis, it could be corrected by the range index of the social preferences that estimate the importance of range for secondary cars as significantly lower (only 23% estimate the range being important for secondary cars versus 54% for first cars). This is in line with common sense. Thus, the barriers are lower for secondary cars and the predicted portion of potential EV buyers is 6.0% for second cars as opposed to 4.2% for first cars. The same effect can be seen for leisure and sports cars.

To examine the validity of the methodology, a slightly modified questionnaire was posted on two internet forums to form a second survey of buyers of the first mass-producted electric sports car. At the time of the survey, some 1200 vehicles had been sold. It is a high-performance roadster with a range of 200 miles, but costs more than $100,000. Of the 36 forum users who opened the questionnaire's link, 21 submitted an answer, and of these, 14 were selected. The price barriers of these EV buyers of sports cars and the chosen use classes were on average 16 points below those of the participants of the first survey who were identified as potential EV buyers. The range barriers were two points higher. This may be attributable to the extraordinary range of more than 200 miles, which is four times that of the competition. With this advantage, participants in the survey could have had a higher priority for range, and not perceive it as a limitation but rather as supporting the purchase criteria.

4. Conclusion

This study of 1.152 German individuals has identified potential categories of EV buyers. The predicted percentage of potential buyers of 5% seems small, but is in line with governmental expectations. Given car sales of more than 3.5 million vehicles per year, however, this percentage will result in annual sales of about 175,000 EVs in Germany.

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