# ECO-DRIVING STRATEGIES IN BATTERY ELECTRIC VEHICLE USE – WHAT DO DRIVERS GET TO KNOW OVER TIME?

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**ABSTRACT**: Eco-driving is of high importance when driving battery electric vehicles (BEVs) in terms of prolonging the vehicle's limited range. A longitudinal field study with 40 participants was conducted to examine which strategies users know before and after driving a BEV for 3 months. Additionally, user requirements regarding information or assistance on energy consumption in the BEV were addressed. Users reported significantly more eco-driving strategies after experiencing the BEV for 3 months. Furthermore, drivers rather agreed that there is a need for additional information on the BEV dashboard, such as displaying the energy consumption of auxiliary functions (e.g., radio, air-conditioning). The results imply that drivers gain a deeper understanding of factors that influence energy consumption by experiencing the BEV for a longer period of time and that it would be helpful to support the driver in terms of energy consumption and eco-driving.

**Keywords:** battery electric vehicle, eco-driving, field study, human-machine interface.

## 1 INTRODUCTION

Given the goal of reducing $CO_2$-emissions in the transportation sector, the implementation of 'green solutions' has gained importance in recent years. On the one hand, there are many technical developments that aim to make individual mobility efficient, like producing fuel efficient cars with smart technologies which operate independently of the driver. On the other hand, the driver himself has the potential to save energy, for instance, by applying an energy saving driving style or choosing energy efficient routes (e.g., [1]). With respect to battery electric vehicles (BEVs), which are supposed to be an inherently ‘green’ transportation technology, reducing energy consumption confers an additional benefit compared to conventional vehicles in terms of prolonging range. Given the limited battery capacity and relatively long charging durations, an energy efficient driving style might lead to a longer usable range per charge [2]. Bingham, Walsh and Carroll [3] found that the energy consumption (i.e. range) of an EV can vary by about 30% depending on driving style. Furthermore, EVs are equipped with a regenerative braking system which enables the driver to actively save energy in deceleration maneuvers. This is also one of the reasons why results of studies examining eco-driving with internal combustion engine (ICE) cars cannot readily be transferred to BEVs [4].

According to Sivak and Schoettle “eco-driving includes those strategic decisions (e.g., vehicle selection and maintenance), tactical decisions (e.g., route selection), and operational decisions (e.g., driver behavior) that improve vehicle fuel economy” [5, p.96]. For the current study, we use the term eco-driving in a more narrow sense focusing on ‘operational decisions’ meaning strategies a driver could apply in order to drive more energy efficiently, ‘strategic’ and ‘tactical decisions’ are of minor importance.

Eco-driving with conventional vehicles has been studied in depth, but besides some research on predominantly technical issues (e.g., [3]), not much is known about eco-driving strategies when driving a BEV. In the present contribution eco-driving in BEVs is approached from a user perspective. More specifically, the objective of the current research is to examine which strategies drivers know in order to save energy with a BEV. We are further interested in determining if there are differences between reported eco-driving strategies after a short test drive with the BEV and after 3 months of BEV driving. Focusing on the human-machine interface we address whether there is a need for additional information regarding energy consumption and retrieval in the BEV.

# 2 METHOD

The current research was part of the second BEV user study of a large scale field trial in the metropolitan area of Berlin [6, 7], embedded within a series of international field studies [8]. Data were collected three times throughout the study: when receiving the BEV (T0), after 3 months (T1) and after 6 months (T2) of BEV driving. At these three points of data collection participants, completed questionnaires and answered structured interview questions. For the current contribution data were collected at T0 and T1.

A converted MINI Cooper with a range of around 170 km under normal driving conditions was used as the test BEV for the study. The implemented regenerative braking system returned energy to the battery whenever drivers lifted their foot from the accelerator. The two-seater contained some BEV-specific gauges: the state of charge display, the remaining range display, the average consumption display and the instantaneous power meter (for further information regarding the displays see [9]).

## *2.1 Participants*

A sample of 40 users was selected to use the BEV for 6 months in a private household setting (for more details regarding the selection process see [10]). The 35 men and 5 women were on average 49.9 years old (*SD* = 10.19) and held their driving license, on average, for 31.0 years (*SD* = 9.94). The sample was well educated, 72.5% held a university degree. Some of the users (40%) stated that they had already driven some kind of electric vehicle (hybrid and/or BEV) before the beginning of the study. Yet, most of them (81.25%) tested such a vehicle only for a short test drive. The majority of the participants (80%) had an annual mileage of about 10.000 to 30.000 km. One participant dropped out after T1.

## *2.2 Data collection*

In order to examine which eco-driving strategies participants know, the following open-ended question was addressed after a short test drive with the BEV (T0) and after 3 months of BEV driving (T1): 'Which strategies do you know to actively prolong the BEV's range?' ('…to drive energy efficiently with the BEV' at T1). All answers to this question were recorded and transcribed; afterwards the statements were coded using inductive category development according to Mayring [11]. A system of categories, developed by reviewing the material several times while defining and re-defining categories, was applied to all answers. As most statements were clearly formulated, minimal effort was required to clarify interpretation. In order to control for possible bias that might occur during the coding process, 50 % of the material was independently coded by two involved researchers. Calculating Cohen's κ, results reveal an almost perfect interrater reliability (κ = .958; [12]). After the coding process was completed, the frequency of each assigned category was analyzed.

In order to assess the need for further information or assistance regarding eco-driving, the following general item was administered at T1: 'I would like to have some additional information regarding the energy consumption displayed in the BEV.' Participants were asked to indicate their agreement on a 6-point Likert scale (1 = *'completely disagree',* 6 = *'completely agree'*). Furthermore, participants were instructed to rate the perceived benefit of four possible additional information and assistance systems for eco-driving on a 6-point scale ranging from 1, *'less helpful'*, to 6, *'very helpful'*. The systems were described as follows:

(1) Statistics for energy consumption (per trip, per day, per week),
(2) Navigation system with eco-routing,
(3) Information about the energy consumption of auxiliary functions (e.g., air condition, radio),
(4) Eco-driving advices (can be switched on and off).

# 3 RESULTS

BEV drivers reported several strategies for improving driving efficiency. Amongst others, they stated that *avoiding high speeds*, *choosing an anticipatory driving style*, *avoiding auxiliary functions* (e.g., air conditioning, radio), *using regenerative braking* and *choosing the most energy efficient route to the destination* would save energy while driving (see Table 1). Reported strategies were similar for both points of data collection. However, in order to investigate whether or not the proportion of participants mentioning a specific category changed significantly over time, the exact McNemar test was calculated for each strategy (Table 1).

**Table 1: Comparison of reported strategies for BEV eco-driving before and after driving the BEV for 3 months**

| Strategy | Percentage of participants (%) | | $p$ (McNemar) | effect size[b] |
|---|---|---|---|---|
| | $T_0$ | $T_1$ | | |
| Avoid high speeds | 47.5 | 35.0 | .332[a] | -0.13 |
| Accelerate moderately | 52.2 | 77.5 | .031[a] | 0.25 |
| Drive evenly (speed & acceleration) | 17.5 | 20.0 | 1.000[a] | 0.03 |
| Use regenerative braking /avoid braking | 62.5 | 72.5 | .454[a] | 0.10 |
| Choose anticipatory driving style | 47.5 | 52.5 | .832[a] | 0.05 |
| Avoid auxiliary functions (e.g., air conditioning, radio) | 55.0 | 77.5 | .022[a] | 0.23 |
| Drive in a way that the instantaneous power meter indicates low energy consumption | 7.5 | 7.5 | 1.000 [a] | 0.00 |
| Let the car roll (sailing) | 0 | 5.0 | .500[a] | 0.05 |
| Choose the most energy efficient route to destination | 5.0 | 7.5 | 1.000[a] | 0.03 |
| Choose optimal tires/tire pressure | 10.0 | 5.0 | .625[a] | -0.05 |
| Minimize load | 20.0 | 10.0 | .289[a] | -0.10 |

*Note.* $N$ = 40; Categories were included if greater than or equal to 5% of the participants reported it; exact McNemar test was calculated for pre-post-testing; [a] binomial distribution was used because precondition was violated; [b] effect size calculation according to Green and Salkind [13].

Results show that the impact of experience was significant for the following reported eco-driving strategies: *avoiding auxiliary loads* ($p$ = .022) and *accelerating moderately* ($p$ = .031). In addition to the changes for each specific eco-driving strategy, we investigated the sum of all strategies stated at T0 and T1 for each participant. As the data violated the assumption of normal distribution, the Wilcoxon test was calculated revealing significant differences ($Z$ = -2.252; $p$ = .024; $r$ = -.25). Results show that drivers reported significantly more strategies after driving the BEV for 3 months (*Mdn* = 4) than after the first test drive with the BEV (*Mdn* = 3).

Furthermore, we addressed the question of whether drivers feel sufficiently informed regarding energy consumption or if they require a specific kind of assistance or additional information. Results reveal that users largely agreed that they would like to have further information regarding the consumption of the BEV ($M$ = 4.73, $SD$ = 0.91) after driving the BEV for 3 months. Moreover, users assessed the possible additional information and assistance systems as moderately to very helpful. Specifically, the information about the energy consumption of auxiliary functions ($M$ = 4.72; $SD$ = 1.025) and the navigation system with eco-routing ($M$ = 4.46; $SD$ = 1.374) were regarded as 'helpful' to 'very helpful' by the users. Whereas displaying statistics for energy consumption (per trip, per day and per week; $M$ = 4.15; $SD$ = 1.443) and eco-driving advices (can be switched on and off; $M$ = 3.82; $SD$ = 1.430) were evaluated as 'moderately helpful' to 'helpful'.

# 4 DISCUSSION

The main objective of the present research was to examine participants' knowledge regarding energy efficient BEV driving strategies, and to evaluate whether any experience effects occur in this domain. Results of the conducted field study indicate that drivers gained knowledge about eco-driving strategies when driving the BEV for 3 months. Although the stated eco-driving strategies did not substantially differ in their content, users reported significantly more strategies after driving the BEV for 3 months. Specifically, the avoidance of auxiliary functions, such as air conditioning or radio, and a moderate acceleration style were reported more often after a longer period of BEV-use. These results point in the same direction as findings from Bingham et al. [3], who analyzed logger data from different drive cycles. They found that auxiliary functions, as well as low acceleration and low variance of acceleration, are important influencing factors on BEV energy consumption. This in turn implies that drivers develop a deeper understanding of BEV energy consumption and learn which factors have a high impact on the energy efficiency of a BEV. This expertise is, at least in part, based on experiencing driving the car for a longer period of time. In this regard, it could be helpful to incorporate additional information into the BEV in order to support the driver in understanding energy consumption, and thereby range prolonging factors, on the first BEV drive.

One could have assumed that regenerative braking usage as a strategy to actively regain energy would have been mentioned more often after gaining BEV experience. However, results from T0 indicate that after the short test drive this strategy is mentioned by the highest percentage of drivers. The number is even a little higher after 3 months of BEV usage.

The mentioned eco-driving strategies, except for regenerative braking usage, do not substantially differ from strategies to drive efficiently with an ICE vehicle. Due to the limited range of EVs, restricted recharging opportunities and long charging durations, BEV drivers are more likely forced to think about and use eco-driving strategies compared to ICE vehicle drivers that mostly save energy for ecological and/or economic reasons. This could be an explanation for the increased knowledge of eco-driving strategies after gaining BEV experience. However, as also Bingham et al. [3] found common ICE eco-driving strategies (smooth acceleration, limited usage of auxiliary features) as important influential factors for BEV energy consumption, drivers in the current study might have experienced this similarly.

Results regarding the human-machine interface reveal a need for further information about energy consumption and BEV-specific assistance for eco-driving as also reported elsewhere [14, 9]. With regard to the reported strategies, users assessed information on the energy consumption of auxiliary loads as ‘helpful’ to ‘very helpful’. User assessment is similar for navigational range assistance, statistical information on energy consumption and eco-driving advice. Given that these results have been found with a highly educated sample of early adopters, it is likely that these findings, especially with regard to the provision of more information and assistance, might have even more relevance for other user groups.

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