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Sustainable behavior in motion: designing mobile eco-driving feedback information systems

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Abstract

Emissions from road traffic contribute to climate change. One approach to reducing the carbon footprint is providing eco-driving feedback so that drivers adapt their driving style. Research about the impact of eco-feedback on energy consumption is the basis for designing a mobile eco-driving feedback information system that supports drivers in reducing fuel consumption. This work develops design knowledge from existing knowledge. Subsequently, we implement a prototypical instantiation based on the derived knowledge. Insights from a field study suggest that our design artifact allows most drivers to decrease fuel consumption by 4% on average. The paper's theoretical contribution is a set of design principles and an architecture of the proposed mobile eco-driving feedback information system. One recommendation is to provide normative feedback that compares drivers with each other. This feedback appears to encourage drivers to decrease their fuel consumption additionally. The design knowledge may support researchers and practitioners in implementing efficient eco-driving feedback information systems.

Keywords Driving behavior · Eco-driving · Fuel consumption · Eco-feedback · Green information systems · Design science

1 Introduction

Traffic causes substantial greenhouse gas (GHG) emissions. Globally the transport sector is responsible for 23% of GHG emissions [1]. Individual traffic emits 11% of the world's total CO_2 emissions [2]. Besides technological improvements (e.g., more fuel-efficient engines), there is substantial unused potential for emission reduction through people's behavior. The choice of climate-friendly transportation, carpooling, fuel-efficient or electric motorization purchases, and driving behavior (DB) are starting points. According to Lárudóttir and Ulfarsson [3], the latter significantly influences the fuel consumption of vehicles per driven kilometer through acceleration, deceleration, and average speed. Hence, one way to achieve reductions in fuel consumption and, subsequently, in CO_2 emissions is through a change in the behavior of car drivers. Information systems (IS) can improve human behavior by giving feedback [4]. Based on additional available information, drivers can adapt to their behavior. As different studies show, it is possible to reduce fuel consumption through feedback systems by between 1 and 7% on average (e.g., [5, 6]).

Current research strands in IS research aim at contributing to sustainability, one of which is *IS for Environmental Sustainability* [7, 8]. The strand investigates IS usage to achieve environmental practices, also known as Green IS [8–10]. Green IS does have the potential to foster pro-environmental behavior [10]. However, solution-oriented studies still need to leverage IS to achieve environmental sustainability [11].

Over the last decades, much work has been done to foster pro-environmental behavior utilizing eco-feedback [12, 13]. With smart, connected cars and more embedded sensors,

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eco-driving feedback information systems (EDFIS) become possible to offer ever-richer and highly individual feedback to drivers. Such EDFIS are promising tools to contribute to a more sustainable lifestyle. Several studies have examined behavioral improvements using eco-feedback to save fuel (e.g., [6, 14, 15]). For this reason, EDFIS are already built into cars nowadays to illustrate environmental and financial consequences of driving (e.g., the consumption meter as the most basic type of feedback).

Hence, research should consider additional types of feedback to achieve further savings of harmful emissions. In particular, to date, little attention has been devoted to the effectiveness of social norms in the context of eco-driving. Social norms illustrate the behavior of others to a specific user and allow decisional shortcuts to what is desired or effective behavior [16]. So far, no widespread solution allowing for comparison between drivers has been established. Drivers interested in such information explicitly need to look it up, which raises the hurdle. A technical innovation that determines our daily lives and allows us to implement social norms is mobile devices. Mobile devices are becoming increasingly popular for EDFIS but also in the mobility sector [17]. Mobile devices like smartphones with sensors, computing power, internet connectivity, user interface, and widespread availability are well suited to give users individual feedback on their DB [18]. However, research has rarely considered mobile-only solutions for EDFIS. We have found only two corresponding contributions [5, 19]. Indeed, mobile EDFIS can make an essential contribution to the avoidance of CO_2 emissions, especially in emerging trends such as car sharing [20]. Additionally, having a mobile EDFIS also allows any driver to work on improving their DB regardless of the car's age. Mobile EDFIS allow tracking drivers' behavior using multiple cars and, thus, providing richer eco-feedback. Furthermore, mobile EDFIS allow addressing different motivational aspects to improve driving behavior. For instance, mobile EDFIS using social norms could provide gamification aspects such as competition between environmentally conscious traffic participants.

Overall, mobile EDFIS promise the potential to reduce fuel consumption in road transport. However, to date, no compilation of design knowledge exists that describes the structure and principles of form and function of such a system in the context of eco-driving. Therefore, we aim at expanding the body of design knowledge for mobile EDFIS. We pose the design objective of our work as follows:

> Design a mobile eco-driving feedback information system that supports car drivers individually in adopting a more environmentally sustainable driving behavior

With this, we aim for design knowledge of a mobile EDFIS that satisfies two design requirements: firstly, improving fuel-efficient DB to reduce fuel consumption over the same distances traveled and, secondly, developing an artifact being an improvement concerning the effectiveness of existing EDFIS artifacts [21]. Regarding the latter, our reference is the instantiation of a mobile EDFIS providing established types of eco-feedback (covering environmental and financial aspects of driving behavior). We do not address the broader scope of influencing, for instance, choosing a mode of transportation [18]. Neither do we consider technological solutions that may reduce fuel consumption (like autonomous vehicles). With the advent of self-driving cars, electric vehicles, and other technological innovations, individual DB will likely lose importance in reducing fuel consumption and CO_2 emissions. Although these approaches, compared to behavioral changes, can have a higher leverage effect on CO_2 emissions, we focus on improving DB, which can quickly show initial successes without renewing the pool of cars on our streets today and likely for several decades to come. We posit that the behavior of individual car drivers will remain relevant for quite some time, as will the search for a means to influence this behavior positively. We note that EDFIS must also consider safety-critical aspects in road traffic, although these aspects are not the focus of our research at hand.

This work fills the described gap, applying the design science research methodology [22, 23], and is structured as follows: First, we introduce our design science research process in Sect. 2. Section 3 summarizes the theoretical background and related academic work. Section 4 develops design principles and proposes an architectural model. Subsequently, we demonstrate and evaluate our findings using a prototypical instantiation within a field study in Section 5. Section 6 concludes with a discussion of implications and limitations.

2 Methodology

This research paper aims to contribute to design knowledge for mobile EDFIS, particularly regarding the effectiveness of social norms. Today, much knowledge from behavioral science exists about the effect of feedback on improving eco-driving. With smartphones permeating our everyday lives, there is an additional opportunity to break new ground and use social norms to reduce fuel consumption. On these grounds, we apply the design science research methodology (cf. Fig. 1), as proposed by Hevner et al. [23] and Peffers et al. [22], summarizing the emergence of our design knowledge. Thereby, we follow the seven guidelines by Hevner et al. [23]: 1) we contribute the design artifact of an EDFIS with design principles and an abstract model. 2) the problem relevance grounds in the necessity of tackling climate change. 3) we evaluate the design by a field study. 4) we contribute the aforementioned design artifact. 5) we achieve rigor in the construction process by gathering existing

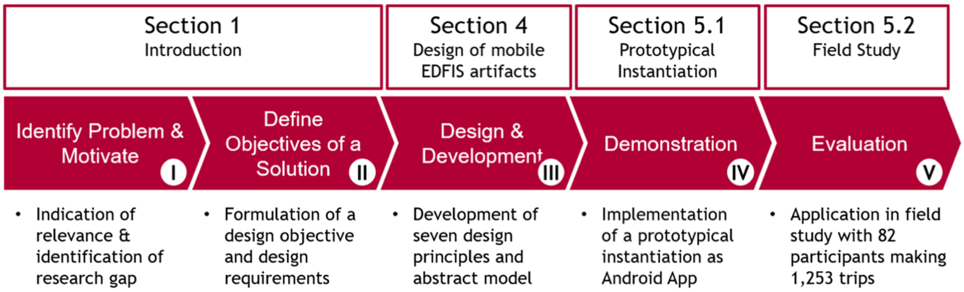


Fig. 1 The design knowledge develops throughout an iterative search process following [22]

knowledge from literature and in the evaluation process by comparing two versions of the EDFIS instantiation. 6) our search process includes identifying design principles and implementing them in a prototypical instantiation, refined through test users, and evaluated in a field study. 7) this paper communicates our process and results to an academic audience.

In Sect. 1, we describe the relevance of our research area and identified a research question (I). Next, we define our design objective (II) and corresponding design requirements. In Sect. 3, we introduce existing scientific knowledge on driving behavior, eco-feedback, and existing EDFIS. On these grounds, we develop theoretical design knowledge (III)—consisting of the design principles (DP) and an architectural proposal of the artifacts—from theory on eco-feedback following Hevner et al. [23]. The result is a level-2 design theory following the definition of Gregor and Hevner [21], which provides constructs, design principles, and an abstract model for mobile EDFIS. Constructs are "representations of the entities of interest in the theory" [24, p. 322]. In this study, relevant constructs are DB, fuel consumption, and eco-feedback. The abstract model consists of these constructs and describes their relationship within the solution space [23].

Our design principles describe the construction of our design artifact in more detail (cf. [21]). We demonstrate our design artifact by implementing a prototypical instantiation (IV). The instantiation is "a type of system solution" [25, p. 180], implementing the presented constructs, DPs, and proposed architecture. Subsequently, we evaluate our design artifacts (V) using data gained from a field study, which applies the prototypical instantiation. We implemented two versions of the prototype. Both versions are identical, except that one version additionally provides social norms as normative feedback while the other does not. This difference allows evaluating the design regarding the effect of the integrated feedback and the additional impact of social norms. With this contribution, we communicate mature design knowledge for EDFIS, which achieves our design objective and its corresponding design requirements.

3 Theoretical background

IS for Environmental Sustainability is a major stream in IS research, defined as "IS-enabled practices and processes improving environmental and economic performance" [7 p. 8]. The research stream focuses on emerging and diffusing environmentally sustainable practices through individuals, groups, organizations, or societies applying so-called green IS [8–10]. Green IS are defined as a "cooperating set of people, processes, software, and information technologies to support individual, organizational, or societal goals" [26, p. 8].

Green IS are a means to enable environmentally-friendly behavior and decision-making of individuals [8, 10]. Therefore, IS scholars call to develop knowledge to improve action formation [10]. EDFIS are a suitable means of promoting environmentally friendly behavior (e.g., [4]).

3.1 Eco-driving behavior

DB is a complex behavior depicted in two fundamental aspects. Firstly, strategic DB represents overarching decisions, also referred to as travel behavior. It includes, among other things, the chosen route and trip goals such as minimizing time or costs but also the choice of transportation mode [27, 28]. The second aspect depicts execution-related DB. It refers to tactical and operational DB, including driver attitudes such as calm or aggressive DB [27, 29]. Studies have found that a low gear-shifting frequency, slow acceleration, and driving speeds not exceeding the legal limit characterize calm DB. On the other hand, aggressive driving involves a higher tendency to shift gears, hard acceleration, and speeds above the legal speed limit [29].

Prior research also found evidence that fundamental aspects of DB have a significant effect on fuel consumption and, thus, lower CO_2 emissions. Ericsson [30] found 62 driving parameters, which can be aggregated to 16 independent factors describing operational DB. Of these, moderate and hard acceleration, a strong speed oscillation, many stops during a trip, and late gear changes from gear 2 to 3 increase fuel consumption. On the other side, deceleration, driving speed between 50 and 90 km/h, moderate engine speed at gears 2 and 3, and low engine speed at gears 4 and 5 decrease fuel consumption. These results are also consistent with the work of Lárusdóttir and Ulfarsson [3]. Their findings provide evidence that the driven distance, hard acceleration events, and somewhat higher average speed increase fuel consumption of vehicles per kilometer driven. Similarly, the results show that higher fuel consumption also results from hard deceleration events, numbers of stops, and idle time during trips [3]. In a similar vein, Bätz et al. [15] have presented a factor model describing DB both on a strategic and an execution-related level. On these grounds, eco-DB is an appropriate lever to reduce fuel consumption and thus contribute to the fight against rising CO_2 emissions.

3.2 Eco-Feedback and prior research on fuel consumption

A prominent approach to address behavioral improvements is feedback. Feedback is a “communications process in which some sender (…) conveys a message to a recipient (…) [that] comprises information about the recipient” [31, p. 350]. According to feedback intervention theory [32], this information enables creating a gap between a person’s behavior and some standard or individual goal, resulting in a person’s desire to reduce this gap. In the context of pro-environmental behavior, this is often referred to as eco-feedback, which is defined as “feedback on individual or group behaviors to reduce environmental impact” [4, p. 1999]. The effectiveness of the eco-feedback heavily depends on what information is displayed and how [4].

Researchers have employed various perspectives to examine the impact of eco-feedback on fuel consumption over the last decades. Those studies have investigated the effect of eco-feedback using different EDFIS. On the one hand, eco-feedback has been applied to improve strategic DB, such as reducing car usage and, therefore, annual mileage. For instance, Graham et al. [33] find a positive effect when providing eco-feedback on environmental and financial savings (CO_2 and money) to a group of students while they do not use their cars. On the other hand, various studies investigated improvements in fuel consumption due to execution-related DB, which is most important in fuel consumption per driven distance (see our first design requirement).

First, in 1989, feedback with other information, task assignment, and control were considered influencing factors to reduce energy consumption [34]. The study has investigated drivers in a business context. The EDFIS was non-digital as they provided eco-feedback employing a bulletin board. Their results achieve fuel savings of up to 7.3% [34]. Siero et al. [34] also applied social norms to the drivers besides eco-feedback, which allowed comparisons among the drivers. Voort et al. [35], instead, conducted an experiment using a driving simulator. The system provided the subjects with their fuel consumption based on their actual DB. Their results similarly indicate fuel savings of up to 7% [35].

With the spread of digital technologies, also EDFIS have changed. The application of digital technologies allows investigating the effect of eco-feedback rather directly and more precisely in naturalistic settings. Today, several cars’ onboard systems contain recommendations like the most fuel-efficient gear [36]. The introduction of the so-called onboard diagnostic II interface (OBD-II) allowed collecting data from the vehicle’s sensors during a trip externally. Boriboonsomsin [6] investigated the effect of eco-feedback using an OBD-II enabled device. Their results from a study with 23 participants provide detailed insights. Eco-feedback on actual fuel consumption and CO_2 emissions improved DB to achieve savings between 1% (highway-context) and 6% (city-context) [6].

Tulusan et al. [14] conducted a field study using a smartphone application to present feedback on DB to 50 corporate drivers. Their results show improvements in fuel efficiency by savings of 3% on average. Their mobile EDFIS provided eco-feedback about operational DB, such as acceleration or speed [14]. Furthermore, the authors derived that car drivers prefer direct feedback on operational DB during the trip instead of indirect feedback afterward [5].

Kurani et al. [37] achieve similar fuel savings in a real-world scenario using a recording and display device. Interestingly, a survey of the participants in the study showed that the drivers had little knowledge about efficient DB. Few could name specific points they could improve to save fuel [37]. Therefore, for instance, Vagg et al. [38] introduce a driver assistance system to 15 vehicles. Their instantiation provides information on inefficient acceleration and early upshifting of the gears to achieve fuel-efficient DB.

Similarly, Magana and Organero [38] did not provide eco-feedback on the actual outcome of DB. Instead, their study provided an eco-score compared to other drivers’ scores and, thus, constituted a gamification element based on social comparison. Drivers successfully improved their DB over time. Dahlinger et al. [19] derive evidence from their results of 62 road assistance drivers that symbolic eco-feedback (i.e., a tree growing or withering) achieves fuel savings between 2–3%. They conclude that practitioners have to consider the design of the provided feedback carefully to implement effective EDFIS.

Overall, eco-feedback affects fuel consumption and fosters fuel savings through influencing DB (insights to behavioral-specific improvements give Bätz et al. [15]). Almost every new vehicle today has some kind of environmental or economic feedback built into it. In the simplest case, this is a consumption meter [39]. In addition, smartphones have become more relevant to apply feedback on driving behavior.

4 Design of mobile EDFIS artifacts

The design artifacts are DPs (describing the principles of form and function following Gregor and Jones [24]) and a proposed architecture for mobile EDFIS. The design artifacts are based on existing knowledge from literature. We formulate our design principles according to Chandra et al. [40].

4.1 Design principles

The following aspects are essential, according to Froehlich et al. [4] and Paay et al. [41], to design effective eco-feedback systems: information, feedback, mobility, expert advice, self-comparison, and community information (for the latter two also change over time).

First, **information** about the individual behavior of the recipient (i.e., the driver) to assess one's behavior must be collected to affect future decisions. It needs to be displayed in a way that is easy to understand, attention-grabbing, trustworthy, memorable, and presented at the decision time [4, 43, 44]. When individuals are motivated to improve their behaviors, displaying information has an educational effect and raises awareness [42].

An individual does not necessarily recognize the gap between the own behavior and the desired behavior from the mere display of information. It is essential to highlight this gap by providing **feedback** at the right moment [43]. Feedback can vary from a high level to a detailed one [4, 13] to draw a person's attention to a specific problem and, thus, encourage to consider how a person's behavior may contribute [12]. Detailed feedback provides dedicated information on how to change a particular behavior. High-level feedback demonstrates the consequences of one's actions [13]. One example is environmental damage through high fuel consumption. Feedback can raise people's awareness of the relevance of their behavior. Likewise, it can increase people's understanding of the consequences of behavioral change but needs to be connected to the moment of the decision causing a particular behavior. In this way, feedback clarifies the links between individuals' actions and the problem at hand, for example, by explaining the increases and decreases in energy consumption that result from specific behavior [12]. Hence, as with information, feedback needs to be connected to dedicated behavior [4, 12]. Nonetheless, the provision of feedback must not distract the driver. Altogether this can be summarized as our first DP:

> DP1: Provide the system with the capability to present information about DB safely and give eco-feedback on relevant aspects of DB in order for users to recognize the gap between their DB and the desired DB.

Closely related, Fischer [12] found that providing eco-feedback is more effective when individuals receive not just one type of eco-feedback but receive multiple types of feedback like consumption over time, environmental impact, or saving tips. Consequently, a combination of numerous types of feedback seems to be favorable [4].

> DP2: Provide the system with the capability to present multiple types of eco-feedback in order for users to identify the most propelling information with regards to their DB.

In the context of pro-environmental behavior, literature differentiates between two concepts of why people adopt eco-friendly behavior [4]. First, *rational choice models* assume that pro-environmental behavior is driven by self-interest, primarily by evaluating expected utility systematically. Specifically, the rational-economic model postulates that people act to maximize the benefits or minimize the expenses. As far as the environment is concerned, this model is likely to be simplified to suggest that people will adopt economically beneficial and environmentally responsible behaviors [4]. Costs may not always be financial. Regarding the environment, GHG emissions can also be considered as costs as more and more carbon pricing initiatives are implemented across the world [44]. Multiple studies on the application of eco-feedback regarding the economic impact of behavior have already proven its effectiveness. Those studies primarily provide economic feedback on energy costs like fuel or electricity costs (e.g., [6, 45]) or monetary savings [46]. Graham et al. [33] provide additional economic feedback on the financial savings associated with avoidance of car driving at all.

Consequently, **DB's economic impact (i.e., the costs) should also be mirrored to the driver** by a mobile EDFIS in the context of eco-driving. Others, however, are less motivated about monetary savings. For instance, people with an environmental-friendly mindset may be encouraged by highlighting the environmental impact of their behavior (or vice versa, the environmental protection due to their behavioral improvements).

Existing studies provide eco-feedback about CO_2 emissions [33] or consumed energy and emitted CO_2 simultaneously [45]. In the context of eco-DB, the most common EDFIS is the fuel consumption meter, which is effective in itself [47, 48]. Boriboonsomsin et al. [6] provide feedback on fuel consumption but also emitted CO_2. Dahlinger et al. [19] and Kurani et al. [37] investigate feedback on fuel consumption concretely and abstractly. Consequently, addressing cost awareness as well as environmental awareness are proven motivational aspects to be effective. In summary:

> DP3: Provide the system with the capability to present feedback on the impact of DB, encompassing both the financial (i.e., economic) as well as the environmental impact of DB in order for users to become aware of the consequences of their DB.

DP3, in particular, is widely acknowledged as an effective tool by researchers. Thus, scientists already investigate other theories to improve driving behavior further. The second concept why people adopt eco-friendly behavior is *social-activation models,* which acknowledge that "personal norm activation […] may trump subjective perceptions of utility" [4, p. 2001]. People perhaps do not make behavioral choices that maximize personal utility (e.g., minimizing costs or maximizing benefits) but make behavioral choices as they feel social norms require them to do so due to an altruistic value system [4, 49]. An extension of this, the *value-belief-norm theory* recognizes that individuals alter their behavior also out of respect towards non-humans beings [50]. Research is divided on whether social norms have an impact on behavior. Froehlich et al. [4] outline that depending on the individual value system, social norms do or do not influence pro-environmental behavior (cf. rational-economic model vs. norm-activation model). Some studies found that social feedback is more effective than feedback merely on the own performance [16, 42, 54–56]. Other studies could not find significant improvements through social feedback [51–53]. Schultz [42] argues that depending on the potential benefits of one's behavior, among others, education is enough to foster pro-environmental behavior if the benefits are high (e.g., cost savings from lower fuel consumption). Nevertheless, if a person perceives the benefits as low, education is not enough. Instead, social norms foster pro-environmental behavior.

Such normative messages can either provide information about behavior, which is approved or disapproved, or information about the behavior of others, which is likely to be effective [16]. Consequently, another effective way to foster improvements towards desirable behavior is by providing information about peers in a similar situation [4, 41, 42]. As long as the rational choice for an individual is also the rational choice for the collective, the effect of eco-feedback is not altered if an individual has additional information about the comparable behavior of peers. The person is triggered in both cases the same way, and no conflict of interest arises. If the individual rational choice is not in the interest of the collective, additional information about similar behavior of peers will alter the individual's decision in favor of the collective [4]. In other words, social norms nudge the individual to adopt the desired behavior. In the context of pro-environmental behavior, social norms can effectively push someone who feels no self-interest to behave in a pro-environmental manner to adopt such behavior based on social norms.

Two effects might weaken the effect of social norms on pro-environmental behavior. Bergquist [54] indicates that a better-than-average effect is observable regarding pro-environmental behavior, meaning that people overestimate their effort regarding environmental behavior compared to their peers. Further, insights from different studies suggest that social comparison can result in the so-called *boomerang effect*. The effect describes how people improve their behavior as long as other people are doing better but are likely to impair their behavior when most people are doing worse [12, 53, 55].

From the authors' point of view, a statement about the perceived benefits of a person is ex-ante impossible, and also, the individual's value system is not observable. Therefore, a key element of the design process is to explicitly investigate the effect of social comparison in the context of eco-driving. To date and in the context of eco-driving, only Magana and Organero [38] have shown that social comparison improves driving behavior. However, they have not quantified the effect in terms of reduction of fuel consumption. Due to this gap in previous literature, we explicitly investigate the effectiveness of social comparison (cf. Sect. 5). As outlined, **community information** potentially triggers individuals even more to adjust their behavior. The community serves as a comparison and may vary from anonymous consumers [38, 45, 56] as well as to known consumers like neighbors [53], colleagues [57], or friends [58, 59]. A popular way to carry out social comparison is rankings [38, 39]. Altogether:

> DP4: Provide the system with the capability to present normative feedback on the DB of a peer community in order for the users to compare it to their DB, given that social norms serve as additional motivation.

Besides motivation, providing eco-feedback over a long period will likely ensure habit formation and a long-lasting effect. Darby [60] and Fischer [12] find that comparing current consumption to previous consumption helps decrease energy consumption. **Self-comparison** of own performance helps to assess personal behavior and promotes change. People are becoming aware of effective and efficient behavioral improvements. Furthermore, constant comparison against previous behavior promotes the long-term adoption of desirable behavior [4, 41, 61]. In the context of eco-driving, constant self-comparison is increasing the utility and acceptance of EDFIS. This effect holds particularly true for learning-oriented drivers [62]. Thus:

> DP5: Provide the system with the capability to present information on the driver's performance over time in

> order for users to increase learning about their actions from monitoring the effectiveness of changes in their DB.

Another aspect of adapting to a more environmental-friendly DB is guidance. Evidence from existing studies illustrates that drivers do not necessarily know how to improve their DB to achieve fuel savings [37]. Consequently, drivers who receive advice regarding potential improvements are able to increase their fuel efficiency significantly throughout multiple studies (e.g., [14, 35]). Insights about eco-feedback to increase energy conservation supports these findings. People need guidance on which behavioral aspects they should focus on to improve energy-efficient behavior [13]. The first step is providing information regarding the consequences of people's behavior so they become aware that an improvement of their behavior is necessary. Merely being aware of the need to change, however, is not enough [42]. Hence people must be guided in which way their behavior needs to change. A feasible way to do so is by giving **expert advice** to the individual, as this provides sound knowledge and suggests a trustworthy option [41].

> DP6: Provide the system with the capability to present expert advice concerning DB in order for users to identify entry points for improvements of their DB.

The medium providing eco-feedback to the user is most effective using interactive computerized devices as "interactivity, and the possibility of choice involve [recipients], raise their attention and allow for tailored solutions" [12, p. 99]. Interactive feedback systems motivate users to deal with their behavior. Ueno et al. [63] find interactive IS encourage reducing energy consumption. Karlin et al. [13] support this as their results outline the largest effect sizes when studies provided feedback using engaging or interactive media. An interactive feedback system may provide rich data that can be analyzed from different perspectives and with the help of various statistics. Still, people must achieve a sense of reflection on their behavior that influences consumption. People must link their behavior to its consequences with the help of behavior-related feedback (Fischer [12] speaks of *appliance-specific feedback* in the context of electricity consumption). As smartphones have become our daily companions, no other technical device is more closely connected to our lives than smartphones.

Consequently, a feedback device needs to be **mobile** to show information at the right moment (i.e., in real-time) and highlight the gap between current and desired behavior—in a safe manner [5, 41, 64]. Especially in the context of carsharing or other forms of multiple people using the same car (e.g., a family car) or individuals using more than one car (e.g., multi-car households or a private car and a company car), EDFIS need to be truly mobile and must not be bound to a specific car or any hardware which is not available in every car. A mobile-oriented design requires an abstract design that is independent of the manufacturing company. Of course, additional sensory equipment (built-in car sensors or OBD-II-dongles) allows for even more specific eco-feedback (e.g., on gear-shifting behavior) by analyzing data that is not measurable by a smartphone only. Due to the reasons mentioned above, additional sensory equipment might limit the user's flexibility, so a mobile-only solution serves as a baseline to design an EDFIS. Henceforth, focusing on the smartphone's sensors poses a viable opportunity for giving personalized feedback regardless of the driven vehicle. This results in:

> DP7: Provide the system with the capability to present eco-feedback via a mobile device in order for users to access the feedback at any time.

4.2 Abstract model

Seven DPs summarize the design knowledge for mobile EDFIS derived from existing literature. Subsequently, we derive a proposal for an architecture, which implements the DPs. The resulting abstract model [24] illustrates the high-level architecture of an EDFIS, depicted in Fig. 2.

The abstract model includes three layers, which structure the EDFIS. Each DP impacts one or more layers (Fig. 2). First, the EDFIS provides a behavior sensing layer to capture the execution-related DB of an individual driver, being acceleration and speed behavior, the number of stops, idle-time, and gear shifting behavior [3]. Besides, the EDFIS provides functionality to collect data on the actual outcome of DB, which is the fuel consumption of the car. Second, the feedback computation layer derives feedback information from the gained data. On the one hand, the EDFIS computes behavior-related feedback, which allows the driver to recognize and adjust inefficient behavior while driving. On the other hand, the EDFIS computes rational and normative feedback, which addresses different motivational aspects and is likely to redirect the driver's attention to the system. The calculation of the normative feedback requires information about the DB of other drivers. Therefore, each EDFIS has an interface to enable data exchange. Such data exchange can, for example, be implemented via a central platform (cloud). Third, the feedback presentation layer provides a user interface, which presents feedback to the driver. The EDFIS offers behavior-related feedback for the driver in real-time in a safe manner. Furthermore, the EDFIS presents rational and normative feedback to the driver after a trip. The EDFIS compares the actual feedback with recent trips and also allows long-term comparisons.

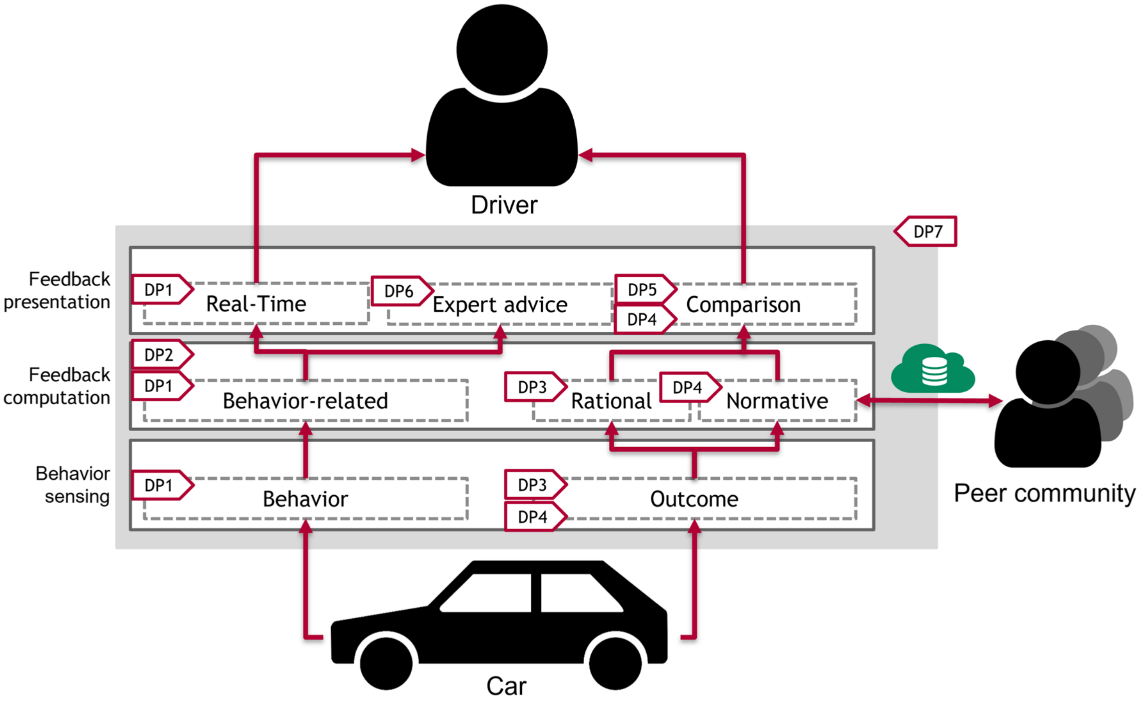


Fig. 2 The architecture of the mobile EDFIS

Using the EDFIS, first and foremost, the individual driver, whose DB is recorded and who receives personal feedback, can adapt to environmental-friendly DB and, at the same time, receives motivational information (rational and normative) to improve driving skills. Second, the normative feedback addresses the relationship between drivers and allows social comparison. Third, rational feedback addresses financial (i.e., fewer fuel costs) and ecological (i.e., healthier environment) rewards. Together, these aspects can lead to more energy-efficient driving behavior, as the theory suggests. For this reason, we next evaluate the developed design knowledge to ensure its utility, quality, and efficacy [23].

5 Demonstration and evaluation

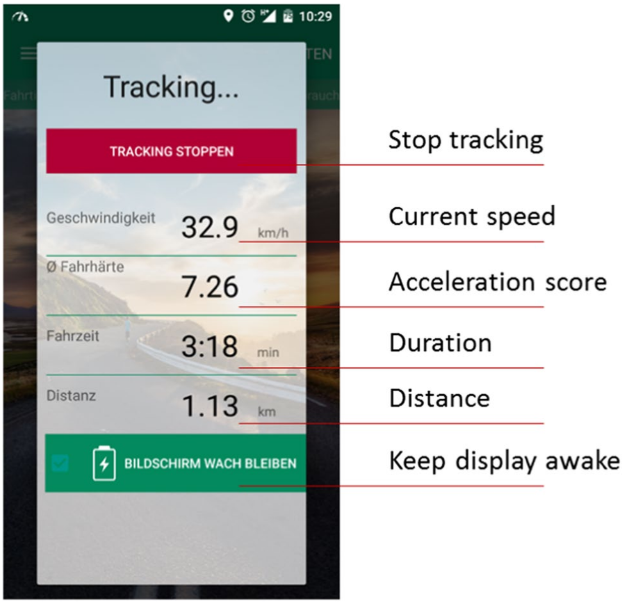
"The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods" [23, p. 83]. We develop the evaluation of the presented design artifacts following the FEDS evaluation process [65]. The evaluation's goals are to demonstrate the utility, quality, and efficacy of the design artifacts, the effectiveness of normative feedback, and the fulfillment of the design requirements (step 1 of Venable et al. [65]). Our proposed design artifacts require human interaction. For this reason, we choose a human risk and effectiveness evaluation strategy (step 2), since "the major design risk is social or user-oriented" and "a critical goal of the evaluation is to rigorously establish that the utility or benefit will continue in real situations" [65, p. 6]. The evaluation properties (step 3) are the design objective and the corresponding design requirements. Four episodes (step 4) constitute the basis of the evaluation: justification from the theoretical background (see Sect. 3 and 4), the prototypical instantiation of a smartphone application, beta tests to gain feedback, and a field study as a major evaluation method (see following subsections).

5.1 Prototypical instantiation of the mobile EDFIS design

We implement two instantiations of the design artifacts to demonstrate the DPs and the proposed abstract model. The only difference between both instantiations is that one instantiation (version economic and environmental (E&E)) does not implement DP4, while the other does (version social comparison (SC)) (cf. Table 1). With this design, we particularly investigate the effect of social comparison. The prototype originates as an Android smartphone app, with advantages like Android's high market share, easy access to the app store, many open-source frameworks, and sensors associated with the smartphone. Since we provide our prototype as a smartphone app, we can presumably reach a large part of society regardless of a person's

Table 1 Comparison of both versions of the mobile EDFIS

Version	DP1	DP2	DP3	DP4	DP5	DP6	DP7
E&E	X	X	X		X	X	X
SC	X	X	X	X	X	X	X



Tracking...

TRACKING STOPPEN

Geschwindigkeit 32.9 km/h

Ø Fahrhärte 7.26

Fahrzeit 3:18 min

Distanz 1.13 km

BILDSCHIRM WACH BLEIBEN

Fig. 3 Screenshot of the abstract feedback during the trip (German original with translations)

car (DP 7). Our prototype uses the device's GPS sensor to track DB (speed and distance). Further, we access the accelerometer sensor to discover the strength of the driver's maneuvers (DP 1).

In addition to the consumption meter, the app provides environmental feedback as emitted carbon dioxide in kilograms per 100 km compared to the last trip and the absolute number of emitted kilograms during this trip. At the same time, it provides economic feedback regarding the fuel costs per 100 km compared to the last trip and the total fuel costs during this trip. The driver is encouraged to enter the fuel consumption, as displayed by the car's consumption meter,[1] at the end of the trip to ensure safety while driving. The app then calculates the environmental and economic feedback (DP 3). Additionally, the app (version SC) provides a social comparison that the app calculates from the consumption input. This feedback is presented as a ratio of drivers with similar engines but lower consumption than the driver who uses the app. Thus, the app provides information about how many other drivers do better regarding their fuel consumption (DP 4). Version SC uses a database containing frequency distributions fetched from the online platform *spritmonitor.de* to calculate this ratio. The app provides six distributions for both petrol and diesel engines: 50 horsepower (hp) or less; 51 to 100 hp; 101 to150 hp; 151 to 200 hp; 201 to 250 hp; and 251 hp or more. Drivers enter their car's fuel type and horsepower once during the initial usage of the app. On these grounds, the app compares the driver's fuel consumption to the consumption of the respective reference group.

The feedback is provided to the driver at different points in time. On the one hand, the driver receives a driving score as behavior-related feedback in real-time to adjust DB while driving (DP 1). A major aspect when displaying real-time feedback is that it must not distract the driver. In this case, the information that was shown to the driver was the current speed, an acceleration score (implying higher acceleration results in lower fuel efficiency), the duration, and the distance of the current trip (cf. Figure 3). At no point in time, the driver needed to interact actively or pick up the phone, and no mechanisms were used to explicitly steer the driver's attention to the feedback to prevent distraction. The driver could choose if the display remained turned on (with the default that it does not). On the other hand, the application provides more detailed feedback at the end of the trip. Particularly, it provided economic and environmental feedback and, if applicable, also social comparison (DP 2 and DP 3–cf. Figure 4). In addition, the app provides a summary of behavior-related DB: mean speed and maximum speed, duration, and distance of the trip. All values are displayed in comparison to the previous trip. Improved values (associated with less fuel consumption) are marked green, while worse values are marked red to reward better DB (DP 5).

When no trip is being tracked, the app provides historical data in the form of charts that allow interaction and comparison of current and previous behavior over a long-term period (DP 5—cf. Figure 5). Besides, the app offers a range of expert saving tips to help users improve their DB (DP 6).

Before publication, we tested the app with seven beta testers. They helped us improve the app's usability and intelligibility and offered first feedback on our DPs. The app has an upload functionality that sends all collected data to our file storage. Overall, our experience is that smartphone usage and rich options to design feedback (e.g., text, graphics) are suitable for providing individual feedback. And as mentioned before, a mobile solution makes our EDFIS

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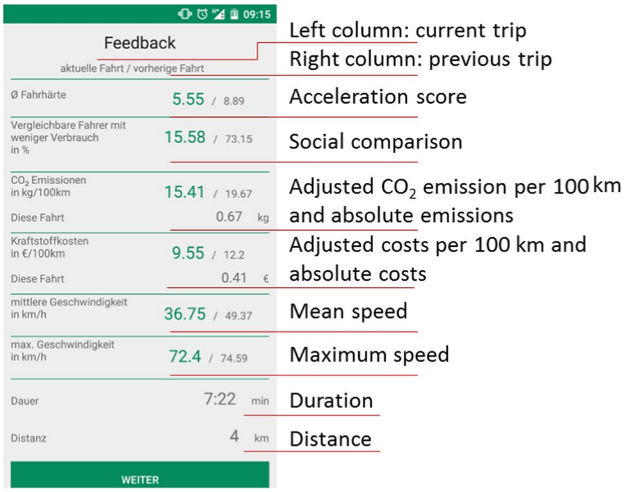
[1] This self-reported data acquisition could be obtained automatically from the car via the OBD-II interface. For demonstrating the design, we spared the hardware and software necessary for the interface.



09:15

Feedback

aktuelle Fahrt / vorherige Fahrt

Ø Fahrhärte 5.55 / 8.89

Vergleichbare Fahrer mit weniger Verbrauch in % 15.58 / 73.15

CO_2 Emissionen in kg/100km 15.41 / 19.67

Diese Fahrt 0.67 kg

Kraftstoffkosten in €/100km 9.55 / 12.2

Diese Fahrt 0.41 €

mittlere Geschwindigkeit in km/h 36.75 / 49.37

max. Geschwindigkeit in km/h 72.4 / 74.59

Dauer 7:22 min

Distanz 4 km

Fig. 4 Screenshot of feedback (version E&E) after the trip (German original with translations)

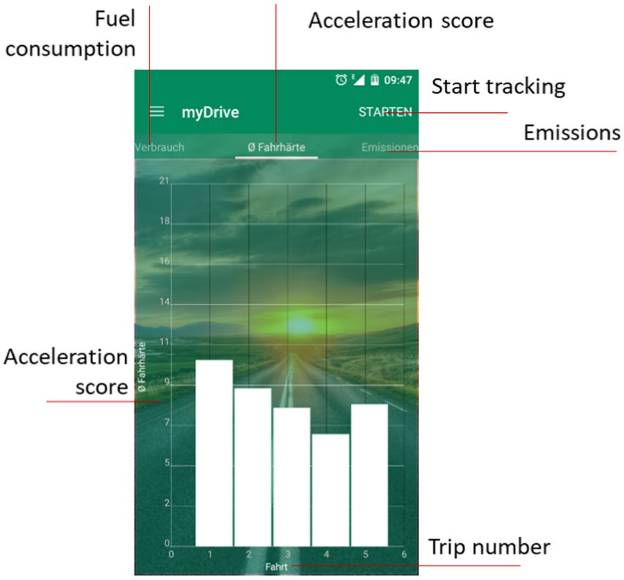


Fig. 5 Screenshot of the historical comparison displaying the acceleration score within the app (German original with translations)

available to a major part of society—justifying DP 7). Given the feedback from the beta testers, we can consider that the proposed solution meets the evaluation criterium of *quality*.

5.2 Field study

We conduct a field study to gain data from real users and a real system [65]. Our prototype has been available in the Google Play Store, free of charge, and accessible for all interested participants. The version of the feedback (version E&E vs. version SC) displayed to the driver was assigned randomly with the first start of the app. We raised awareness for the research project and our app via news reports in local newspapers, a national online news platform, a local TV channel, and radio reports.

Over eight weeks, drivers used the application and uploaded their trip data. We exclude trips that contain incomplete data, such as missing speed or consumption data. The resulting data set originates from 82 participants making 1,253 trips (between 8 and 41 trips per participant; mean 15.3; median 12). With initial usage, all participants answered a questionnaire to reveal information about their demographic factors, cars and car usage, and individual mindset of their environmental, cost, and social awareness. The age of the participants ranges between 21 and 67 years, and 43.7 years on average. Most are male (80), whereas merely two women participated. Participants drive primarily in a private context (70) rather than in a business context (12).

Moreover, most of the participants' cars are powered by diesel engines (51) rather than gasoline engines (31). Most cars have 101 to 150 horsepower (46), whereas eight have less and 28 have more power. According to the participants' self-report using a seven-point Likert scale, they mainly have an environmental-friendly mindset (80% at least somewhat agree, level three on the seven-point scale) and care for the costs that result from driving (93% at least somewhat agree). Conversely, the relevance of social comparison is less important to them (48% at least somewhat agree). The participants' characteristics of both versions are comparable as a Chi-squared test of homogeneity is not significant for all reported characteristics (demographics, car characteristics, environmental attitudes).

We analyze the effectiveness of the app in lowering fuel consumption. We have information on fuel consumption (l/100 km) by a trip for at least eight trips per participant. To detect potential changes over time, we compare their fuel consumption of trips one to two to their fuel consumption of trips three to eight. We assume the first two trips as a baseline as the feedback effect may need to evolve, and drivers need to get familiar with the app. If the feedback does have an immediate impact when first using the app, this approach underestimates the fuel-saving effect. For now, we disregard trips nine and following. In doing so, we mitigate concerns of a changing effect over time, depending on the total number of trips per participant. Besides, we have a sample of the same size for every participant.

We calculate the individual changes in fuel consumption for each participant in both versions. We investigate mean changes in fuel consumption for all participants. The 40 participants of the version SC decrease their consumption by about 0.35 l/100 km on average (median 0.14 l/100 km), which corresponds to a saving of 4% per participant on average. In total, 42 participants of the version E&E achieved

Table 2 Significance and size of the fuel-saving effect for both versions; H_0: Fuel saving is less or equal to zero

Version	n	Mean savings	Median savings	p-value t-test	p-value Wilcoxon signed-rank test	Cohen's d
E&E	42	0.08 l/100 km	− 0.03 l/100 km	0.285	0.705	0.04
SC	40	0.35 l/100 km	0.14 l/100 km	0.022	0.025	0.21

fuel savings of about 0.08 l/100 km on average (median -0.03 l/100 km, i.e., an increase in fuel consumption).

Next, we investigate the effect size and the significance (significance level of 5%) of the fuel-saving effect. We calculate the difference between the mean consumption for the first two trips and the mean consumption of the six remaining trips. These differences are then tested with the statistical H_0: Fuel-saving less or equal to zero. For version SC, the one-sample t-test allows to reject H_0 (p-value = 0.022). Thus, we can conclude that the reduced fuel consumption is significant for drivers who applied the app. Although the fuel savings are not normally distributed, the t-test is justifiable as n is bigger than 30, and the t-test tends to be robust. Nevertheless, we additionally perform a Wilcoxon Signed-Rank test, leading to comparable results. Again, we see significant fuel savings (p-value = 0.025). Subsequently, after testing for the existence of a fuel-saving effect, we also evaluate the size of the effect. Thus, we calculate the effect size, also referred to as Cohen's d. We observe an effect size of 0.21, which is a *small effect* by convention (Table 2).

For version E&E, the one-sample t-test does not allow to reject H_0 (p-value = 0.285). There has been no significant fuel-saving effect. Nevertheless, we also perform a Wilcoxon Signed-Rank test, again leading to comparable results. We could not reject the null hypotheses (p-value = 0.705). For completeness, we also evaluate the size of the effect. Thus, we again calculate the effect size, which is 0.04 (almost no effect). That altogether differs from the fuel savings of the participants using the mature version (Table 2).

The difference in means between both groups is 0.27 l/100 km. We apply a t-test to investigate the differences between both groups. Based on our previous results, we assume the savings in version SC are higher than in version E&E. Thus, the statistical H_0 is that the fuel savings in version SC are higher or equal to the savings in version E&E. We cannot reject H_0 as the p-value of the t-test is 0.104. We also apply a Wilcoxon-Mann–Whitney test as none of the two samples (savings in the version SC and savings in the version E&E) are normally distributed. The result leads to the conclusion that, indeed, the savings in version SC are significantly higher than in version E&E (p-value = 0.044). In line with these findings, the Kolmogorov–Smirnov test also indicates that both samples are drawn from different distributions. The cumulative distribution function in version E&E lies significantly above the cumulative distribution function in version SC (p-value = 0.036). The result implies that the version SC, giving feedback on social comparison, is more effective than the version E&E, not giving social feedback. Furthermore, Cohen's d between both is 0.28, and thus we observe a *small effect* (Table 3).

Following Karlin et al. [13], there might be an upper limit on users' time dealing with feedback. Therefore, instead of comparing merely eight trips per person, we also perform the analysis mentioned above on all available trips per driver to investigate the fuel-saving effect over the entire time each participant used the app. Results remain overall the same. For version SC, average fuel saving increases to 0.36 l/100 km, Cohen's d slightly increases to 0.22, p-values for t-test and Wilcoxon test are 0.022 and 0.051, respectively. This indicates a significant fuel saving effect over more than eight trips and at least for the period of active usage of the smartphone application. The increasing effect when extending the analysis period suggests that we do not only observe an effect of initial adoption. For version E&E, results also remain overall the same. The same applies to the difference between both versions.

As a result, we found indications that our app, as an instantiation of our DPs (particularly including DP4) and abstract model of a mobile EDFIS, constitutes an *effective* solution artifact. Our proposed design artifact leads to a more sustainable DB. Our data indicate that behavior-related feedback and feedback on rational and normative aspects of driving encourage most participants to drive more fuel-efficient. The described effect is observable for the first eight trips of each participant and all recorded trips up to eight

Table 3 Comparison of the effectiveness of both versions H_0: fuel savings in group E&E are greater or equal to savings in group SC

	Difference of mean fuel savings	p-value t-test	p-value Wilcoxon signed-rank test	p-value Kolmogorov–Smirnov test	Cohen's d
SC versus E&E	0.27 l/100 km	0.104	0.044	0.036	0.28

weeks. In addition and in line with the design objective of this paper and the results from the field study, the implementation of the DPs derived from literature ensure the *utility* of the proposed design as it unites insights from multiple studies in the context of pro-environmental behavior.

To summarize, we show that our solution artifact meets the design requirements and our design objective. We find an indication that participants decrease their fuel consumption while applying a prototypical implementation of our design artifact throughout a field study. Data analysis shows that drivers reduce their fuel consumption on average by 4% using an instantiation of the proposed design artifact. The instantiation presumably creates a stronger awareness of eco-driving as the study participants had to—consciously or unconsciously—reflect on their DB by using the app. It lowers fuel consumption, as it enriches the information provided by the built-in fuel consumption meter or any other feedback system that the field study participants had in their cars. Thus, our evaluation establishes the utility, quality, and efficacy of the design artifacts.

6 Discussion and conclusion

Following the design science research methodology suggested by Peffers et al. [22], our paper presents design knowledge for a class of mobile systems that address harmful CO_2 emissions by individual traffic. Seven DPs and the resulting architecture codify knowledge on designing a mobile EDFIS that allows drivers to adjust their fuel consumption per driven kilometer—a crucial element of the feedback is social comparison. Our abstract model is an architecture that describes the constructs' interaction (driving behavior, fuel consumption, and eco-feedback). The architecture summarizes the principles of form and function of a mobile EDFIS. These principles allow measurement of DB and fuel consumption to provide feedback to the driver effectively. We propose to highlight the gap between desired and actual behavior (DP 1) via a mobile device (DP 7) and to provide multiple types of feedback (DP 2). In particular, provide feedback on economic and environmental impact (DP 3—widely used in today's cars) and normative feedback (DP 4). The user of an EDFIS should have the possibility to assess performance over time (DP 5) and receive expert advice on how to change behavior (DP 6). While modern cars have already implemented some of the design principles, DP 4 usually is not. When evaluating both versions of the app, the version SC, implementing social comparison, outperforms the version without social comparison.

Our design knowledge develops throughout a design science research process following Peffers et al. [22]. First, we analyze the literature on eco-DB, eco-feedback, and existing EDFIS artifacts that have been applied throughout various studies. Subsequently, we derive design knowledge and propose an architectural model for mobile EDFIS. To demonstrate and evaluate our findings, we implement a smartphone app as a prototypical instantiation. Forty participants successfully decreased their fuel consumption by 4% on average throughout a field study making at least eight trips. In doing so, we verify the utility, quality, and efficacy of the design artifacts and the fulfillment of the design objective and its corresponding design requirements.

From a theoretical perspective, we present a nascent design theory with design knowledge as operational principles and architecture (level 2 contribution), according to Gregor and Hevner [21] and a situated implementation artifact (level 1 contribution), according to Gregor and Hevner [21]. We do not present a mid-range design theory (level 3 contribution), constituting a comprehensive and well-developed theory [21]. The derived design artifacts constitute *improvements* in the terminology of Gregor and Hevner [21], as we propose a more effective and efficient solution for a relatively well-known application domain. To the best of our knowledge, no design theory exists. Hence, our contribution presents a novel and consistent nascent design theory in the field of mobile EDFIS.

Our contribution is twofold. First, based on the presented design knowledge and the results from our field study (with two versions), we find evidence that normative feedback, while controversially discussed in other contexts [4, 53, 55], plays a vital role in eco-driving. The first version of the prototype, without normative feedback, does not lead to an adjusted DB, while the inclusion of normative feedback in the second version leads to a significant change in DB. Although only about half of the probands per iteration reported that social comparison is at least somewhat important to them,[2] the extension of the prototype with normative feedback (DP 4) leads to significant improvements in reported fuel consumption. One possible explanation is that social comparison motivates drivers to achieve higher fuel savings compared to other drivers as they might not be aware ex-ante of their performance with regard to their peers and thus underestimate the relevance of that comparison [38, 39]. Another explanation is that feedback about the behavior of others highlights the need for even more pro-environmental behavior and motivates eco-DB as an accepted and desirable behavior (cf. focus theory of normative conduct, see Cialdini et al. [16]). Overall, giving normative feedback in the context of eco-driving is a key finding of this study.

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[2] The participants' characteristics of both groups are comparable as a Chi-squared test of homogeneity is not significant for all reported characteristics, in particular regarding the importance of social comparison.

Interestingly, we could not observe any significant correlation between the self-reported importance of social comparison and achieved fuel savings. This finding indicates that the field study participants have been accessible for normative feedback independently, whether the social comparison is essential to them or not. In a similar vein, although most participants reported that they have an environmental-friendly mindset or respectively care for the costs their driving is causing, they do not improve their driving in this regard (especially version E&E). We assume that, unless we observe a social desirability bias [66] in reported attitudes, participants have adjusted their behavior before the study to the extent that they accept the costs/emissions their driving is causing.

Second, the contribution of this paper is design knowledge helping to design successful feedback systems in the context of driving. The instantiation of the design knowledge in our app is only of secondary interest, as our primary goal is to investigate the effectiveness of our EDFIS design. The instantiation in the app is only an exemplary way to evaluate the design (cf. level-2 design theory [21] in Sect. 2). Other systems—e.g., integrated into modern car infotainment systems—following the suggested design and fulfilling the design objective and corresponding design requirements can have a share in fighting climate change and even increase safety aspects. From a practical perspective, the design knowledge is helpful for car drivers, who can contribute to ecological sustainability, reduce their fuel expenses, and contribute to more environmentally friendly societies. Furthermore, these findings are beneficial for companies in various cases. Firstly, automotive manufacturers and their suppliers can offer more sustainable and environmentally friendly products. EDFIS enable a more fuel-efficient use of vehicles while manufacturers are working on alternative powertrains. Secondly, third parties are entering the market and offering solutions for connected vehicles on the Internet of Things (IoT). IoT-based smart vehicle services can also be used as EDFIS and contribute to a more sustainable way of life [15]. In times of Friday-for-Future demonstrations, it is possible that an attractive market for services that enable a more sustainable lifestyle will emerge. Thirdly, companies have been striving that corporate car drivers have an efficient driving style and thus save fuel costs. Various studies have been conducted with field staff [14] or mail-van drivers [34], for example, to investigate the impact of feedback on fuel consumption. EDFIS can, therefore, generate savings without offering financial incentives to employees.

Naturally, the findings of our paper are limited, as the results cannot be considered complete or universal. We find an indication that our DPs help decrease fuel consumption on average and for most drivers. However, a few factors limit these findings. First, the results do not explain which feedback works best for a specific individual. We derive the DPs from the literature and justify them on the basis of their relation to pro-environmental behavior, but we cannot make any statement whether some feedback types (particularly DP 3–6) are either redundant or not working in an isolated environment. It is possible that by combining different types of feedback, the driver receives the appropriate feedback and ignores the other feedback types. Additionally, the proposed design principles only pose as one way of implementing an EDFIS since DP 7, for example, is not compulsory in this context. Rather, we the goal of this study is to demonstrate the advantages of mobile EDFIS solution. Further, personality has an impact on DB (e.g., [67]) and also on the effect of feedback [31, 62]. Thus, future research should further investigate the dependency of different feedback types and personality traits and derive implications refining our design artifacts. Second, we solely examine the effect of anonymous social comparison, whereas comparison with known persons can have other impacts (e.g., [53, 59]). A context-dependent detailing of a specific implementation that addresses DB to decrease CO_2 emissions may provide additional principles. Third, we investigate the effect of feedback based on the first two trips as a baseline compared to the following trips, and the maximum usage was only eight weeks. Further, in our field study, we do not have a control group, not obtaining feedback as the app would have delivered any value for someone tracking their trip without being able to assess it. We cannot fully disentangle the effect of social comparison from the other types of feedback provided. However, with version E&E we have built a benchmark that implements most functionalities of today's cars and serves as a suitable comparison. Also, it might be the case that we recruited individuals specifically eager to change their DB (self-selection bias), who then did so more or less independently of the EDFIS specific functionality. As already outlined, having a control group report their fuel consumption without triggering reflection on DB and, thus, potentially changing DB was not possible. A certain willingness to adopt and use an EDFIS will always be a prerequisite for the system's success. Further research is needed to verify the effectiveness of our derived design knowledge in different settings and with different instantiations. Besides, we have not focused on safety–critical factors. Feedback must not distract the driver. Safety–critical factors, particularly drawing the driver's attention while driving, may influence the design of a system [68] and should, therefore, be further investigated in future research. Finally, we do not consider different trip profiles. We do not differentiate between city streets, highways, speedways, or various covered distances. However, different trip profiles imply distinct fuel consumption and savings, as several authors illustrate (e.g., [6]).

Future research should further analyze our design artifacts, as well as extend and refine them. Researchers should investigate diverging samples of drivers and various human characteristics (e.g., values, preferences, demographic factors) to examine whether our design recommendation is efficient for different types of drivers. Future work should also investigate similarities and differences to feedback systems in other domains beyond eco-driving or smart driving systems. In the future, smart homes will likely become more popular and provide opportunities for implementing eco-feedback systems.

In conclusion, our paper addresses mobile eco-driving feedback information systems' design to improve driving behavior and decrease fuel consumption. Harmful emissions at the hand of individual traffic constitute a considerable percentage of global GHG emissions and are associated with severe social consequences. Thus, better driving behavior contributes to the global challenge of achieving a more sustainable lifestyle.

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