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Development of a Mobile Application for Android to Support Energy-Efficient Driving of Electric Vehicles

Sonja Dreyer[2], **Sören C. Meyer**[3],

and **Michael H. Breitner**[4]

[1] Copies or PDF file are available on request: Institut für Wirtschaftsinformatik, Leibniz Universität Hannover, Königsworther Platz 1, 30167 Hannover, Germany (www.iwi.uni-hannover.de)

[2] Doctoral Student, Institut für Wirtschaftsinformatik (dreyer@iwi.uni-hannover.de)

[3] Doctoral Student, Institut für Wirtschaftsinformatik (meyer@iwi.uni-hannover.de)

[4] Full Professor for Information Systems and Business Administration and Head of Institut für Wirtschaftsinformatik (breitner@iwi.uni-hannover.de)

Abstract

Energy-efficient driving of electric vehicles is a challenging and current field of research. One of the biggest issues is the limited range of electric vehicles. Hence, it is useful to find a way of encouraging an energy-efficient driving behaviour. Thus, the aim of this paper is to point out different factors which influence the optimum driving behaviour regarding energy efficiency. This is underpinned by an analysis of measured data, where the most important influencing factors are quantified. Based on these elaborations within this paper a mobile application to support energy-efficient driving of electric vehicles is designed.

Keywords

Mobile Application, Electric Vehicle, Influencing Factors, Application Development

1 Introduction

The issue of electric vehicles is more topical than ever before. Big automotive manufacturers are investing a lot of money for the research and development of them. As a consequence, the number of registered electric vehicles has been increasing continuously for the last years as it can be seen in figure 1. Nevertheless, the amount of electric vehicles is low compared to the overall registered cars.

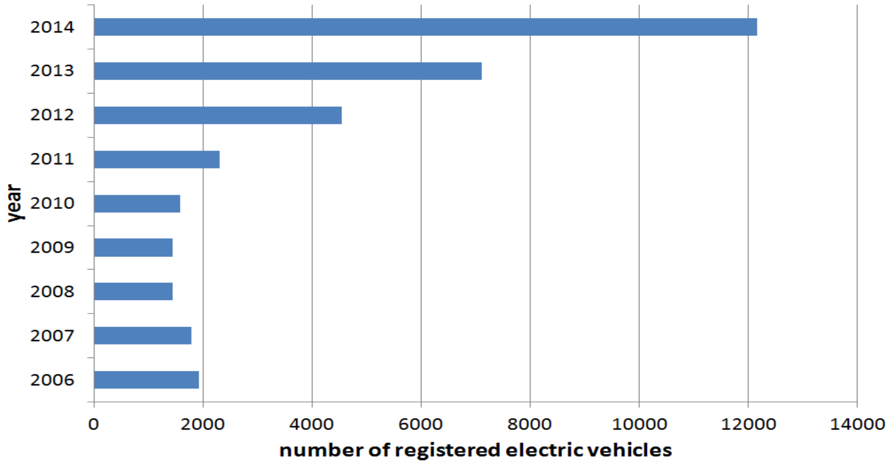

Figure 1: Number of registered electric vehicles in different years in Germany
Source: Statista GmbH 2015.

In this, there are different challenges which have to be mastered regarding electric vehicles. One of the major problems of electric vehicles is the range. Due to the use of a battery system the maximum range is very limited considering the current state of technology. Thus, driving energy-efficiently is essential. That is the reason why tools which are optimising the current driving behaviour are very useful. Hence, investigating more intensively how to drive energy-efficiently helps to optimise the range of electric vehicles which is why different possible factors are analysed within this paper to determine the respective degree of influence. However, as the mere analysis is not useful for the driver of an electric vehicle, this can only be a first step. In a second step all this information is utilised to design a mobile application which allows to evaluate the current driving behaviour and to display this on the screen of the mobile device in real time. Due to this, the driver is able to adapt the driving behaviour continuously. Thus, this paper provides a concept for an energy-efficient driving application on the use case of the Volkswagen (VW) e-up!.

The aim is to elaborate a mobile application to support energy-efficient driving. Therefore, every important influencing factor is considered as far as possible. This is feasible due to a comprehensive analysis of different influencing factors. The elaboration of these factors in combination with measured data is the basis for the following design of the mobile application. The special feature is that the design is not only elaborated on theoretical considerations and calculations but also based on measured data.

In general, the methodology of this paper follows the concept of Hevner et al. (2004) and his seven guidelines for "design science in information systems research". The first guideline demands that something innovative has to be produced. In this paper that is done by the development of the mobile application, which is designed in chapter four. According to the second guideline, the topic has to be relevant. The relevance is explained in chapter one and hence is given. The requirement in guideline three is a well-founded evaluation of the elaborated aspects. The different influencing factors which are explained in chapter two are evaluated in chapter three with base on data collected in test drives. Thus, the evaluation can be seen as well-executed. This guideline is followed by the demand of solving a problem in a better way than before. Within this paper, this is done by developing the mobile application and so supporting the driver of an electric vehicle to drive more energy-efficiently. The fifth guideline deals with the elaborated artefact. It has to be ensured that it is coherent and consistent and besides it has to be determined how well it works. This is mainly done in chapter five in the course of the critical appraisal and the limitations. The penultimate guideline demands a contracted problem space to be able to reach the objective of the research. In this case, the problem deals with energy-efficient driving and its influencing factors and there is a clear definition in the first chapter of what has to be covered by this paper. The last guideline formulated refers to the results. They have to be presented and communicated clearly what is done in chapter six within the conclusion and the outlook. A theoretical background is given in the chapter after the introduction. In this chapter factors that influence the maximum range of an electric vehicle are elaborated. Within this chapter, there is differentiated between factors which are changing during the journey and those who are depending on the respective vehicle. The third chapter contains the statistical analysis of selected influencing factors which is done through data raised during test drives. In the following chapter a mobile application to support energy-efficient driving is designed. Finally, the paper ends with a critical appraisal and the description of limitations. Moreover a conclusion and an outlook are given.

2 Factors That Influence the Maximum Range of an Electric Vehicle

To maximise the range of an electric vehicle and consequently driving energy-efficiently there are different factors which have more or less impact on energy-efficient driving. These factors can be distinguished in two different categories. In the first category are the factors which are changing during the journey, the dynamic influencing factors. These factors are explained and analysed in chapter 2.1. In chapter 2.2 are those factors which depend on the respective vehicle, the static influencing factors.

2.1 Dynamic Influencing Factors

The recuperation is one of the biggest advantages in comparison to conventional vehicles with a combustion engine. The frequency and efficiency of recuperation has a decisive influence on the maximum range. The special feature of an electric motor is that it can be used as motor or as generator (Wildemann 2012). The converted electrical energy is stored in the battery and can be used for following driving processes. The current speed of the electric vehicle also plays a very important role regarding the maximum range. To be able to maintain a certain speed, different resistances have to be overcome. As a consequence it can be said that an increase of the speed results in a decrease of the maximum range. Thus, there is no optimum speed where the motor efficiency has its maximum or the range has an optimum. Because of that it is very useful that the maximum possible speed is limited. Another advantage is that the heat development in the battery system which rises with a higher speed is also limited due to the speed limit (Donhauser 2015).

Physically, the acceleration is the time derivation of the velocity. Thus, the acceleration is the temporal change of the speed. This is why different resistances have to be overcome to be able to accelerate and so to increase the speed. These resistances are the same as in case of the speed. Because of this, there is more energy needed to accelerate than in case of driving with a constant speed. Because of that it is recommendable only to accelerate as much as it is necessary and only as long as it is necessary. The optimum acceleration would be zero because to be able to accelerate it is always necessary to use additional energy. That would not be application-oriented though.

It is possible that the respective electric vehicle has different driving modes to reach energy-efficient driving. In case of the VW e-up! "ECO+" is the most economic one and so it should be used as often as possible. The air resistance is another important factor regarding energy-efficient driving and the maximum range of an electric vehicle. In general, an increase of the speed leads to a higher aerodynamic drag force. To overcome this force more energy is needed. In turn, this decreases the maximum range significantly. With the following formula 1 it is possible to calculate the aerodynamic drag force.

$$F_d = \frac{1}{2} * A * c_d * \rho * v^2 \tag{1}$$

An important influencing factor on the aerodynamic drag force is the speed. As the other factors are constant or can be assumed to be constant, the speed is the only influencing factor which is changing dynamically. As it can be seen in the formula, the speed has a quadratic impact on the aerodynamic drag force.

The factor of the gradient contains the influence of driving uphill and downhill. The gradient influences the maximum range and by that the optimum behaviour to drive energy-efficiently. Another influencing factor regarding the maximum range is the road surface. Depending on the road surface the optimum braking and acceleration behaviour does change. This is because the friction between tyre and road surface is different. The outdoor temperature is also an influencing factor for energy-efficient driving of electric vehicles. Cold reduces the efficiency of the electric vehicle significantly (Schoblick 2013). So the range of the car is clearly lower when the temperatures are lower. Not only cold can

become a problem regarding the range of an electric vehicle but also high temperatures have an influence on the performance. Mainly this decrease is due to additional energy consumers (Schoblick 2013). The wind and slipstreams also have an influence on energy-efficient driving and on the maximum range. As one can imagine, headwind can result in increased energy consumption. Wind which is blowing from the front requires more energy to reach the desired speed than in case of no wind. The tailwind has an influence as well. But in this case it is the other way round. Tailwind reduces the energy consumption needed to accelerate or maintain the speed because it is a force in the same direction as the driving direction of the vehicle. Besides the cases of headwind and tailwind, crosswind also has an influence on the ideal driving behaviour. Depending on the angle in which the car is struck, the wind has a positive or a negative influence on the energy consumption.
Additional energy consumers inside the car are influencing the maximum range tremendously. Most of these additional energy consumers enhance the driver’s comfort. It is helpful to consider the use of additional energy consumers inside the car. The losses in the drive train are an appreciable factor regarding energy-efficient driving of electric vehicles. In principle it is possible to lose energy in every component of the drive train. Furthermore, these components have to be connected to work where energy can be lost. The last point mentioned is anticipatory driving. Anticipatory driving is an important topic regarding an energy-efficient way of driving. Through anticipatory driving it is possible to drive more smoothly and extend the range at the same time. In general, a proactive style of driving can help to drive more energy-efficiently.

2.2 Static Influencing Factors

The first factor mentioned is the weight. The total weight of the car, this means the weight of the car itself and of the passengers, has an influence on the kinetic energy. The kinetic energy is proportional to the total weight of the electric vehicle including all passengers multiplied with the square of its velocity. As there is proportionality between kinetic energy and the total weight, it is obvious that the necessary motion energy increases in case of a higher total mass. In turn, this implies a higher consumption and so a shorter range of the electric car. This is especially because of the fact that due to a higher total weight the roll resistance increases (Nehrkorn 2013). The tyre pressure is another influencing factor regarding the maximum range. In case of a higher tyre pressure the contact area between the tyres and the road surface is smaller. This means that the friction is less and with this the roll resistance (Nehrkorn 2013). In turn, this leads to a reduction of the energy consumption of the electric vehicle. Because of this it could be thought that a very high tyre pressure would be a good option to increase the range. But an important point is that as soon as the energy consumption decreases because of a higher tyre pressure the braking distance increases (Nehrkorn 2013).
When a battery gets older the efficiency may not be as high as in the beginning. This is a critical point because the battery is a very important influencing factor regarding the range of an electric vehicle. Additionally, a battery system is expensive which is why the ageing of the battery is a factor which should carefully be scrutinised.

3 Statistical Analysis of Selected Influencing Factors

3.1 Using the data collected in test drives

As already explained, the recuperation is a very important influencing factor and as the respective degree of efficiency of the recuperation is important information, it is determined and compared with the used negative acceleration afterwards. The degree of efficiency of the recuperation is calculated by dividing the recuperated energy by the in total needed energy.

$$\eta_{rec} = \frac{E_{rec}}{E_{total}} \quad (2)$$

Based on the degree of efficiency which has a value of 57.78 % considering the data of a long term test drive, it is possible to calculate the maximum energy consumption of the motor and the energy which has to be recuperated to be able to drive 160 km, the range which is indicated by the producer of the e-up!, the VW AG. The range of 160 km results when driving in conformity with the New European Driving Cycle (NEDC). This driving cycle raises the claim to represent the typical utilisation of a car in Europe (Denton 2013). To determine the maximum average net consumption, the formula 3 can be used. The net average energy consumption results when dividing the energy of the battery by the range, in this case 160 km.

$$E_{net,avg} = \frac{E_{batt}}{d_{NEDC}} \quad (3)$$

The net energy consumption consists of an offsetting of the energy needed by the electric motor and the energy saved again by recuperation. The energy needed because of additional consumers is not taken into account because they are not necessary for electrical driving.

$$E_{net,avg} = E_{total,avg} - E_{rec,avg} \quad (4)$$

As only the net energy consumption is known, a connection between the total energy needed and the energy which can be recuperated has to be created. This is possible due to the degree of efficiency of the recuperation.

$$E_{rec,avg} = \eta_{rec} * E_{total,avg} \quad (5)$$

This can be inserted in the formula to determine the average net energy consumption and then can be converted.

$$E_{total,avg} = \frac{1}{(1-\eta_{rec})} * E_{net,avg} \quad (6)$$

Due to this it is possible to determine the range with the values collected in a long term test drive and to compare this with the 160 km determined by the NEDC. Therefore, the following formula 7 is used.

$$d = \frac{E_{batt}}{\frac{E_{total,avg}}{100\,km} - \frac{E_{rec,avg}}{100\,km}} \quad (7)$$

Regarding that formula, the distance which can be driven when accelerating with an intensity of 20 % and recuperating afterwards all the time is 132.6 km. The other way round, to be able to reach the range of 160 km the net energy consumption must not exceed a value of 11.6875 kWh/100 km. As there are also further measurements regarding accelerating and rolling out afterwards, it is also possible to determine the expected range in case of short term test drives.

The following calculations are using the degree of efficiency of the recuperation determined for the longer term test drive. Values of ten test drives made in the recuperation level B, in the driving mode "Normal" and with an acceleration intensity of 20 % are used to determine the range. Furthermore, these are the characteristics of the data used for all calculations before.

The previous formula for the range can be used again but there it is not yet possible to determine the range. The reason for this is that the total average energy needed and the average energy recuperated are not known yet because they are no part of the measurements. That is why these two values have to be calculated out of the net energy consumption firstly. To get a valid value for the net energy consumption, the average value of the net consumption of ten test drives in the recuperation level B with an acceleration intensity of 20 % is determined. In this case, the net energy consumption amounts 14.67 kWh/100 km. On this basis it is possible to determine the total energy consumption of the electric motor and the energy regained due to recuperation with the formula already used before.

$$E_{net,avg} = E_{total,avg} - E_{rec,avg} \quad (8)$$

As $E_{net,avg}$ is known, the other values can be calculated following the case of determining the values to reach a range of 160 km. The degree of efficiency of the recuperation can also be used because the characteristics of the test drives did not change.

$$E_{total,avg} = \frac{1}{(1-\eta_{rec})} * E_{net,avg} \quad (9)$$

With the formula 9 the average total energy consumption results in a value of 34.75 kWh/100 km. Now the only unknown factor is the average recuperation energy and so can be determined. Consequently, the energy which can be regained due to recuperation on average is 20.08 kWh/100 km using the efficiency of the recuperation for the longer term test drive.

Based on these results the predicted range d which can be driven without recharging in the meantime can be determined. Thus, based on the data collected through accelerating three times with an intensity of 20 % up to 50 km/h and rolling out afterwards in the recuperation level B, which means that the engine brake is used, the estimated range is 127.5 km.

A maximum acceleration intensity of 20 % is representative for a normal driving behaviour. Because of that all the calculations before are dealing with this acceleration intensity. But as it is not possible to determine the current acceleration intensity with the mobile application which is designed in chapter 4, the intensity has to be converted into an absolute acceleration. As the acceleration intensity of 20 % is the one which is considered in the mobile application, the absolute acceleration of this intensity is calculated and results in an acceleration of 1.62 m/s². Analogue to the absolute acceleration when accelerating with an intensity of 20 % the absolute negative acceleration when letting the car roll out in the recuperation level B is calculated and results in an acceleration of -1.05 m/s².

3.2 Evaluation of the Results

There are different aspects which should be taken into account when evaluating the data and calculations of the previous chapter. One important aspect is the acceleration. To accelerate less strong helps to save energy and maximise the range. In the test drives it has been found out that an acceleration intensity of 20 % already is relatively strong. Thus, it is realistic that accelerating with this intensity or less in the traffic is sufficient. However, it is possible that the absolute acceleration is changing during the time which is why it could be possible that in some points the absolute acceleration is higher than this value. This can be neglected though because of the fact that the current acceleration determined by the mobile application is calculated due to GPS which is neither very precise. Another relevant point is the used driving mode. It is found out that the driving mode has nearly no influence on the energy consumption. That is the reason why the driving modes can be neglected when not using additional energy consumers. Thus, the different driving modes "Normal", "ECO" and "ECO+" are only useful for those who have no idea of how to save energy.

Apart from the driving modes it is also possible to select a recuperation level out of the five different levels D, D1, D2, D3 and B. Depending on the chosen level, the amount of energy which is recuperated does change. This is because depending on the respective level of recuperation the engine brake is stronger or weaker. In case of using the level B the degree of efficiency of the recuperation is about 58 %. In this, the prior acceleration has no influence on this degree of efficiency. As explained earlier, the energy consumption is higher when accelerating stronger but the energy regained by recuperation is also higher. Thus, the degree of efficiency of the recuperation is nearly the same when calculating this for stronger accelerations before recuperating. Although it is not possible to determine the degree of efficiency of the recuperation for the other four recuperation levels, comparing the net consumptions when driving in the same way and only changing the level of recuperation is possible. Following the collected data, there is a difference regarding the net energy consumption when using different recuperation levels. In the recuperation level D there is nearly no engine brake which is why the energy regained is very low. The engine brake when using the recuperation level D1 is clearly higher than in the level D but a little less than in the three highest levels. The level D contrasts with the recuperation levels D2, D3 and B where the energy recuperated is higher. It is remarkable that the energy regained in these three levels is nearly the same. But there are differences regarding the distance and the time needed to roll out. This means that the energy recuperated in total is the same, but with a decreasing level of recuperation the distance until the electric vehicle is on a standing position is increasing. In connection to this the time needed for rolling out is also higher. Thus, the energy regained due to recuperation per metre or per second decreases with a decrease of the recuperation level.

It is also possible to compare the energy recuperated when rolling out and hence only to use the engine brake with the energy recuperated when braking relatively strong with the brake pedal. It is not an emergency braking but a relatively strong one like in case of a traffic light suddenly turning red. On the one hand the used recuperation level has an influence on the energy regained. Although the brake pedal is used, the energy recuperated increases with an increase of the level. On the other hand it is obvious that the energy regained by braking is clearly less than in case of rolling out.

The last important aspect which has to be evaluated is the estimated range. According to the NEDC the range of the VW e-up! is 160 km. But when calculating the range out of the values collected in the test drives, the range is less than estimated. But the values calculated for the forecasted range are not so bad when considering that the way of driving with accelerating and letting the vehicle roll out all the time is not energy-efficient. Nevertheless, it is possible to accelerate with an intensity of 20 % and reach the mileage of 160 km or even more. This is possible because it is not realistic that it is necessary to accelerate and roll out all the time. There are also distances in which it is neither necessary to accelerate nor to roll out. In this distance it can be driven with a constant speed like with 50 km/h in the city without much traffic. Thus, the driving behaviour driven in the test drives is not realistic and because of that not energy-efficient at all which is why the calculated range is clearly less than the estimated one determined according to the NEDC.

In summary, it is possible to gain important information from the test drives. But the values differ a little bit in the different test drives when driving under nearly the same conditions. On the one hand this is because it is not possible to measure the data exactly. On the other hand there are several influencing factors which are already explained in chapter 2 and may change meanwhile. It is looked closer at these limitations in chapter 5.

3.3 Application of the Results

As calculated, the net energy consumption must be less than or equal to 11.687 kWh/100 km to be able to drive 160 km with the VW e-up! without recharging the battery meanwhile. It also is already discussed that this net energy consumption can be reached realistically when moving in the normal traffic. However, it is not possible to measure the current net energy consumption with the mobile application which is designed in chapter 4. The reason is that one objective of this mobile application is to support energy-efficient driving of electric vehicles without connecting the mobile device with the car. Thus, it is not possible to receive the data of the energy consumption. But instead of these data the current coordinates can be received due to GPS by which it is possible to determine the current speed and the current acceleration. Thus, nevertheless it is possible to support the user of the mobile application.

It is possible to formulate several hints and recommendations how to drive energy-efficiently. One hint relates to the used driving mode. For those who have not yet dealt with maximising the range of an electric vehicle it is recommendable to use the driving mode "ECO+". This is especially effective when many additional energy consumers inside the car are used.

Another point where it is possible to save energy is the acceleration behaviour. It is already explained in the evaluation that an acceleration intensity of 20 % is realistic. Consequently, the intensity can be seen as the limit of acceleration. Because of the fact that the relative acceleration in percent cannot be measured by the mobile application, it has to be implemented that the maximum acceleration is 1.62 m/s². But for different reasons it is useful to implement a buffer in case of the limit of acceleration. The first reason is that this is only an average value when accelerating from standstill up to 50 km/h. Thus, it is possible that the acceleration is changing during this distance and hence sometimes is above that value. Furthermore, it is based on measured data. Because of this, measurement errors cannot be excluded. In addition, the different possible influencing factors explained in chapter 2 also may have influenced the measurements and thus may influence the drive when using the mobile application. Another reason why implementing a buffer is reasonable is that the acceleration calculated due the GPS coordinates is not fully precise.

Regarding the acceleration it is important to mention that it is not useful to accelerate only to be able to recuperate after that. As calculated, only about 58 % of the energy needed to accelerate can be regained with recuperation. This applies for the highest recuperation level B. In case of this level the engine brake is stronger than in case of the other recuperation levels, which is why it is possible to recuperate a relatively large amount of the energy introduced. Because of this, it is recommend-able to use the recuperation level B to drive more energy-efficiently. To be able to benefit from the recuperation it is necessary not to use the brake pedal but only using the engine brake in order to let the electric vehicle roll out. To be capable to check whether the user of the mobile application to support energy-efficient driving is using the brake pedal or not, a value for the negative acceleration in the recuperation level B is necessary. It is calculated that the absolute negative acceleration when rolling out without a gradient in this level is 1.05 m/s². This means that it is not energy-efficient to have a negative acceleration deviating from this value because this means that the brake pedal or another recuperation level is used. Like in case of the limit for the positive acceleration there are some limitations which make it useful to implement a buffer in case of the negative acceleration. The limitations are the same like in case of the positive acceleration.

In addition to all the results regarding energy-efficient driving, it can be said that it is beneficial to drive anticipatory to save energy even though the mobile application supports energy-efficient driving of electric vehicles. The reason is that the mobile application is only able to check the current speed and the current acceleration regarding the implemented limits but not the driving behaviour as such.

4 Design of a Mobile Application to Support Energy-Efficient Driving

4.1 Inner Structure of the Mobile Application

As already explained, it is not possible to determine the current energy consumption in the mobile application. But instead of this it is possible to analyse the current speed and the current acceleration due to GPS. Every second the current location is collected in form of coordinates. Thus, it is possible to determine the covered distance per second. As the speed is the time derivation of the distance, it is possible to calculate the current speed. Furthermore, the acceleration is the time derivation of the speed. Because of this, it is possible to determine the current speed and the current acceleration. With basis on these two variables, it is possible to support energy-efficient driving of electric vehicles. In the mobile application the current driving behaviour is evaluated in a traffic light system. A red coulor indicates an energy-inefficient driving behaviour. Amber means it is medium energy-efficient and green indicates an energy-efficient driving behaviour. Hence, it is necessary to determine when to evaluate the driving behaviour with which colour.

Firstly, the focus is put on the structure of evaluating the current driving behaviour regarding the speed. As there are no data available for the net energy consumption when driving with different speeds on a longer distance, it is not possible to make an evaluation of the current speed. The only known information is that the VW e-up! has a maximum speed of 130 km/h. Thus, it is not energy-efficient to reach this speed because in this case the electric vehicle would brake to not exceed this speed limit. Because of this it is useful to warn the driver if the user is driving with a speed close to this value. In this case, one possibility is a pop-up window when driving nearly 130 km/h. Additionally, an acoustic signal is possible. As the determination of the speed due to GPS is not that exact and because of the fact that the driver needs time to react, it is an expedient idea to let the pop-up window already occur when driving with a speed of 120 km/h and accelerating at the same time. To make the text not too long to ensure not to distract the driver, one possible text for this window could be "130 km/h almost reached". To visualise the evaluation of the current speed, the following figure gives an overview of the structure.

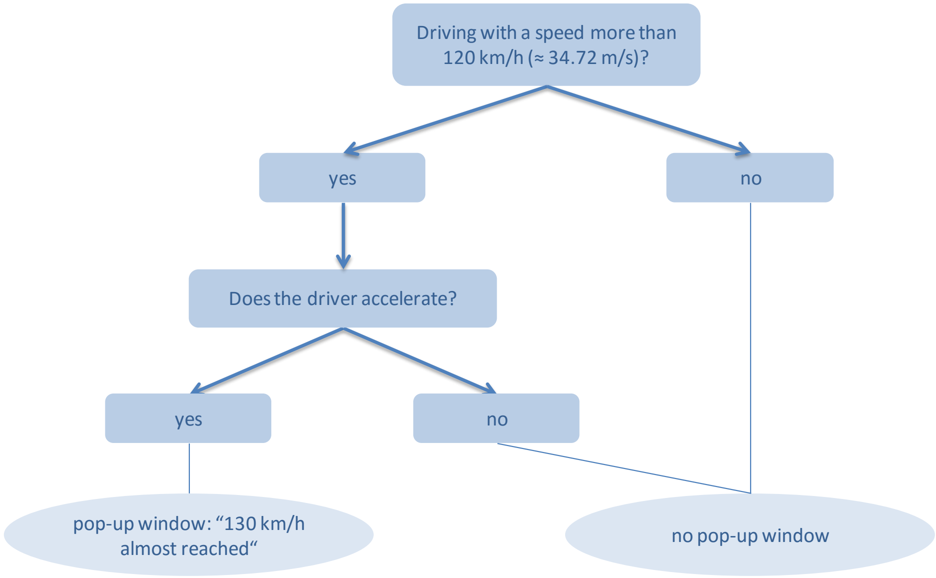

Figure 2: Structure of the evaluation of the current speed

In case of the acceleration it is possible to evaluate the current driving behaviour and to determine which colour corresponds to which driving behaviour. Regarding acceleration there are two possible directions. The first one is the positive direction. This means that the driver is accelerating so that the speed is increasing. In case of the negative direction it would be best if the driver lets the car roll out and so recuperates. There is also the possibility that the speed is constant which means that there is no acceleration. This last case is the easiest one. When neither accelerating nor using the engine brake on the one hand there is no extra energy needed for changing the current speed. On the other hand there are not so many losses. Because of these facts the driving behaviour has the colour green when there is no acceleration existing. The second possibility is that there is a positive acceleration. Like already analysed, a maximum of an acceleration intensity of 20 % is sufficient for normal driving. But there is also mentioned that it is useful to implement a buffer because of possible inaccuracies of the measured data and the GPS coordinates. The suggested buffer for implementation is 5 % of the limits. Depending on the current acceleration there are different processes which take place. The structure of the evaluation of the current acceleration is shown in the subsequent figure.

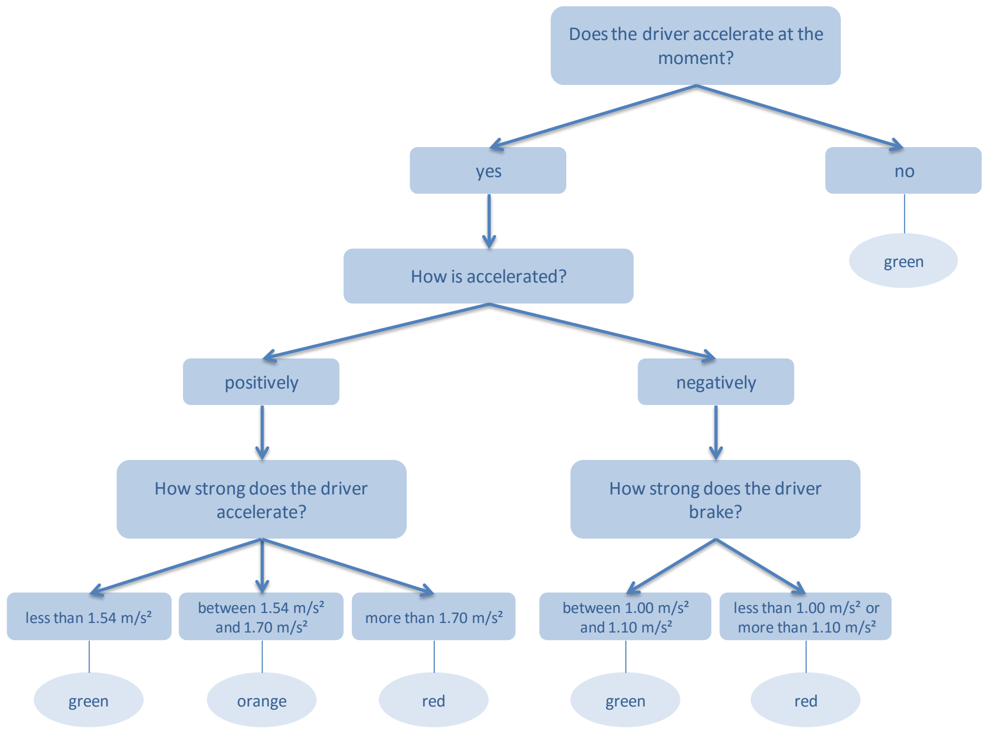

Figure 3: Structure of the evaluation of the current acceleration

Consequently, based on the acceleration intensity and the calculations made before, it is possible to evaluate the current driving behaviour.

4.2 Graphical User Interface

As not only the inner structure of the mobile application is important, the focus in this chapter is put on the graphical user interface. It is essential that the design is attractive and furthermore, that it is easy to understand how to use the mobile application. To get an idea of how the mobile application to support energy-efficient driving for electric vehicles could look like, in this chapter it is visualised. The idea how to realise the mobile application is continued in the following.
When starting the mobile application a start page is shown as it can be seen on the left side of figure 4. In this first draft a photo of the VW e-up! can be seen. Besides, a loading bar enables the user to estimate how long it will take until the mobile application can be used. When expanding the application and making it usable for electric vehicles apart from the VW e-up!, the photo can be changed easily. After finishing loading the mobile application, the user gets to the main menu. Hence, this screen is one of the most important ones in the mobile application. On this screen, it can be chosen from four different buttons. This can be seen on the right side in the figure. The first possibility is to start driving and so to use the mobile application directly to maximise the range of the electric vehicle. The second possibility is to read how the mobile application works. To do this, the button "Help" has to be selected. The button next to the "Help" button is the button to read hints regarding configurations which should be made in the VW e-up! to save energy. In the settings it is possible to make different adjustments. When pressing the return button of the mobile device the page which is called up is always the main menu independent from the current page why there is not an extra button for this on each page. The pages which are activated when pressing the "Start" button are presented in figure 5. Firstly the pages are shown which are activated when pressing start for the first time. The idea is that the user of the mobile application receives some hints about how to set up the VW e-up! to save energy. On the left side in figure 5 the screen which is called when starting the mobile application for the first time can be seen. It is explained that making some configurations in the VW e-up! can help to drive more energy-efficiently.

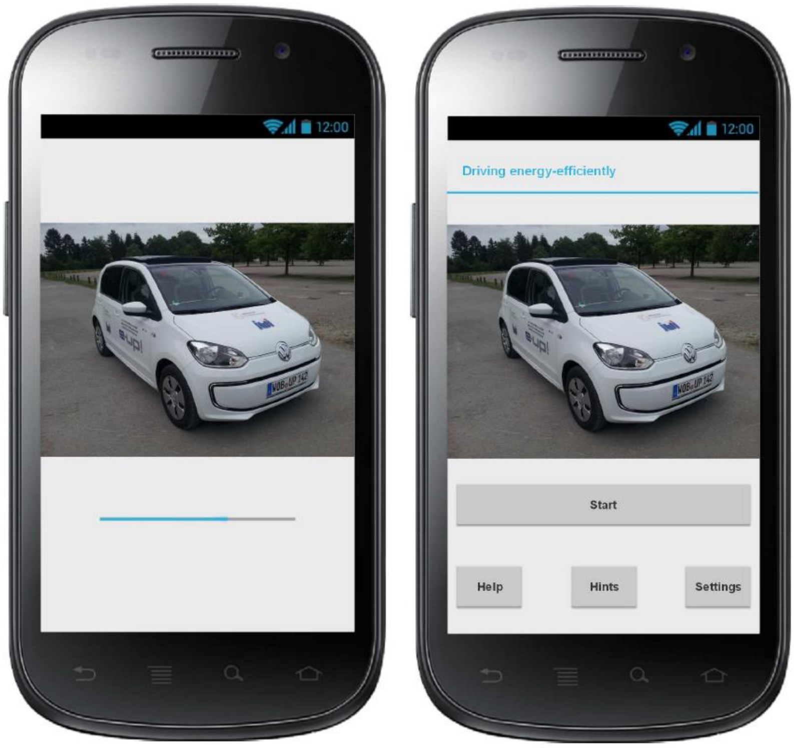

Figure 4: Start page and the main menu

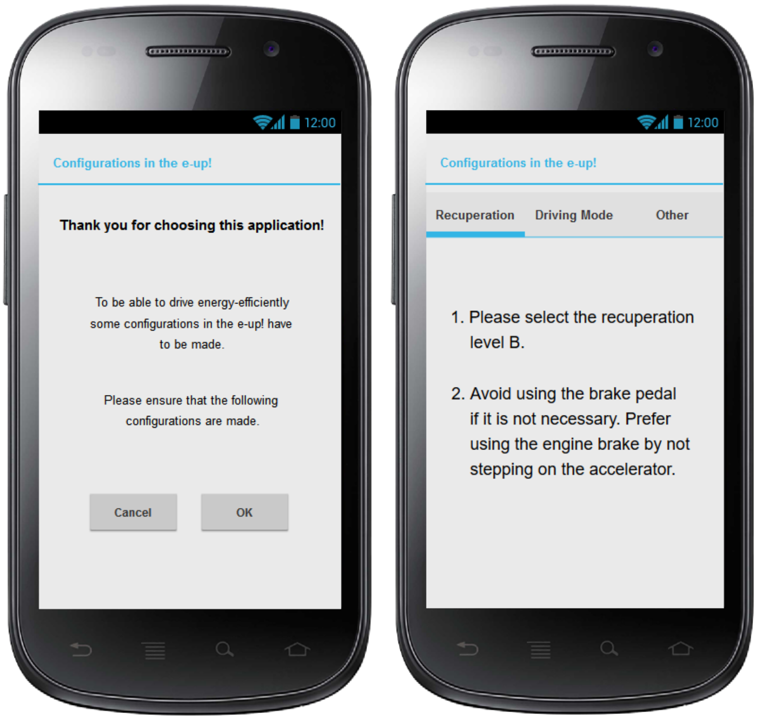

Figure 5: Introduction and recommended configurations (I)

The user has the option to read the hints or to start driving without reading the hints by selecting the "Cancel" button. When pressing "OK" the user who wants to drive energy-efficiently gets information regarding the recuperation, the driving mode and further recommendations. On the right side in figure 5 the first of the three categories is shown. Two hints regarding recuperation are given in the display. The second category of hints deals with the driving mode, shown on the left side of figure 6. On the right side of figure 6 additional hints are listed.

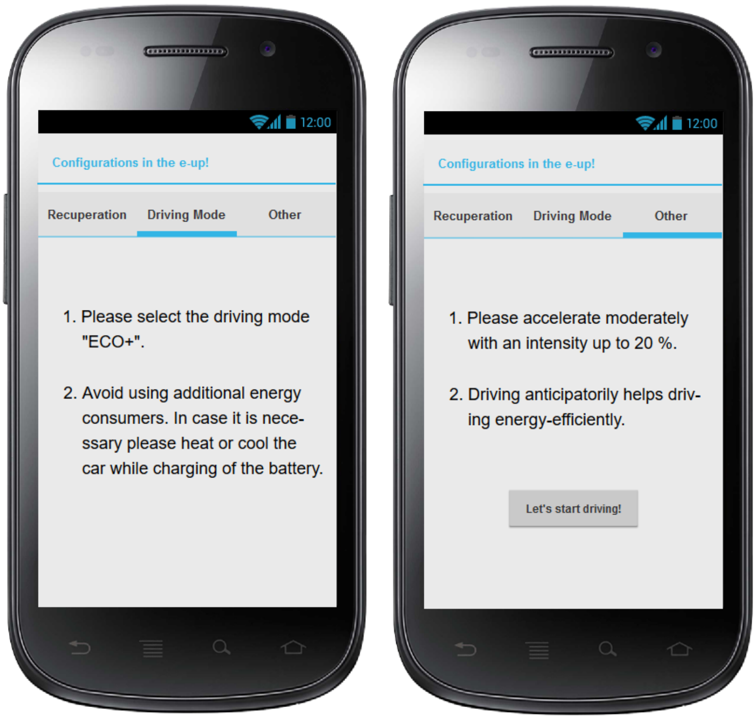

Figure 6: Recommended configurations (II)

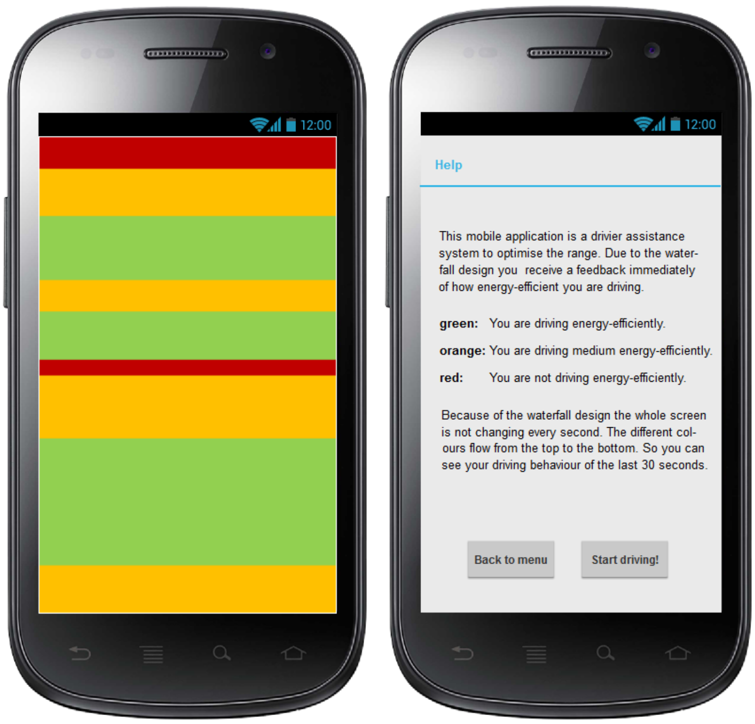

Figure 7: Display during the journey and the help

In the moment when the user of the mobile application presses one of the buttons to start, the user sees a blank screen. This screen is built up like a waterfall. Thus, the colours on the top of the screen are the newest while the colour on the bottom evaluates the driving behaviour 30 seconds ago, exemplarily shown on the left side of figure 7.

To really understand how this waterfall design works, there is a help integrated in the mobile application. This page can be activated by pressing the button "Help" in the main menu. There it is explained how to use the mobile application. The whole "Help" screen can be seen in figure 7 on the right side.

Figure 8: Hints and settings

Apart from the possibility of start driving and reading the help, there are two more options in the menu. One option is to read all the hints again which are presented at the first use of the mobile application. The last option is the button "Settings". In the settings menu the user can make general configurations. Both pages can be seen in figure 8.

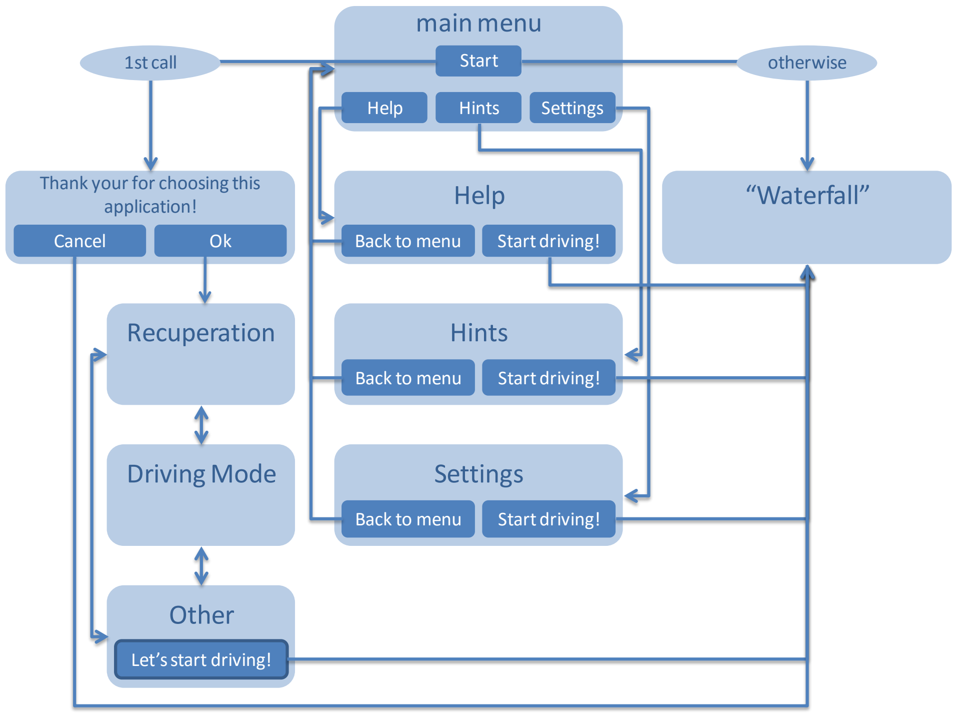

Figure 9: Call logic of the individual pages of the mobile application

Like presented in this chapter, the structure of the mobile application is very simple. Due to this it is possible that the driver can use the mobile application intuitively. Furthermore, the design is simple which is why the mobile application does not distract the driver during the journey.

The figure 9 shows the call logic of the individual pages which are presented above. Additionally, it is always possible to use the back button of the mobile device. When pressing this button the page which is activated is always the main menu independent from the current page. Because of the fact that this is always the same, this is not part of the figure 9.

5 Critical Appraisal and Limitations

When thinking about electric vehicles, the range is a decisive factor. That is why elaborating how to drive energy-efficiently is a very essential field of research. Within this paper many different influencing factors are considered with the objective to transfer the knowledge gained in this way into a mobile application that supports energy-efficient driving of electric vehicles. But not only theoretical reflections are the basis for the mobile application but also practically measured data. Because of this, the compiled possible design in this paper for such a mobile application can be seen as well-founded. Nevertheless, it is inevitable to simplify or neglect facts to reach the objective explained in the introduction of this paper.

An analysis of different factors which are influencing the optimum driving behaviour is made. As it is not possible to consider every single influencing factor when designing the mobile application, limitations have to be made. On the one hand these limitations concern the impossibility of quantifying the respective influencing factor. For example, this applies for the air resistance. In the theory it is possible to calculate the air resistance. But to transfer this into the magnitude of influence on the optimum driving behaviour is highly complex. The same is valid for the gradient. Although in theory it is possible to determine the current gradient, there is no possibility to define the magnitude of influence within this paper. The reason is that there are no test drives made with different gradients, which is why it is not possible to take this into account when designing the mobile application. In case of the road surface, the temperature and the wind at the particular time and place are also very difficult to quantify and determine the influence on the range of the electric vehicle. Additionally, there is the problem that it is neither possible to determine these factors permanently during the journey when the driver uses the mobile application. On the other hand there are some influencing factors which are changing very slowly which is why they can be assumed to be constant. This applies for the tyre pressure and the age of the battery. Nonetheless this can be seen as a limitation. Another influencing factor which is not implemented in the concept of the mobile application is the weight of passengers. The reason is that there are not made test drives with different numbers of passengers. Because of this it is assumed that there is only the driver of the electric vehicle inside the car without any passengers. In addition to this, it has to be said that it is possible that there are additional influencing factors, depending on the electric vehicle and the current driving situation, which are not analysed within this paper.

Apart from the theoretical analysis there are also some limitations with respect to the measured data. One point is that the number of test drives could be larger to ensure that the evaluation is correct. Furthermore, some of the values had to be measured manually and not with the integrated on-board system. Additionally, it is important to mention that some simplifications are made. Regarding the acceleration there are only calculated average values. This means that it is neglected that the value of acceleration may vary, for instance, during speeding up from 0 km/h to 50 km/h. Furthermore, it is assumed that the degree of efficiency which is calculated once can be used for other test drives to calculate different values. Another limitation is that the analysis is made for journeys in the city. This means that there is no analysis when driving faster than 50 km/h.

6 Conclusion and Outlook

Because of the fact that electric vehicles become more and more popular, it is of importance to consider the topic of the limited range. Due to the current state of the art the range of electric vehicles is relatively small in comparison to vehicles with a combustion engine. Additionally, there is the problem that recharging the battery can take a lot of time. Because of this, especially in case of electric vehicles, energy-efficient driving is very important.

This paper is picking up on this point and elaborates a possibility to support energy-efficient driving of electric vehicles. That is the reason why the objective of this paper was to design a mobile application which is supporting such a driving behaviour. This concept is influenced by a theoretical and a practical part. The theoretical part is the analysis of different influencing factors which affect the optimum driving behaviour. On the one hand factors which are changing dynamically are analysed. With respect to this, one of the most relevant factors regarding electric vehicles appears to be the opportunity of recuperation. Depending on the driving behaviour the driver is able to recover a certain amount of energy. On the other hand influencing factors which are not dynamic but depend on the used electric vehicle are scrutinised. One of these influencing factors is the age of the battery which can be a decisive point regarding the range.

The precise observation of these influencing factors is one important corner stone for the mobile application. The other corner stone is the analysis of measured data. These measured data are collected during test drives with a VW e-up!. Thus, many different influencing factors which also may interact are considered at least indirectly due to the measurements. It is possible to analyse and evaluate the data based on different calculations. One example for such a calculation is the determination of the degree of efficiency of the recuperation depending on different influencing factors. As calculated, a value of 58 % is realistic for this degree of efficiency. Another essential point regards the range of 160 km, reached when driving in conformity with the NEDC. It is elaborated that the net energy consumption must not exceed a value of 11.6875 kWh/100 km to be able to cover this range. As analysed, this net energy consumption can reached realistically when not accelerating too strong. In connection with this, another result of the analysis of the measured data is that a maximum acceleration intensity of 20 % is sufficient to remain part of the flow of traffic.

Based on these different elaborations it is possible to design the mobile application. As there are two important parts of the concept, this is divided into the inner structure of the mobile application and the graphical user interface. The inner structure shows the general design of how incoming data are processed. In this, one aspect regards the current speed. As there is a speed limit of 130 km/h implemented in the VW e-up! it is helpful to control the current speed. Another point concerns the current acceleration. Because of the fact that an acceleration intensity of 20 % is sufficient, the current acceleration has to be checked. Furthermore, it is essential to analyse the current braking force. It is recommended in this paper to use the highest recuperation level B. Thus, the current negative acceleration is compared to the negative acceleration of -1.05 m/s^2.This value occurs in case of using the engine brake and also the recuperation level B. As the application is based on measured data buffers are implemented. On the contrary, the graphical user interface treats the external appearance of the mobile application. So, the previous analysis results in a mobile application with the objective to support the user to drive an electric vehicle in an energy-efficient way. But as it is not possible to consider every single influencing factor and each partial result of the analysis of the measured data, it is followed by a critical appraisal and limitations.

Although there are some limitations, recommendations for action are elaborated within this paper. The probably most important point refers to the acceleration, the positive one as well as the nega-tive one. In case of increasing the speed it is recommendable to accelerate moderately. Furthermore, it is important only to accelerate if it is necessary because a positive acceleration means the use of extra energy. The other possibility is to reduce the speed. Therefore, it is recommendable to select the highest recuperation level, B, of the VW e-up! to recuperate as much energy as possible. In addition to careful acceleration behaviour, it is sensible to use additional energy consumers as sparingly as possible to maximise the range.

With basis on the limitations made in chapter 5, it is possible to develop ideas of how to expand the mobile application and in general of further research. On the one hand this could be done by a detailed market analysis. By elaborating carefully which aspects are no part of such a mobile application yet, it would be possible to reach more users which are interested in electric vehicles. Furthermore, maybe there are more influencing factors which can occur depending on the particular driving situation. As in this paper only influencing factors which occur in nearly each case are considered, there might be additional ones which only occur because of specific reasons. To underpin this it could be useful to make more test drives. This is also a useful way to improve the reliability of the data further.

In case of expanding the mobile application, the colour scale to evaluate the current driving behaviour could be expanded. This means that apart from the two extremes green and red which are standing for driving very energy-efficiently and not driving energy-efficiently at all, there could be different shades between these two extremes to give a more detailed feedback. Nevertheless, the user should not be confused by too much information. Furthermore, the mobile application could be expanded regarding the type of electric vehicle. In this paper there only analysed the driving behaviour when driving with the VW e-up!. Including more types of electric vehicles would increase the potential number of users.The same effect can be reached by offering the mobile application for different operating systems.

In summary, this paper is a good starting point for further research and is a comprehensive basis for thinking about energy-efficient driving of electric vehicles. This paper and the within elaborated mobile application to support energy-efficient driving of electric vehicles can be seen as an important contribution in the field of analysing the optimum driving behaviour to maximise the range of electric vehicles.

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