FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Parker's Commute - Digital Game to promote the Use of Electric Vehicles

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Abstract

Achieving sustainability and fighting climate change requires urgent action, as well as changes in the habits of the population. One of the areas of action to overcome this challenge is the reduction of the consumption of fossil fuels, something that can be significantly aided by the adoption of electric vehicles. However, the general public has great reluctance to make this change.

There is a considerable lack of knowledge and clarity about the functioning of electric vehicles among the general population. Many people dismiss them from the get-go due to thinking that they cannot serve their everyday needs. For example, a common concern is that the vehicle's battery is not sufficient to allow for the vehicle to be used comfortably and flexibly (something commonly referred to as "low-battery anxiety"). This concern is why many people dismiss electric vehicles or choose a model with a battery capacity that is excessive for the use that the user will give it.

Therefore, this dissertation has the goal of combining the current knowledge on (1) digital games applied to behavioral change and (2) the technology of batteries and electric vehicles. The accurate simulation of electric vehicles applied to behavioral change is an innovative aspect of this approach to the problem.

This project aims to create a tool that can help the public assess more easily how electric vehicles can help them meet their needs. The tool is integrated with Google Maps to provide customization and immersion to the player's experience.

A set of 46 participants was gathered to help validate the developed prototype. This process consisted of the elaboration of a questionnaire to be answered by the participants before and after playing the game, to gauge the impact that the game had on their opinions. The observed trend was that, while the majority of the participants were receptive to the purchase of EVs from the start, their knowledge regarding the factors that weigh on that decision grew significantly, and their opinion about EVs improved. In addition, the participants concluded the study by evaluating the prototype according to the System Usability Scale, with the average score ranking the prototype above average in terms of accessibility and ease of use.

Keywords: Digital Game, Electric Vehicle, Behavioral Change, Sustainability

Resumo

Para alcançar a sustentabilidade e combater as alterações climáticas é necessário tomar ações urgentes e alterar os hábitos da população. Uma das áreas de ação para ultrapassar este desafio é a redução do consumo de combustíveis fósseis, algo que pode ser significativamente impulsionado pela adoção de veículos elétricos. Contudo, o público geral tem uma grande relutância em fazer esta mudança.

Há uma falta considerável de conhecimento e clareza relativamente ao funcionamento dos veículos elétricos entre a população. Muitas pessoas descartam logo à partida essa alternativa, devido a pensarem que esta não é capaz de atender às suas necessidades quotidianas. Por exemplo, uma preocupação comum é a de que a bateria do veículo não seja suficiente para permitir um uso confortável e flexível deste (um fenómeno denominado de "low-battery anxiety"). Esta preocupação é a razão para muitas pessoas descartarem a opção de um veículo elétrico, ou escolherem um modelo com uma autonomia que é excessiva para o uso que lhe será dado.

Assim, esta dissertação tem o objetivo de combinar o conhecimento atual nas áreas de (1) jogos digitais aplicados à mudança comportamental, e (2) da tecnologia de baterias e veículos elétricos. A simulação precisa de veículos elétricos aplicada à mudança comportamental é um aspeto inovador desta abordagem ao problema.

Este projeto visa criar uma ferramenta que possa ajudar o público a avaliar mais facilmente o modo como os veículos elétricos poderiam atender às suas necessidades.

Um conjunto de 46 participantes foi reunido para ajudar a validar o protótipo desenvolvido. Este processo consistiu na elaboração de um questionário para ser respondido pelos participantes antes e depois de jogar o jogo, para medir o impacto que o jogo teve nas suas opiniões. A tendência observada foi que, enquanto que a maior parte dos participantes já se mostravam à partida recetivos à compra de veículos elétricos, o seu conhecimento acerca dos fatores que pesam nesta decisão cresceu significativamente, e a sua opinião sobre veículos elétricos melhorou. Além disto, para concluir o estudo os participantes avaliaram o protótipo de acordo com a System Usability Scale (Escala de Usabilidade do Sistema), com a média dos resultados a colocar o protótipo acima da média em termos de acessibilidade e facilidade de utilização.

Palavras-chave: Jogo Digital, Veículo Elétrico, Mudança Comportamental, Sustentabilidade

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As I finish this final step of my university life (at least for a while), there are a few names without which this dissertation would be poorer, due to the impact that they had in its development and in myself, and therefore I am using this chapter to dedicate the end-result to those people:

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“Sometimes you’ve just got to lick the stamp and send it.“

Daniel Ricciardo

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Abbreviations and Symbols

AC	Alternating Current
AI	Artificial Intelligence
DC	Direct Current
DS	Design Science
EM	Electric Motor
EMS	Energy Management System
ESS	Energy Storage System
EV	Electric Vehicle
GDD	Game Design Document
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
ML	Machine Learning
PEC	Power Electronic Converter
SoC	State of Charge
SoH	State of Health
SUS	System Usability Scale

Chapter 1

Introduction

1.1 Context

The fight against climate change calls for changes in the behavior of the general population. It is known that, unless rapid action is taken in this regard, humanity's future may very well be in jeopardy.

One of the areas in which this problem can be tackled is the (currently) excessive reliance on fossil fuels for the day-to-day lives of many people. One of the solutions is the adoption of electric vehicles. However, the general public is not keen on making this change, due to a lack of knowledge about the capabilities of modern EVs.

1.2 Motivation

Climate change is one of the major challenges for the current and future generations. The effort to achieve sustainability should be shared by all people, especially the younger generations.

As such, helping the public be more informed about the actions they can take to help in this fight is of ever-growing importance.

1.3 Objectives

The main goal of this dissertation is to encourage the use of electric vehicles, by promoting literacy regarding their functioning. To achieve this, some smaller goals must be achieved. One of them is to accurately simulate the factors which influence the behavior of an electric vehicle since only a realistic experience will give the user correct information about the real capabilities of these vehicles. Another goal is to produce an engaging experience that makes the user stay motivated to keep learning. Finally, these goals must be fulfilled while maintaining a degree of simplicity that allows any person to play the game.

1.4 Contributions

This project intends to create a game that increases literacy regarding electric vehicles and their capabilities. Thus, its main contributions to the area of study are:

- Enumeration of the factors that affect electric vehicle performance;
- Implementation of a game to promote the use of electric vehicles;
- Analysis of the impact of the game on the receptiveness to the use of electric vehicles.

1.5 Document Structure

The document starts with an analysis of the State of the Art, in chapter 2, where the current knowledge in the areas of **Electric Vehicles and Batteries** and **Games for Behaviour Change** is presented. In chapter 3, the problem to be solved is stated together with the planned solution. Chapter 4 describes the methodology that has been followed during this dissertation. Chapter 5 explains the game that was developed, and how it tackles the problem. Chapter 6, elaborates on the game's implementation, from a programmatic point of view. Chapter 7 describes the testing process that was used to evaluate the implemented prototype and the results that were obtained. Finally, chapter 8 presents the conclusions from this thesis, as well as the limitations that were found, and possible future development directions.

Chapter 2

State of the Art

Given the multidisciplinary nature of the problem, the State of the Art must span over two very distinct areas. Firstly, in 2.1, the topic of electric vehicles and batteries will be covered, with the current developments on these technologies being fundamental to the development of an accurate simulation experience. Then, in 2.2, the focus will be the application of games in the context of behaviour change, which is the goal of this dissertation, regarding the stance of the public regarding electric vehicles.

2.1 Electric Vehicles and Batteries

In the fight against climate change, the use of EVs and HEVs is an effective way of reducing the consumption of fossil fuels, which means these alternatives are promising in the scope of modern mobility. This is not entirely unknown, with the interest in these vehicles being on an upward trajectory. Just in 2018, the worldwide sale of HEVs reached 1.6 million units, with this figure having been estimated at 2 million by 2019, 7 million by 2020, 30 million by 2030, and up to 100 million by 2050 [106]. As such, while HEVs are not the main focus of this work, they could certainly become integral to any future developments, which makes them relevant to this section.

2.1.1 Architecture of Electric Vehicles

The powertrain for EVs is made up of the powertrain controller, an Energy Storage System, an electric traction motor, and the associated power electronic converters [39]. There are two variants of the latter, the dc-dc converters and the dc-ac converters. Regarding the energy storage, we can have a mix of electrochemical battery, fuel cell, and flywheel [40]. The architecture is shown in Fig. 2.1.

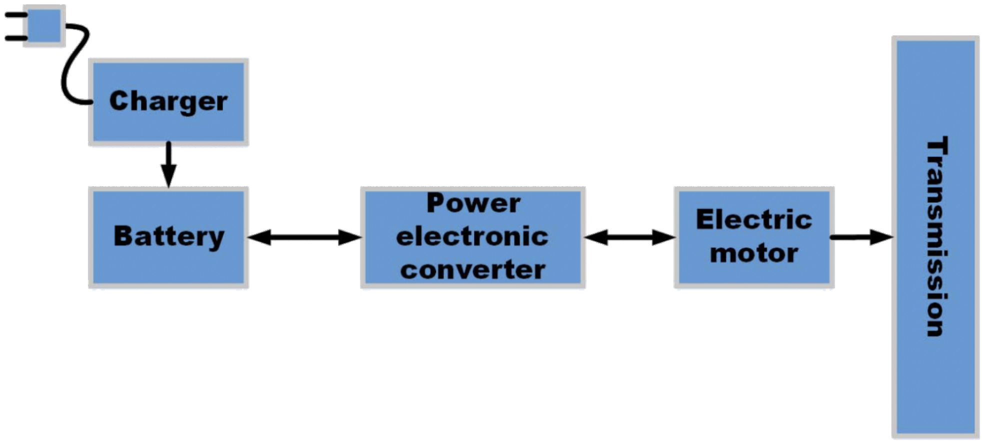


Figure 2.1: Basic Architecture of Electric Vehicles [41]

2.1.2 Architecture of Hybrid Electric Vehicles

With HEVs, the situation is slightly different, with the main difference being the existence of two (or more) power generation units. The primary source of energy is the ICE, with the EM acting as an extra source, responsible for the saving of fuel, as well as assisting with situations where there is a demand for additional vehicle power. The excess power generated by the ICE, as well as the kinetic energy produced by the vehicle, are used to recharge the EMs batteries. Due to the complexity of the components to be integrated in these powertrains, various configurations arise [106]. These configurations are depicted in Fig. 2.2.

- **Series Hybrids**
  The traction force is provided exclusively by the EM. The ICE is connected to a generator, which is connected to the PEC, allowing the power produced by the ICE to charge the batteries of the EM. It is also possible for the ICE to power the EM, while leaving the charge of the battery untouched. Conceptually, it could be considered an EV with an ICE battery charger, which provides additional driving range to the vehicle. However, due to the frequent power conversions, this configuration has an associated inefficiency when it comes to the energy consumed.

- **Parallel Hybrids**
  The EM and the ICE both supply traction power, being connected to the transmission of the vehicle, but not to each other. The lower power of the components reduces the energy loss, although this model is quite less efficient in "stop and go" traffic [41].

- **Series-Parallel Hybrids**
  Similar to the series architecture, but with an additional mechanical coupler connecting the ICE to the transmission, so as to take advantage of the positives of the two previous types, with the advantage of reduced size components (EM, ICE, ESS) [118].

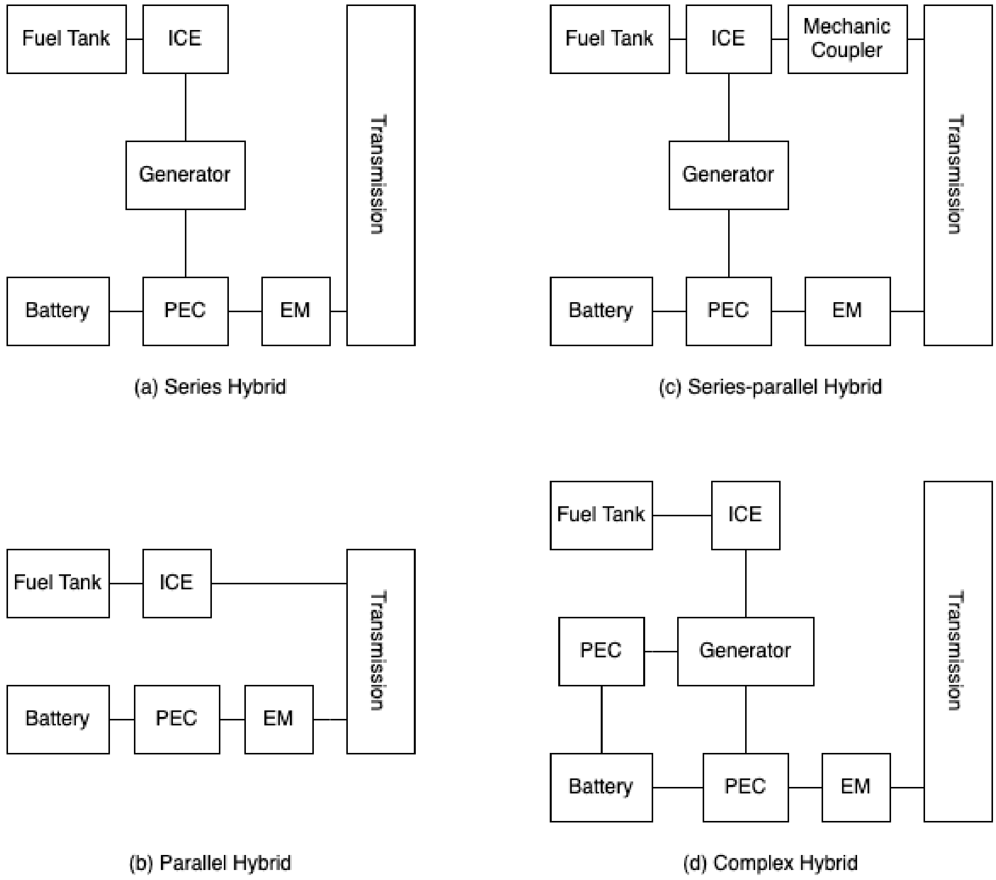


Figure 2.2: Architecture of Hybrid Electric Vehicles [41]

- **Complex Hybrids**
  Based on the Series-Parallel architecture, an additional energy converter is coupled to the battery and to the generator, allowing greater flexibility in modes of operation, and therefore a more versatile and flexible use of the vehicle. However, due to its complexity, this architecture becomes costly [26].

2.1.3 Vehicle Control Optimization Strategies

HEVs are complex and dynamic systems that must satisfy a great variety of objectives, such as adequate vehicle performance, reduced emissions, or fuel efficiency. The optimization between these different goals is handled by the EMS, meaning this module must be adequately selected according to the objectives which must be prioritized. That said, there are three main types of EMS [41].

2.1.3.1 Rule-Based EMS

There are two variants of the rule-based EMS. The first one is the **deterministic rule-based EMS**. In this variant, the goal is to improve fuel and energy efficiency, minimizing losses and emissions. To achieve this, it employs *Optimal Working Condition-based Strategies* and *Frequency-Decoupling Methods*.

The first (*Optimal Working Condition-based Strategies)* is composed of simple strategies meant to define what components power the vehicle (between ICE and EM) during use. One example is the *Thermostat (ON/OFF) strategy*, which consists in ensuring the battery SoC remains within predefined lower and upper bounds, under the cost of limiting the supply of power to the vehicle (this strategy applies mainly to city driving, with frequent start-stop cycles, and in particular to series HEVs [56, 68, 86, 89]. Another example is the *Power follower strategy*, also known as the *baseline strategy*, where the ICE takes the role of primary power supplier, with the EM becoming a merely supportive source, using rules based on heuristics and human intelligence to respond to the driver's power demand [41, 48, 125]. The final example is the *State machine strategy*, or *multimode strategy*, which uses a decision tree-based algorithm to change between a set of predefined operation modes, depending on the circumstances of the use given to the vehicle [72, 112]. For example, there can be a mode where the ICE propels and charges the vehicle simultaneously, or a mode where both the ICE and EM supply power, in order to meet a higher level of demand.

The latter (*Frequency-Decoupling Methods*) is a strategy where the power demands are divided into low-frequency and high-frequency, using a low-pass filter, a high-pass filter, a gliding average strategy, and wavelet transform [10]. Then, fast-acting power sources will be responsible for the high-frequency components, while slow-acting sources will be responsible for the low-frequency components [41, 65, 93, 115, 132].

The second variant is the **fuzzy logic rule-based EMS**. As is the case with all fuzzy logic systems, its success relies heavily on the appropriateness of the membership function and fuzzy rules, which depends on human reasoning. The main advantages it brings are robustness, regardless of the mathematical model associated, and adaptability [107]. We can divide the fuzzy logic into three categories [41].

The first, we call *Optimized-Fuzzy-Rules Control*. We give the name "Optimized Fuzzy" to fuzzy logic that has been improved by an optimization algorithm. The membership function can be optimized by a series of different methods, such as the divided rectangle (DIRECT) optimization, particle swarm optimization (PSO), genetic algorithms (GA) [87], or the bee algorithm [32]. This strategy helps to improve fuel economy and vehicle performance, and to reduce emissions.

The second is called *Adaptive Fuzzy Logic Control*, which is characterized, as the name would indicate, by its self-adaptation capabilities. This results from a combination of fuzzy logic with the use of artificial neural networks, requiring prior data in order to effectively maximize fuel economy and maintain the battery SoC [27, 41, 67, 108, 110].

The third and final one is *Predictive Fuzzy Logic Control*. In this strategy, the trip itinerary and information is known beforehand, and it uses the GPS technology to track the vehicle and determine the length of the trip. With this information, it predicts the state of the vehicle, and makes adjustments dynamically [55, 79].

2.1.3.2 Optimization-Based EMS

This type of EMS uses constraints to continually approximate the optimal configuration to satisfy the many goals that are desirable in these systems. In this regard, we can categorize the optimization-based EMS by online and offline strategies.

The **online** strategies do not require prior data, and they do not assure optimized solutions for real-time adaptation. One example of these strategies are the *Equivalent Consumption Minimization Strategies* (ECMS). These are used in the parallel hybrid vehicles, under charge-sustaining conditions [41] (that is, when the goal is to maintain the battery SoC at a certain level).

The ECMS has been used as an EMS in the second example, which are the *Model Predictive Control-Based Strategies* (MPC-based) [121]. The MPC results from an improvement over the dynamic programming (DP) optimization methods, since, unlike with DP, there is no need for prior data such as the length and conditions of the trip, and the state of the vehicle.

In the **offline** strategies, prior data, regarding the trip to be made and regarding the vehicle's operation, is required. This data is used to tailor the operation to the specific vehicle in question. For example, in series hybrids, we could consider the cost function to be the energy required by the vehicle, whilst in parallel hybrids we'd consider it to be the fuel consumed. With this in mind, there are several types of methods used in this manner. First, there are the *Direct Algorithms*, which are computationally heavy, and therefore unviable for practical implementation [100, 133]. A common case of these is DP. Then, there are the *Indirect Algorithms*, which use mathematical maximization/minimization methods to more efficiently achieve an optimal solution. The main example of this is the Pontryagin minimum principle (PMP). The PMP is able to achieve a solution by condensing a global optimization into a local Hamiltonian optimization problem [87]. However, the large computation time remains problematic with these methods, albeit not as seriously as with the former [61, 135]. In order to decrease this computation time, the *Gradient Algorithms* were adopted, which use the derivative of the cost function to solve the problem. Within these, there are different categories, with the more effective and appliable of them using quadratic equations to model the problem, which is why the HEV is modeled in the same way [37, 130]. Finally, when derivatives are not practical to obtain, or simply not available, the *Derivative-Free Algorithms* are used, and very efficient. These are the more commonly known optimization methods, such as simulated annealing, GA [64], PSO, and the DIRECT algorithms [88], with the GA and PSO being used more commonly, due to their speed and effectiveness.

2.1.3.3 Learning-Based EMS

This type of EMS uses in-depth data from information obtained in real time to obtain the optimal configuration, being totally data-driven. As with the other types, we have different variants of learning-based EMS (LB-EMS). The first, *Reinforcement Learning* (RL), is based on continuous interaction of the agent (our EMS) and the environment around it, and works through the continuous collection and processing of information by the model. The RL-EMS has been used in series, parallel, and plug-in hybrid vehicles [44, 77]. In the next one, *Supervised Learning*, the model is trained to predict and approximate, based on the existing data, until the desired level of accuracy is reached [28]. Alternative to the latter, in *Unsupervised Learning*, a mathematical method is used to extract general rules from the data. There can be an objective function to be minimized [51]. Finally, in *Neural Network Learning*, a large variety of behaviours can be designed, as the very concept of the algorithm is the emulation of how the human brain functions. There are prior examples of the use of NNLs, with Elman networks having been used for maintaining battery SoC [109], or backpropagation networks having been used for the HEV EMS [76, 83].

2.1.4 Power Electronic Converters for Electric Vehicles

We can categorize the PECs for HEVs in two ways. First, we have unidirectional and bidirectional converters. Then, we also have DC-DC and DC-AC converters.

Regarding the **DC-DC converters**, the unidirectional dc-dc converters are used for supportive components of the vehicle, such as safety, utility and entertainment features. The bidirectional converters, on the other hand, are used during battery charging, regenerative breaking, and for backup power. When the power flow occurs from the low-voltage end of the converter to the high-voltage end, it is referred to as "boost operation". Likewise, when it occurs on the other direction (e.g. during regenerative breaking or battery charging), it is referred to as "buck operation". These converters also supply the backup power to the motor, in case of malfunction with the ICE or electric drives [41].

With the **DC-AC converters**, the bidirectional converters are responsible for transferring power between the battery and the wheels, in this direction for driving power, and in the reverse direction for regenerative breaking [41].

2.1.5 Status Estimation in Lithium-Ion Batteries in Electric Vehicles

Given that the management of EVs and HEVs is heavily reliant on knowing the state of the vehicle's battery, it is paramount that the information on the battery's status be as accurate as possible. This comes in the form of two metrics, *State of Charge* and *State of Health*.

2.1.5.1 State of Charge

The SoC is the percentage of the current battery capacity, out of the maximum battery capacity. This value is heavily used by the EMS, as efficient battery usage and battery longevity are two very important factors that are taken into account when optimizing the vehicle's operation.

As such, it is natural that different methods of estimation have been explored and developed, leading to two main variants. Firstly, **Model-based Methods** have a four stage process [126].

First, an adequate battery model must be selected to simulate the dynamics of the battery in question, with the Electrical Equivalent Circuit Model (EECM) [47] achieving the best balance between accuracy and computational efficiency, out of the popular alternatives. After this, different tests must be carried out to obtain data which will be used in the next step, which is the recognition of model parameters using this data, via the application of GA or PSO, methods that have been mentioned often over the course of this chapter. However, the EECM does not fully emulate all of the battery's intricacies, meaning that a final step is required. This step involves the application of filtering algorithms, to minimize errors between the observed data and the actual data.

In contrast, **Data-driven Methods** do not need to consider the electrochemical dynamics of the batteries, using machine learning methods such as artificial neural networks [92], support vector machines [80], support vector regression [43], fuzzy logic [78], or Gaussian process regression [31]. One limitation of these methods is that, as they utilize electrical parameters such as voltage, current and temperature to predict the SoC, they do not take into account the influence of the battery SoH, something which causes inaccurate estimation as the battery ages and undergoes an ever-increasing number of charge cycles. Furthermore, the training process of data-driven methods is time consuming, something which may hinder their practical application [126].

2.1.5.2 State of Health

The SoH is the relation between the current maximum battery capacity, and the initial maximum battery capacity. Due to chemical and mechanical degradation, the maximum battery capacity slowly decreases over time, which will then affect the SoC readings, meaning that it is necessary for the SoH to be accurately estimated, if the vehicle is to keep being well optimized.

Once again, there are different methods of estimation. In addition to Model-based and Data-driven methods, which also exist for SoC estimation, there are the **Differential Analysis Methods**. These methods use the voltage curves to obtain data features related to SoH, using differential calculations. However, these approaches are not very adaptable, struggling to perform under different working conditions. For this reason, they are more often employed as complementary techniques for other methods of real-time SoH estimation [126].

Secondly, as was the case with SoC, **Model-based Methods** are used to estimate SoH, with particular emphasis on the already stated EECM.

Finally, **Data-driven Methods** function similarly for SoH as they do for SoC. It has been found that the selection of high-quality input characteristics are necessary for precise SoH estimation, with the root-mean-squared error, mean absolute error, and maximum relative error being critical metrics to evaluate the error between the estimated value and the real value [73, 126].

2.1.5.3 Co-Estimation Methods

Due to how interconnected these metrics are, it is natural that some methods take advantage of this relationship to better predict both values. While this is a technically difficult proposition, the variation of a multitude of factors is indicative of the SoC, in a short timeframe, and of the SoH, in a longer timeframe. Another positive factor regarding the co-estimation of these metrics is that it takes into account how each of them affects the other.

As is the case with the estimation methods for both metrics, individually, there are *Model-based Methods* and *Data-driven Methods*. Regarding the former, there are alternatives using the Electrochemical Model (ECM) and the EECM, although they suffer from requiring complex testing conditions and procedures [126]. When it comes to the latter, the same methods already referred also apply here.

Because both types of methods depend on the measures of electrical parameters, their accuracy is limited [90], demanding a great effort in analysis and configuration in order to obtain satisfactory results.

2.1.6 Charging of Electric Vehicles

In the modern day, there are various types of solutions for the charging of EVs. The more traditional **wired** solutions keep improving, while new and innovative **wireless** solutions are the subject of research and development. These developments are especially important given the weight of vehicle autonomy in the public's opinion regarding EVs.

2.1.6.1 Wired Charging

Regarding wired charging solutions for EVs, there are two types of charging that should be well distinguished.

Firstly, **AC (alternating current)** charging uses the current that we can obtain from the electrical grid. It can be transferred at different speeds without suffering with inefficiency. AC charging is used to charge the battery via the on-board charger (OBC), which can be classified in two groups. The first of these is *1Φ On-Board Slow Charging*, which is used in level 1 charging (e.g. charging the vehicle with a typical household electric outlet). As would be expected, this method is slow, with charging time reaching upwards of 6 hours [17, 82, 101, 113]. The second is *3Φ On-Board Fast Charging*, which takes advantage of specialized equipment to reduce charging time, due to increased power. In this case, charging time decreases to $2 \sim 3.5$ hours [25, 82, 102, 120].

Alternatively, there is **DC (direct current)** charging. DC can be stored by batteries, and so the vehicles convert the AC provided by the previous charging methods to DC. It has a constant rate of transmission, and is typically used in fast-charging of the vehicles. Once again, this charging can be classified into two groups. The first is *Off-Board Fast Charging*. Dedicated charging stations for EVs contain a rectifying unit which enables the direct charging of the vehicle's battery. This type of charging is renowned for its speed, achieving charging times of under 1 hour. As such, these stations have recently began being offered by large companies, such as BMW, Hyundai, Nissan, and Tesla [12, 54, 74, 82, 97]. The second is *Off-Board Rapid Charging*, which uses more power and current to even further reduce the charging time. In concrete, with this approach it is achievable to charge a vehicle to 80% within 15 minutes [82, 119, 134, 139]. This technology is primarily provided in rapid chargers manufactured by Tesla, specifically for their own vehicles.

2.1.6.2 Wireless Charging

While wireless charging of EVs is definitely a possibility that will be extensively explored in the future, most of the developments in this area so far are experimental, with very little practical applications currently available. There are three categories for these technologies.

The first one is **Near-Field Charging**. Within this category, there are three main technologies, and it is the most expansive, given that it's the one where there are already functioning examples or prototypes of the technologies being researched. Firstly, *Inductive Charging* is fairly close to being a standard alternative. The concept is similar to the already widespread wireless charging for smartphones, for example. Power is transferred in the form of an electromagnetic field, from a charger to a receiver pad, which is part of the vehicle [8, 75, 127, 128, 129]. While further development is still necessary for this technology to meet the standards at which it may become commonplace, there are already some EVs that support it, with the first big commercial example being the *BMW 530e Plug-In Hybrid*. However, this technology obviously has drawbacks, such as a lack of efficiency, or a short charging range. The second technology is *Magnetic-Resonant (MR) Charging*, which is capable of much higher range and power delivery than the former. While widespread implementations of this technology have been conceptualized, these would require heavy investment in infrastructure, probably at a government level [82, 85]. Since this development would go a long way in eliminating low-battery anxiety as a whole, the ongoing research creates highly optimistic prospects for the adoption of EVs. Finally, there is *Capacitive Charging*. Two metallic plates, integrated with the transmitter and receiver pads, act like capacitors in parallel connection, generating an electric field, which induces electric current in the receiver pad [9, 82, 94, 95, 98, 111, 122].

The second one is **Medium-Field Charging**. The driving principle is the use of mechanical force as a medium to carry energy, through the interaction between two synchronized magnets [91, 116, 123, 124].

Finally, the third one is **Far-Field Charging**. where Electromagnetic Radiation (EMR) is used to transmit power over a long distance. EMR is used under three formats. Firstly, *Laser Charging*, which has its practical uses in rare applications, such as drones or orbital vehicles [137, 138]. Secondly, *Microwave Charging* has been tested with regards to platforms based on balloons, helicopters, experimental airplanes and experimental cars [15, 82, 103, 105]. Finally, *Radio Wave Charging* is based on the propagation of electromagnetic fields. It does not yet have any practical applications, as more research is still required to increase the levels of efficiency obtained through this technology [21, 57, 82, 104].

2.1.7 Summary

In this section we went over some important notions regarding how EVs work, such as their architecture, different optimization strategies that are used, SoC and SoH estimation in Lithium-Ion batteries, and various charging methods for them.

EV architecture on a base level consists on a PEC, which converts the electrical energy from the battery into kinetic energy for the engine. The architecture then gets more complex for HEVs, as different methods exist to combine the electrical and combustion motors (series, parallel, or variations of a combination of both).

Regarding the optimization of these systems, there are different strategies that are employed, drawing from different fields of AI. There are rule-based systems (deterministic or fuzzy logic), optimization-based systems, and ML-based systems.

Likewise, there are different methods to estimate the EV's SoC (current battery charge) and SoH (current maximum autonomy). Regarding the former, there are model-based methods, which require intricate knowledge of the specific vehicle, and data-driven methods, which use ML methods to reach their value, under the caveat that their performance degrades as the SoH changes. Regarding the latter, we have these same two types of methods, as well as differential analysis methods, which use mathematical analysis of recorded data to estimate the SoH. Finally, there are co-estimation methods, which explore the relationship between these two values to attempt to reach more accurate results.

Charging of EVs can occur through wired or wireless methods. Wired methods are more developed, being used universally in the EVs that are presently available to the general public. On the other hand, wireless methods are highly experimental, with few cases of current real-life applications. It is also worth mentioning that there are two variations of PECs, one which is unidirectional, only powering the EV's movement, and the other bidirectional, recovering some of the energy from the EV's movement to charge the battery.

2.2 Games for Behaviour Change

Since a large part of the problem is a lack of knowledge about how electric vehicles work, fighting this gap must be a priority, and since the goal is to appeal to the general public, this should be done in a way that is engaging and easy to learn. More classic means of diffusing knowledge, such as books or scientific articles, are not so effective in this regard.

Games, on the other hand, are immersive and interactive by nature [34], and are able to aid the learning process due to factors such as the immediate feedback that the player receives, or the fact that the player is in control, and thus able to explore as their creativity demands [63]. In addition, games go hand in hand with the processing of complex information, which gives them the potential to be a powerful support tool learning and for behavioural change [18].

The fact that games and game-related activities engage the user in a flow of challenges and rewards, something that naturally fuels the player's motivation, is commonly recognized, with an ever-growing number of applications exploring gamification and persuasion to encourage certain behaviours on the user [99]. Their goal, as is my own in this dissertation, is to guide the user's behaviour by creating an environment based on known theories, without discouraging them [6].

2.2.1 Gamification and Serious Games

Before anything else, it is important to distinguish a game from simple play. A game is a structured and interactive activity with an explicit set of rules, where a player must overcome challenges to achieve a pre-established goal [33]. Play, on the other hand, implies an environment where the outcome is not exact, and where improvisation is often the rule.

Next, we must distinguish the concepts of *Gamification* and *Serious Games*.

Gamification is defined as the use of game elements in non-game contexts [33], with aspects that maintain the same structure from game design without ever fully crossing to a playful design. The use of game design techniques implies that the user is seen as a player, and so the experience must be designed to keep them engaged. To achieve this, the decision of what game elements are useful in a given moment or context must be taken very seriously.

With this in mind, there are two main approaches for gamification [84]. The first is reward-based gamification, which is more commonly employed. It is designed around the use of points and point thresholds, and better fitting for short-term activities, where the user is led to behave in a specific way in order to increase their score. The second is user-based gamification. This approach empowers the user, instead of controlling them, by adding value to the other components. As such, it is better employed in less time-sensitive situations.

Finally, there are several components that can be used to implement gamification [66], such as the use of *mascots*, to increase relatability in the user, the implementation of a *scoring system/scoreboard* to exploit the user's innate sense of competitiveness, the implementation of **badges/trophies** to reward the user for performing specific actions, and the use of *challenges/missions* and a *progress bar/levels* to keep the player continually engaged. More detail can be found in Table 2.1.

Table 2.1: Examples of Gamification [66]

Mascot	- Makes the user access the application more often, in order to care for a mascot - This mascot can be customizable, so that the user can further relate to it
Scoring System / Scoreboard	- This system appeals to the need for competition that exists in each individual - The motivation to beat others will lead the users to use the application more frequently
Badges/Trophies	- Specific rewards for each activity that the user completes - The user will feel motivated to complete all activities provided by the application, in order to collect all the badges - In some cases, recurring activity may be encouraged, by making it mandatory to obtain/retain certain badges - Also appeals to the sense of competitiveness in the user, as they may compare badges with others
Challenges/Missions	- Focuses on a form of personal competition as a way of forcing the user to use the application - Presents a periodic (weekly or monthly) challenge which makes the user feel motivated to complete it as fast as possible
Progress Bar/Levels	- Progress bar has a beginning and an end, while levels do not possess an upper bound - Allows the user to quantify their effort, motivating them to work to reach the next level, or to fill the progress bar

Serious Games are games with a purpose other than entertainment. While they are often perceived as games for learning and training in specific, and while these certainly are examples of serious games, the definition is broader than those examples in specific [35]. Serious games have become popular, being used pedagogically for political, social, economical, environmental or humanitarian causes [11]. They are a useful tool to fight the demotivation caused by boring practices, which is why they're so associated with educational contexts, by simulating real world situations or processes, elaborated with the purpose of solving a problem [38].

Serious games distinguish themselves from entertainment games, where changes to the player are a mere byproduct of the experience, and not its very purpose [117]. Still, a game is expected to be fun, and so an expectation is created that the game will provide a sense of enjoyment, something that must be considered when designing it. Another distinguishing factor is that serious games will focus more on problem-solving than on the player's experience [114].

2.2.1.1 Advantages and Disadvantages of Serious Games

It is true that digital games formerly had a negative connotation, being associated with extremely negative situations, such as addiction [16], sedentarism [69], propension for violence [7], and depression [22]. However, we now know that they are correlated with a multitude of cognitive benefits [49], such as quicker focus of attention, better problem-solving skills, uplifted humour, and improved creativity and social behaviour. In fact, it has been shown that they can help with the education of people with cognitive difficulties, as in 2002, researcher Mark Griffiths performed a study in which people with conditions such as autism and ADHD were shown to learn more easily via the application of serious games [52]. He found that games make it easier to assimilate information, which is transmitted through image, video or sound, rather than extensive text. In addition, the motivation brought by the proposed challenges indicated that competitive and collaborative aspects can be promoted as a motivating factor.

However, serious games are obviously not without flaws, and some aspects must be heavily considered regarding the use of serious games, particularly in educational contexts. In particular, the overuse of this kind of tool can be extremely detrimental, as if such an experience becomes routine, not only does it become less effective, since the novelty of it wears off, but it will also make conventional learning substantially harder [42]. Even a well designed game must be applied correctly, or else it will lose its purpose.

In all, there are more advantages than disadvantages when it comes to serious games, and a responsible and careful employment of them will only exacerbate the rewards, while minimizing the risks.

2.2.1.2 Structure of a serious game

This work will follow a triadic game design proposed by Casper Harteveld [58] to structure the creation of the intended game. This proposition contemplates three worlds of design: *reality*, *meaning*, and *play*.

The world of **Reality** is what connects the real world and the game world, creating a model of reality based on the common points between both. These points can vary wildly depending on the type of game, as reality is so complex that there is an almost infinite number of aspects that can be used to relate both worlds.

The world of **Meaning** adds some sort of value to the game, be it knowledge, proficiency, data acquisition, or, as is the case in this work, **behavioural change**. This world is strongly connected to the very definition of serious games, providing something more than mere entertainment.

Finally, the world of **Play** is responsible for the factors of fun, immersion, and captivation. It defined the design of the game, its genre, and the role to be played by the player, and it’s at the base of the entertainment factor, creating the setting for the game to add value.

2.2.2 What Drives Behaviour Change

Since the goal of this thesis is to promote behavioural change on the players of the game, it is necessary to be up to date with the scientific knowledge on what motivates behaviour change.

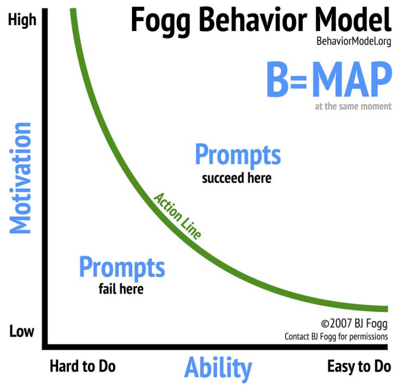


Figure 2.3: Fogg Behaviour Model [46]

2.2.2.1 Behaviour Change Theories

There are different theories on what motivates behaviour change. While these theories do not directly contradict one another, they see the topic from slightly different angles, which is why it is important to understand both points of view.

In this section, I will focus on two main theories regarding behaviour change, the *Fogg Behaviour Model* and the *Self-Determination Theory*.

The **Fogg Behaviour Model** [46] defends that, in order for a behaviour to happen, there are three factors that are required. The first is *motivation*. The individual must have a reason to want to change such a behaviour. The second is *ability*. The individual must be capable of performing the required actions. The third and final one is called the *trigger*. The trigger is an event that makes the person start to adopt the intended behaviour. This can be a remarkable event in the person's life, or a moment of realization, among many other possibilities. As can be seen in Figure 2.3, motivation and ability experience a trade-off relationship. The balance between these three factors can be translated into game design fundamentals, with most common game design practices being idealized around affecting this balance to achieve a certain goal.

The **Self-Determination Theory** [30], on the other hand, defends that humans seek three different goals (Figure 2.3). Firstly, a sense of autonomy, of personal agency in their behaviour. Secondly, a sense of competence, of capability and, to a degree, mastery in the activity that they are performing. Finally, they look for a sense of relatedness, of being able to connect to their peers. The conjunction of these three factors allows people to satisfy their psychological needs. In addition, this theory defends that human beings inherently adopt growth-oriented behaviours, and that, as long as motivated, a person's choices will always trend in that direction. Finally, it is strongly defended that the existence of internal sources of motivation correlates directly to a trajectory of personal growth.

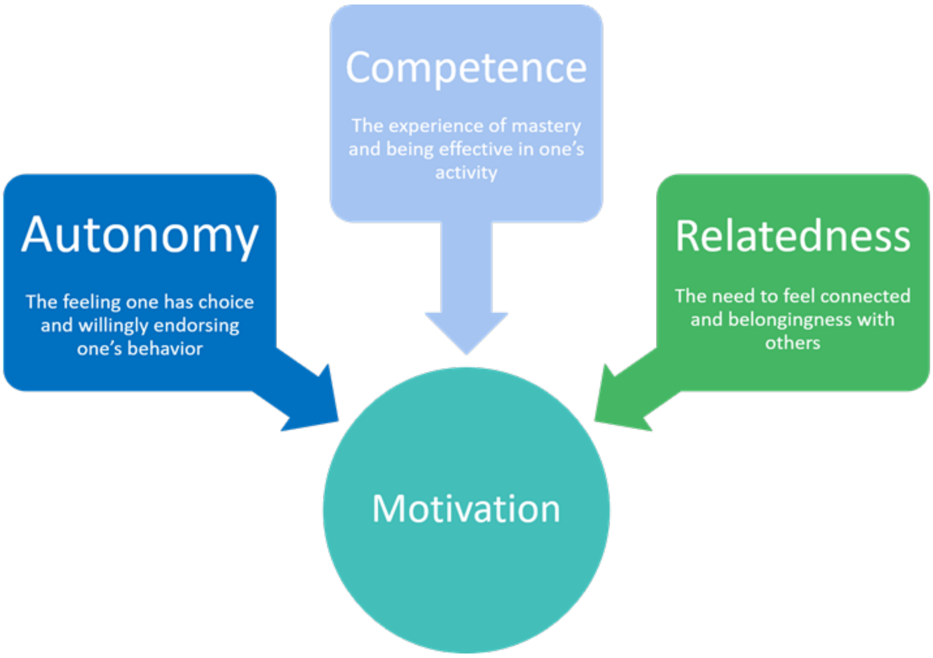


Figure 2.4: Self-Determination Theory

It is important to highlight that both theories focus the value of boosting a person's motivation, which is why we must be able to distinguish between the different types of motivation that exist.

2.2.2.2 Extrinsic and Intrinsic Motivation

While it is undeniable that motivation is key in many aspects of psychology, the distinction between *Extrinsic* and *Intrinsic* motivation is necessary for understanding how to encourage players to adopt new behaviours.

Extrinsic Motivation is the motivation that comes from a prospective reward from performing a certain task [81]. For example, let us imagine a competition in which the winner receives a trophy. This constitutes an example of extrinsic motivation, as the prospect of receiving the trophy will be an additional motivation for the competitors to try to win the competition.

In contrast, **Intrinsic Motivation** is the motivation that comes from the very act of performing a task [131]. A personal goal will always carry more weight than any goal established by others, which makes this motivation of extremely valuable in the context of game design [23]. As such, it is much more valuable to develop interesting activities which are by themselves motivating, than it is to motivate people to do tedious things, by enticing them with a reward [24, 29]. Let us revisit the example in the previous paragraph. An example of intrinsic motivation would be the competitors' personal sense of competitiveness, of wanting to be the best. This would be a much stronger motivator than any physical reward.

2.2.3 Serious games and Behavioural Change

Given that this work has the goal of inciting behavioural change through the implementation of a serious game, it is important to know how games can be used to influence behaviour. There are two main methods for this [45].

The first is to include procedures of behavioural change in the process of playing the game. A good example of this practice is the game *Squire's Quest!* [14]. Designed to lead kids to improve their nutritional habits when it comes to fruit and vegetables, it integrates procedures specified by Social Cognitive Theory [13], which is one of the most cited regarding behavioural change. These procedures include goal setting and decision making, among others. These procedures were tailored to incentivize the preference for fruits and vegetables, and in this case these efforts were successful, as it was concluded that the game led kids to improve their consumption of these types of foods.

The second is to utilize a story, introducing concepts of behavioural change through this story. Namely, this can be done through a relatable protagonist. The empathy developed between the person and this protagonist is exploited, as showing the protagonist undergo these changes, through events that cause conflict, is particularly effective.

2.2.4 Related Works

Since the objective of this dissertation is concrete and well defined, it is important to be aware of past efforts in works with a similar objective, and to be able to learn from what worked well in these efforts.

- **Festarola [96]**
  A serious game developed to strengthen problem-solving strategies, and promote self and shared regulation learning. Children were led to solve math problems, under the context of organizing a party. The use of a relatable topic helped the participants of the study feel motivated.

- **Grab2BeHealthy [62]**
  Designed to raise awareness for diabetes, in this game the players are rewarded for grabbing healthy food, and penalized for selecting unhealthy food. As such, this game greatly emphasizes the score element as a source of (extrinsic) motivation.

- **iLift [70]**
  This game was designed to assist in the training of health professionals, in lifting and transfer techniques. It is one of the most interesting examples in this list, as it is specifically designed to work as an autogenous trigger for a behavioural change system. It achieves this by not guiding the user too clearly towards the desired behaviours, relying on exploration instead. A dashboard element acts as an extrinsic motivational factor which is aligned with the player's personal goals, making it carry intrinsic value as well.

- **It's a Deal [53]**
  This game aims to teach intercultural communication to British and Spanish students. It achieves this by making the player go through different episodes which contain different business-related experiences. In these experiences, the player must recognize the most appropriate response, in dialogue situations.

- **Packy & Marion**
  Released by Nintendo in 1994, in this game the player takes the role of a character with Type-1 Diabetes, monitoring the levels of glicose, administering insulin and selecting healthy foods to be ingested. A study was conducted where the participants played this game, and the result was a drop of 77% in Diabetes-related trips to the ER [20].

- **Play It Safe [136]**
  This game was developed in the context of a study regarding different forms of teaching. It aims to teach participants about cybersecurity concepts, through making them solve security problems, and mini-games to unlock clues to solve those problems. The study in question showcases the difference between the effectiveness of learning through the game, through reading, and through an e-learning tool developed for this study as well. In the end, the game-based learning approach yielded superior results, compared to the alternatives.

- **School of Empathy**
  This game was created to encourage a positive behavioural change regarding bullying situations. The game approaches three core ideas for the users' learning. Firstly, improving assertive and appropriate behaviour in a situation where someone is suffering from bullying. Secondly, accepting the differences between people. Finally, being more conscious about the impact that an action can have. *School of Empathy* teaches young people about what really happens when bullying situations occur, and also how to detect and help manage these situations. [45].

These examples, plus the already aforementioned *Squire's Quest!*, are all good examples of how to use digital games to encourage behavioural change, and they all show different aspects of how to effectively achieve this goal.

2.2.5 Summary

In this section, we went over the use of games in behaviour change, explaining gamification, serious games, and how they can be used to influence behaviour.

Serious games are games used with a purpose beyond entertainment, being effective in creating learning experiences that yield superior results to conventional ones. They must, however, be used sparingly, as overuse can lead to a certain dependence.

There are different theories regarding what drives behaviour change. One of them, the Fogg Behaviour Model, defends that behaviour change requires three factors: capability to adopt a behaviour, motivation to do it, and a prompt that triggers that change. The other, the Self-Determination Theory, defends that humans seek control of their own choices, a sense of competence in the activities they perform, and a sense of relatedness to their peers, and given these factors the person will act towards personal growth.

Despite their different approaches, both theories agree that the person's motivation is paramount for behaviour change to occur. In this aspect, there are two main types of motivation: extrinsic, which comes from the prospect of a reward, and is effective in the short term; and intrinsic, which comes from the behaviour itself, and, therefore, works better in the long term. Of course, different related works apply these concepts in different ways to achieve their goals.

Chapter 3

Methodology

In this chapter, an approach to the problem will be made. First, in section 3.1, the scientific problem to be tackled will be described. Then, in section 3.2, the solution perspective that is currently envisioned will be explained. After this, the methodology used during the development of this dissertation will be explained, in section 3.3.

3.1 Problem Statement

The adoption of electric vehicles is one of the major steps that can be taken in the struggle to achieve sustainability on our planet. However, the scientific evolution of electric vehicles and battery technology is not matched by the public perception regarding this topic. The many misconceptions that exist make it so that there is a strong resistance to the use of these vehicles by the general public, who instead keeps favoring conventional vehicles, even in cases where this is not advantageous to the vehicle owner.

As such, the problem that presents itself is how to convey the correct information regarding the capabilities of modern EVs, in a format that is easily accessible and digestible, to maximize the diffusion of knowledge, and increase general literacy regarding this topic.

3.2 Proposed Solution

This work will develop a digital game that aims to spread accurate information about the capabilities of modern EVs, debunking common misconceptions by allowing the player to experience how day-to-day mobility problems could easily be handled using these vehicles.

To make this an effective tool for promoting literacy about EVs, the game should portray an accurate representation of how these vehicles behave, by realistically simulating their functioning. Ideally, the prototype will be able to show exactly how an EV would fit into the user's daily routine, which would involve giving the player the freedom to tune their experience to different contexts.

Furthermore, the scientific knowledge on the application of games to behavioral change defends that it is key to allow the player to reach the desired behavior by their initiative, rather than forcing them to adopt a certain way of playing. Therefore, the game should provide an engaging experience, and allow the user to explore, and discover how the EV would behave and perform in different situations.

Although the application of competitive elements would be a classic way of encouraging this exploration, as defended by the literature, in this project a different direction was chosen. Instead, a larger focus will be placed on the immersion of the player, by allowing the customization of the game experience to the routine of each user. This necessarily makes it impossible for a direct competition environment to exist, as the very concept of the game involves a different experience for each player.

3.3 Methodology

Design Science is a research paradigm based on the concept of learning by doing [60]. More concretely, it is centered on the iterative creation of new and innovative artifacts. The end goal of DS is to create things that are effective or useful and to learn as a result [36]. These artifacts can take the form of decision-support systems, modeling tools, governance strategies, or evaluation methods, among others [50].

The goal of this dissertation is to develop a game to incite behavior change. As such, since the final objective is a concrete practical artifact, DS is an appropriate paradigm to follow.

According to [60], a DS research project should follow seven guidelines, which can be found in Table 3.1.

Table 3.1: Design-Science Research Guidelines [60]

Guideline	**Description**
Guideline 1: Design as an Artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Search Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

It is necessary to reiterate the importance of rigorous, high-quality research in a work such as this one. Without striving to maintain this rigor, it is impossible to produce quality work, and to gain credibility among researchers from different areas [59].

In research projects which follow the DS paradigm, there are three research cycles [59] which must be included and identifiable.

The first is the **Relevance Cycle**. This cycle connects the context and environment of the research project to the activities which are being developed.

The second is the **Rigor Cycle**. This cycle connects the scientific knowledge upon which the DS research project is built with the DS activities.

Finally, the third is the **Design Cycle**. Central to the DS research project, this cycle iterates between building artifacts, and evaluating said artifacts.

The connection between these cycles can be visualized in Figure 3.1.

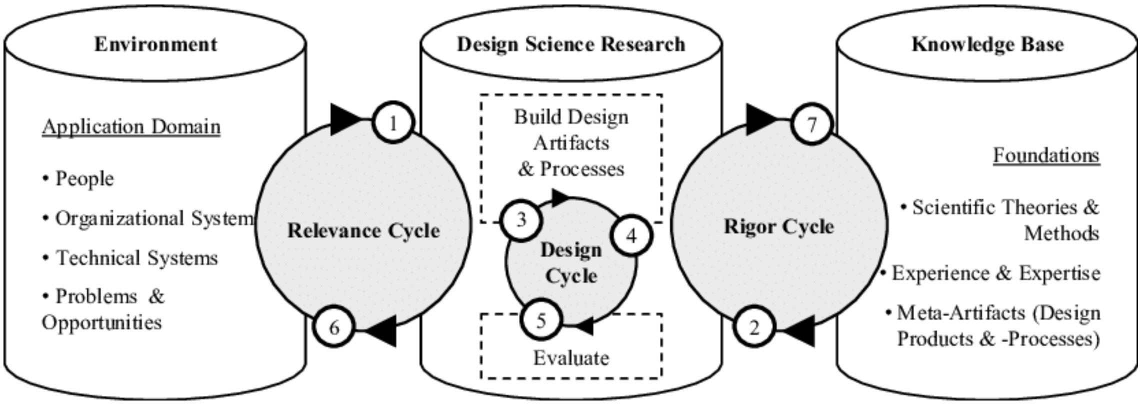


Figure 3.1: Design Science Research Cycles [60]

Chapter 4

Parker's Commute - A game for behavioural change

The Game Design Document describes how the game is built and is a common tool in the video game industry to organize the game's direction of development. In this chapter, the template is adapted to provide an overview of the game that was developed.

4.1 Background

Parker's Commute is a browser game developed with the intent of encouraging the use of EVs, by spreading knowledge that aims to dispel common misconceptions about their functioning, capabilities, and limitations.

This game was developed independently and from scratch, in the context of this thesis.

4.2 Project Description

The proposed idea was to design and implement a simple game where the player must plan their routine, using an EV for their commute, with each level being a separate day. The player's goal is to fully exhaust the available battery on their EV, which helps them better understand how different factors affect the battery expenditure for a given situation.

4.3 Game Overview

4.3.1 Concept

Parker's Commute is a simple simulation browser game where the player experiments with routes, using real locations through integration with Google Maps, to try to spend the most battery possible in their EV.

According to the website *Auto Express*, "The electric motor is often credited to Hungarian engineer Anyos Jedlik, while French physicist Gaston Plane invented commercial, rechargeable lead-acid batteries in 1859. It took an Englishman - **Thomas Parker** - to combine the two in a carriage to create the first production electric car, built in London in 1884." [4] According to this story, Thomas Parker used the car for his daily commute, something that surely wasn't efficient, performance-wise. This connects well to the core game concept, as will be explained ahead, and therefore the name "Parker's Commute" was born.

4.3.2 Genre

The gameplay of *Parker's Commute* is based on solving puzzles using real-life data which is different for each player, making this a simulation puzzle game. At the same time, given the context under which the game is developed, and the goal that it is intended to fulfill, it is also a serious game.

4.3.3 Target Audience

The main intended audience of *Parker's Commute* is made up of any adult that has, or will have soon, the capability of purchasing a car. This is because the goal of the game is to determine whether we can change the opinions of people who are in a position to decide between different types of vehicles, by having them be exposed to potentially new information through playing the game.

4.4 Gameplay

The game is made up of four levels, with increasing complexity. They require the player to form a route that satisfies the requirements of battery expenditure, through a combination of route distance, weather conditions, and other power-ups. The player is left to explore different options at their will, receiving visual feedback on the approaches that they try. This is the reason why the game connects so well to the story of Thomas Parker - the user must purposefully take an inefficient route to go along their daily routine, to exhaust the EV's battery.

After forming a route, the player clicks the "GO" button, which triggers the game's backend to access the Google Maps API and verify the length of the route that was attempted. This, in combination with the weather conditions, is used to calculate the percentage of the car's autonomy that was spent. The route progress is then shown, one location at a time, as a progress bar is animated to show the progressive draining of the battery.

On failure to beat the level, the player will see a message indicating this.

On success, the player is given an estimation of some relevant data regarding their data. This data includes the distance traveled, which is given by the API, and an estimation of the saved CO2 emissions [1] and the amount of saved gas [3], as well as the price of this amount of fuel [2], which is calculated from the current rate for gasoline in Portugal, at the time of visit. These estimations compare the performance of the EV to an average combustion vehicle and are based on the average data for combustion vehicles relative to the year 2020, which is the latest available information for yearly averages on these subjects.

Apart from this, the player also receives the choice to either progress further, or to keep experimenting with different routes.

4.4.1 Player Controls

The game interface is designed to be as accessible and simple as possible. As such, the game can be played to its full extent by simply using a mouse, or touch controls if applicable. All of the actions that the player can take, which include navigating menus, selecting and adding locations to the route, and activating/deactivating power-ups, are executed by clicking the game's buttons with the left button of the mouse, or by touching the button on a touchscreen device. The only exception to this rule is the action of removing a location from the route, which is done by clicking it with the right mouse button. Since there is no right-click on touchscreen devices, in this case, this action is also performed by tapping the respective button on the screen.

4.4.2 Interface

4.4.2.1 Main Menu

The game starts, naturally, with the main menu. The main menu (Fig. 4.1) is very simple, containing only the title, and the buttons to play the game or to read the credits. The credits screen (Fig. 4.2) contains only the information of the people responsible for this project, and a cross button to exit.

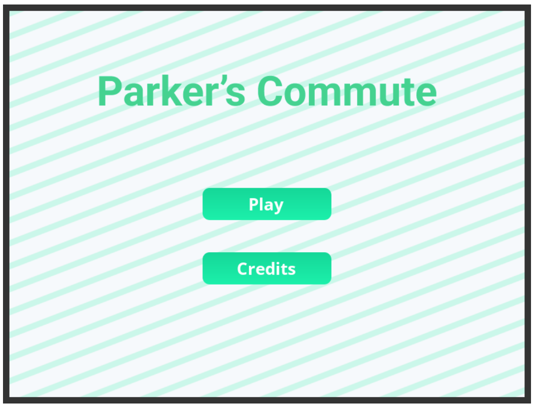


Figure 4.1: Main Menu

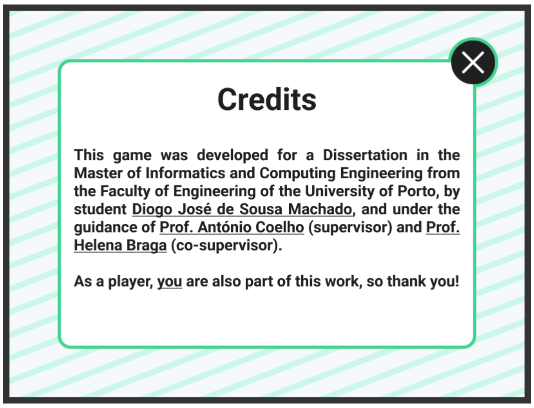


Figure 4.2: Credits Screen

When clicking the play button, the player can receive one of two responses. If the backend was unsuccessful in searching the locations provided by the player, the screen will show a message indicating that the user must change the data for the game to work (Fig. 4.3). Otherwise, the player will see a message indicating that the game is about to begin (Fig. 4.4).

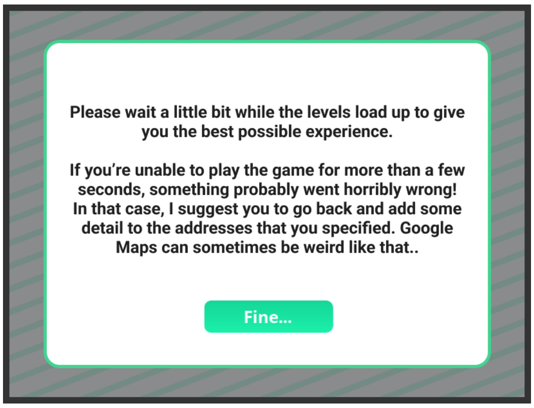


Figure 4.3: Error Message at Start of Game

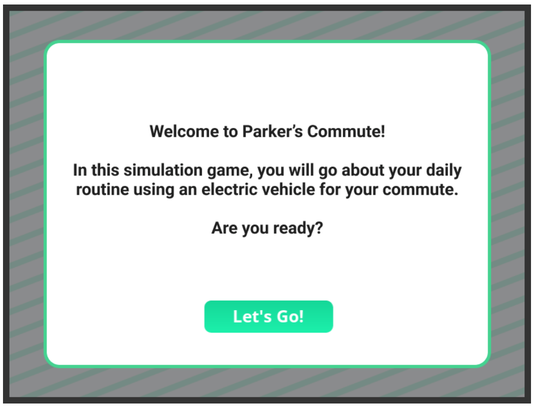


Figure 4.4: Start of Game Indicator

4.4.2.2 Tutorial Modals

Entering the first level, the player is first greeted with a basic tutorial for the game (Fig. 4.5). This tutorial tells the player what their goal is in each level, explains the rules of the game, and teaches the player how to play, showing the controls, as well as the visual feedback that is to be expected in normal gameplay.

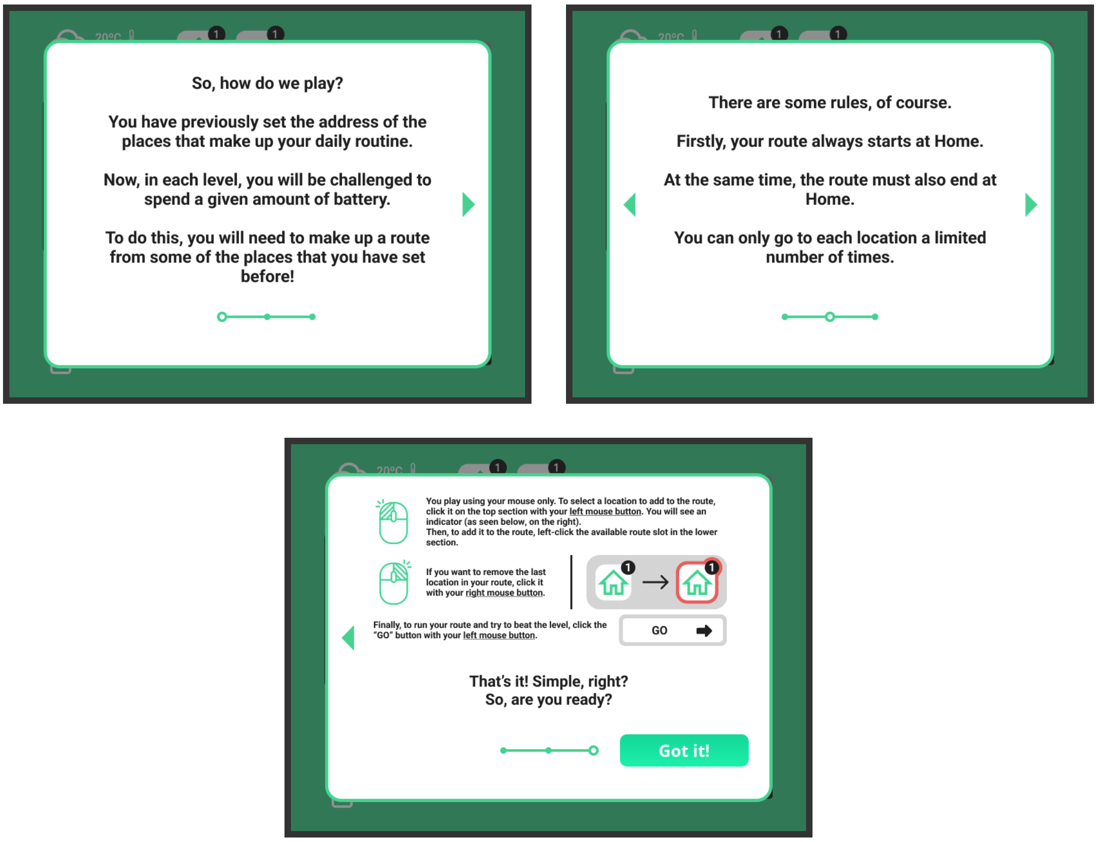


Figure 4.5: First Tutorial before Game

4.4.2.3 Level layout

After exiting the tutorial, the player is greeted with the game interface (Fig. 4.6). Starting on the top left, we can see the weather conditions associated with the level. These conditions are a factor in the gameplay, as will be explained later. Then, in the top center area, we have the locations that will be used in the level, as well as the number of uses available for each of them. On the top right, we can see the "GO" button, which is greyed out, as the player has not built a valid route at this point.

On the left, we have the power-ups bar, which will be explained later, and the center is occupied by the Google Maps window showing the player's route. This window will update as the player performs actions, and will always reflect the player's current route. It can be interacted with so that the player can analyze the route and make correct decisions.

Below, we have the route bar, which at this point contains only the starting location (the player's home). The white square is the available slot where the player can add a location.

Finally, at the bottom, we have the battery percentage that has to be drained in this level, as well as the illustrative battery bar, which is animated when the player tries to beat the level.

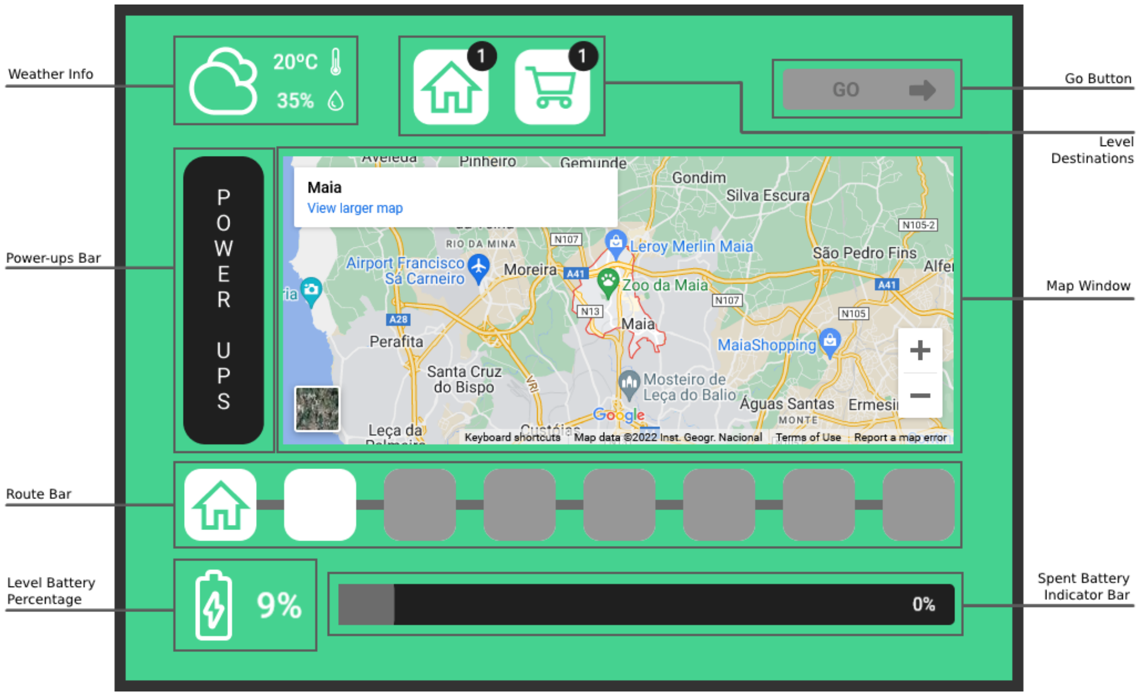


Figure 4.6: Game Interface in the First Level

When a player clicks a location, a red visual indicator will convey that it is selected. As more locations are added to the route, the grey squares will turn white as they become available (and grey again, if the player removes locations to change the route). Both of these changes can be observed below (Fig. 4.7).

Finally, when the route is valid (i.e.: when it leaves the starting location and then returns), the "GO" button is no longer greyed out, and it can be clicked to try to complete the level (Fig. 4.8).

Figure 4.7: Visual Indicators in the Level

Figure 4.8: Soon-to-be-completed Level

4.4.2.4 Post-Level Screens

Upon clearing the level, the player receives information relative to the route that was created (Fig. 4.9). Apart from the distance of the route, provided by Google Maps with a high degree of accuracy, the player can also see estimates of the saved CO2 emissions, the saved amount of fuel, and the saved cost of such fuel. At this point, the player can either go back, to experiment with different routes, or advance to the next level.

On the other hand, if the player fails the level, a different screen appears, prompting them to try again (Fig. 4.10)

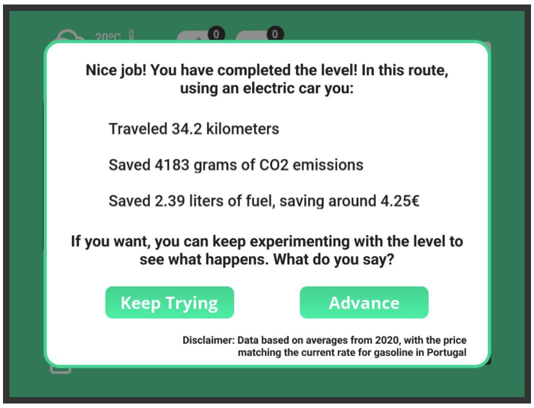


Figure 4.9: Post-Level Information Screen

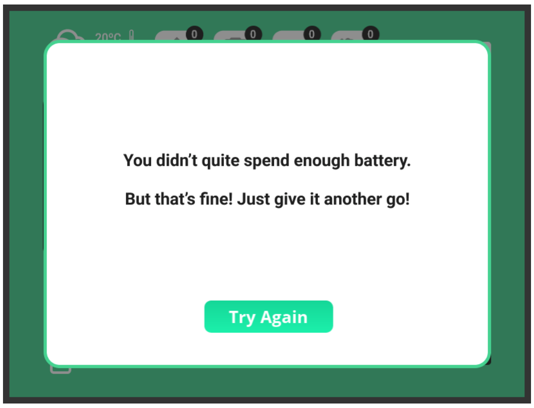


Figure 4.10: Level Failed Screen

4.4.2.5 Power-ups

After a second tutorial, the player is now introduced to the new feature of power-ups. These appear on the bar to the left, and they can cause different effects. Below, we can see an example, as the starting conditions present cloudy weather (Fig. 4.11), and, after activating the power-up, the weather is now sunny (Fig. 4.12). On other levels, we can have different weather conditions, such as snow (Fig. 4.13).

Figure 4.11: Level at start conditions

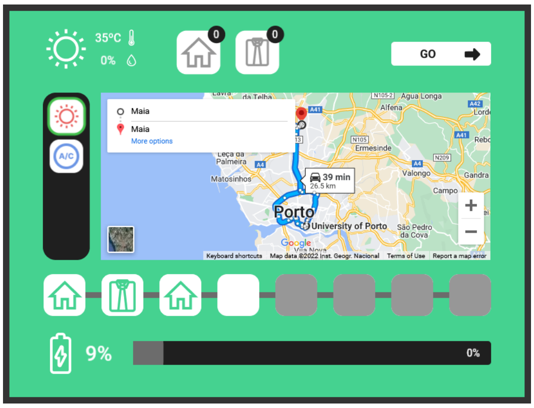


Figure 4.12: Level after activating power-up

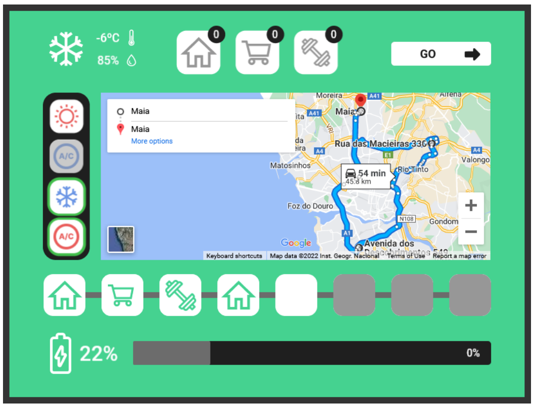


Figure 4.13: Level with snowy weather from power-up

One final power-up worth mentioning is the one that cuts the required battery expenditure for the level in half, as it has a very visual impact (Fig. 4.14).

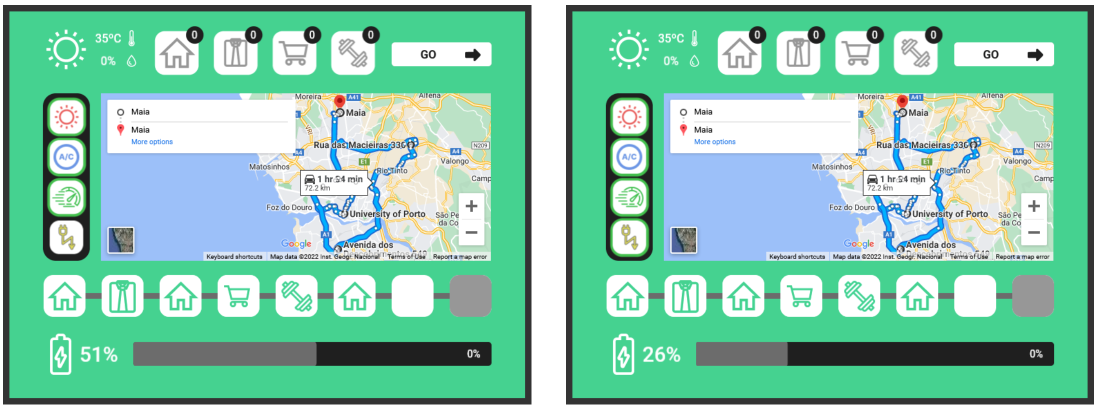


Figure 4.14: Effects of the Power-Down power-up

4.4.2.6 Post-Game Screen

Finally, after the game is completed, a summary of the game similar to the post-level reports is shown (Fig. 4.15).

Figure 4.15: Post-Game Screen

4.5 Levels

The levels are designed to progressively introduce game mechanics and complexity. While the task to be fulfilled doesn't change, the game begins by introducing the mechanics at an elementary level, before expanding into situations with several options.

4.5.1 Level 1: Introduction

After a short tutorial, the first level introduces the basic gameplay of the game. The player is tasked with making a route to go from home to the supermarket, and then back home. This shows the mechanic of adding and removing locations from a route, as well as the gameplay aspect of seeing the route on the Google Maps frame update with the player's action.

4.5.2 Level 2: Power-ups

The second level is where we first introduce the idea of power-ups. The player is tasked with making a route to go from home to work, and then back home. This by itself is not enough to beat the level, as the use of a power-up is required. An inquisitive player might experiment with seeing the difference between trying to beat the level with and without the power-ups. At the same time, this level begins to show other factors that affect the vehicle's battery expenditure, as the power-ups are related to weather and the vehicle's air-conditioning unit.

4.5.3 Level 3: Multiple Routes

In the third level, we introduce the notion of various possible routes. The player is tasked with making the route pass through the supermarket and the gym, with the correct order being calculated through the Google Maps API. In addition, more power-up options are available, with the options to activate extremely hot or cold weather, as well as the respective A/C mode. This serves the purpose of showing the difference in impact between these two situations, with and/or without the A/C on.

4.5.4 Level 4: Even More Multiple Routes

Finally, in the fourth level, we increase the level of complexity of the route, having now three places to include in the route, as well as the possibility to return home in the middle of the route. This makes the number of different route possibilities larger, which almost inevitably will lead to the player trying several permutations, and in the process seeing how the differences between those alternatives change the result in the vehicle.

4.6 Tools and Resources

4.6.1 Visual Assets and Style

The visual elements of the game are important in setting the mood to improve the player's experience. The first major decision was the primary color of the game. A decision was made to use a color resulting from the mix between Green and Cyan, alluding to both the matter of ecology, which is the main motivation behind this project, and the feeling of peacefulness, which is key in any environment which aims to encourage learning.

Furthermore, a minimalistic style was adopted in the design of the game's assets, since, firstly, the visual development of the prototype was not one of the key objectives, and so it would be an inefficient use of time to develop more elaborate designs, and, secondly, the use of simple assets is beneficial towards visual clarity and intuitiveness.

4.6.2 Game Engine

The game was developed using a JavaScript framework called Phaser [1]. This framework is responsible for the entirety of the management of graphical assets and scenes, which made the development of the game much easier. In addition, since it is meant for the development of simple browser games, Phaser also helped to handle not only the website integration but also the processing of user inputs.

4.7 Summary

In this chapter, we used the structure of the GDD to describe multiple facets of the game, first giving a general idea of the concept, and then going into deeper detail regarding the various aspects of gameplay. The game that was developed was designed around a few core ideas that help us achieve our goals, such as accessibility, simplicity, and the encouragement of exploration. As such, we created a browser game that can be played with a mouse/trackpad or through simple touchscreen commands. The game is integrated with Google Maps, to allow for an experience that is truly tailored to each player.

In this game, the player organizes their routine in a way that maximizes battery expenditure, as a way to explain that it is difficult to run out of battery on an EV through normal usage. At the end of every level, the player receives information regarding the route that they took, and how EVs compare to combustion vehicles in that specific scenario, further accomplishing our goal of establishing EVs as a good alternative. Finally, at the end of the game, the player receives this same information as an aggregate of the entire game, which reinforces the same idea on a slightly larger scale, further driving the point home.

[1] Phaser HTML5 game framework: https://phaser.io/

Chapter 5

Implementation and Logic

After the higher-level analysis of the game in the previous chapter, we will now go into further detail regarding the implementation of the game. This chapter will go over the game's code structure, as well as the modules that were implemented, and the relations between them.

5.1 Code and Directory Structure

Right from the start, there are two separate elements in the implementation of this game: the `code` module, which contains the client-side (i.e.: browser) application code for the game, and the `server` module, which implements the server-side functionality. We will start by focusing on the former, and explain the latter later on.

5.2 `game` directory

At the root of the directory, we have the HTML and CSS files for the pages of the website in which the game is made available, as well as the `node.js` configuration files for the modules that were used to implement the game. Apart from this, the project repository contains two Git submodules related to the Phaser framework in this directory. One of them contains the framework's documentation, which is useful not only as a reference but also from a development standpoint, as it allows the code editor to include the framework's classes in the syntax highlighting and code auto-completion. The other contains the framework's distribution files, which are used by Parcel to more efficiently build the application, rather than needing to import the library from the web.

Finally, we have the `src` directory, which is where the code for the game is contained. Within this directory, we have the following elements:

- the `assets` directory, containing all of the graphical assets used in the game;
- the `modules` directory, containing the code used to implement the game logic and configuration;

- the `scenes` directory, containing the code used to implement the different interfaces of the game, as well as some of the logic regarding navigation between them;
- the `game-setup` script, which is responsible for the customization of the experience for each player;
- the `main` script, which is used to initialize the game from the web page.

5.2.1 Modules

- `config` **module**

  Within the `modules` directory, the first module is the `config` module. This module globally sets variables such as the keys for the APIs that are used (in this case, Google Maps and our backend API), the location of the directory containing the assets to be loaded, and the locations which were previously specified by the user, making them available for the application.

- `CST` **module**

  Next, we have the `CST` module (short for "constants"). This module specifies macros for all fixed values that are accessed throughout the rest of the code, to completely remove the existence of magic numbers in the code, as well as to make any interface changes trivial.

- `Level` **module**

  Next, we have the largest module of all, which is the `Level` module. The level module encapsulates all of the logic for code related to the gameplay, from setting up the interface for each level based on its configuration, to processing user input, as well as calculating the distance of the player's routes and animating the level completion check. Finally, it also handles the requests made to the backend.

- `LevelConfig` **module**

  Then, we have a configuration only-module, which is the `LevelConfig` module. It contains the initial configuration for each of the levels in the game, such as the locations and their number of uses, or the desired configuration to beat the level, or even scripts to be run at the start of the level (usually showing a tutorial, with the help of the `Level` module).

- `Powerups` **module**

  Next, we have another configuration module, the `Powerups` module. This one, in turn, contains the configuration for the power-ups used in the game, from the visual aspects, such as changing the weather conditions or the size of the battery bar, to the relations between the power-ups, be it that they require a previous power-up to be usable, or that they are incompatible with another different power-up. In total, there are six of them:

- the *Cold* power-up, which reflects the effects of cold weather on the vehicle's autonomy, and is incompatible with the *Hot* power-up;
- the *Heating* power-up, which reflects the effects of turning on the A/C to combat cold weather on the vehicle's autonomy, and requires the *Cold* power-up;
- the *Hot* power-up, which, like the *Cold* power-up, reflects the effects of this type of weather on the vehicle's autonomy, being incompatible with it as well;
- the *Cooling* power-up, which is analogous to the "Heating" power-up, but relates to the "Hot" power-up instead;
- the *Double-Time* power-up, which aims to reflect the impact of hasty or careless driving on the vehicle's autonomy;
- finally, the *Power-Down* power-up, which simulates a malfunctioning of the battery, serving the purpose of showcasing how a reasonable amount of battery is almost always more than enough to last for the route of a rather complex day.

- `Utils` **module**

  Finally, we have the `Utils` module, which contains general utility functions to be used in other modules, such as common array operations which are non-trivial (hard-copying or removing items by value), rounding to different numbers of decimal places, or repositioning certain elements when the browser window is resized.

5.2.2 Scenes

- **Load Scene**

  This scene is responsible for loading and mapping all of the graphical assets used in the game. After this, it accesses the `LevelConfig` module to process the API calls required to calculate the requirements for each level. It does not have a visual appearance, only briefly existing before the main menu of the game is shown.

- **API Call Scene**

  This scene is used whenever an API call must be made. It can be called in two contexts: at the start of the game, to calculate the requirements for each level, and whenever the player tries to complete a level with the route they've built. In both cases, the scene receives the URL, makes the request to the API, and then calls the `Level` module to process the response. On the latter, however, the scene also takes the appearance of a dark, translucent overlay over the game screen, to not only indicate that processing is taking place but also to block user inputs while the calculations are occurring. If no response is obtained, the overlay times out and disappears after a short amount of time.

- **Menu Scene**

  This scene contains two buttons that can be clicked by the user: the Play button, and the Credits button. When the Credits button is played, the credits for the game are shown on top of the menu screen. When the Play button is played, first the scene checks whether all of the calculations for the solutions of the levels have been completed. If there's even a single level for which the requirements haven't been calculated, a prompt will appear indicating this. Otherwise, the scene will show a small prompt before advancing to the level.

- **Credits Scene**

  This scene is incredibly simple, containing only some text in the form of an image, and a button that can be clicked to close the credits.

- **Modal Scene**

  In user interface design for computer applications, a modal window is a graphical element that is subordinate to an application's main window. In the context of this project, we give this name to smaller scenes that appear over the main game screen to provide information. The main use case for this scene is for tutorials at the beginning of levels. It can receive one or more images, which will be treated as the pages for the modal screen. In the case of multiple pages, the player can navigate back and forth before closing the modal.

- **Modal End of Level Scene**

  This scene works much like the regular modal, with the variation of receiving data. It is called when a level is completed and shows the stats for the level, such as the distance of the route, the saved CO2 emissions and the saved fuel, and its respective cost. At the bottom of this scene, there are two clickable buttons, to either go back to the level and explore, or progress to the next level.

- **Modal Game Over Scene**

  This scene, like the previous one, receives data related to the gameplay. This time, it shows the accumulated values of the same data, over the entire game, to give a slightly bigger picture of how quickly these add up through the daily use of EVs. It then sends the player back to the main menu.

- **Level Scene**

  Finally, this scene is the most complex, containing a series of elements that work together to create the gameplay experience. Receiving the level configuration in the beginning, the scene displays everything, from the available location and power-ups to the level of available battery and weather conditions. At the center, it shows the main element of the game concept, which is the Google Maps window reflecting the route built by the player. The scene reshapes the data from the level configuration and passes it on to the `Level` module, which handles the creation of the interface. If the level configuration contains any script to be run before the level is played, this scene will be responsible for running it.

5.3 `server` directory

The code for the server is very short, with the directory having only a single level. Apart from the `node.js` configuration files, as well as the `Procfile`, which is the configuration file required to deploy the API on Heroku, the code for our API is contained in a single file, `index.js`.

Within this file, the environment variables are defined, and then the server is created using the `node.js` HTTP module. The point of this API is to act as a proxy to allow us to access the Google Maps Directions API, which blocks client-side requests and therefore has to be accessed in this way. The API receives the request, which takes the same parameters as the Google Maps Directions API, and forwards the request to that API. It then receives the response and passes it back on to the client-side application.

5.3.1 Deployment Tools

The project was built using a tool called Parcel [1], which is a build tool for web applications that made it very easy and convenient to develop the game and deploy the website on which the game is hosted. This tool runs on top of `node.js`, which is the base of our project.

The website was hosted using GitHub Pages [2], and the API that handles interaction with the Google Maps API was hosted on Heroku [3].

5.4 Summary

In this chapter, we elaborated on the structure of the project code directory, explaining in detail the organization of both the `game` and `server` directories, which contain the client-side and server-side code, respectively.

The `game` directory contains the code for the game, as well as the code for the website built for hosting it, and all the configuration files needed to manage dependencies and run the game. The game's code files are mainly divided in two categories: *modules*, which are small libraries of functions used across the project, as well as the logic of the game, and *scenes*, which define the different game interfaces that the player interacts with. This application was built using Parcel and deployed using GitHub Pages.

The `server` directory contains the code for the server that was developed to make the integration with Google Maps possible, as well as the configuration files necessary to run it. The server was deployed using the Heroku service.

[1] Parcel build tool: https://parceljs.org/
[2] GitHub Pages website hosting service: https://pages.github.com/
[3] Heroku API hosting service: https://www.heroku.com/

Chapter 6

Evaluation

The purpose of this dissertation is to create a game that promotes a positive opinion in the users. As such, two evaluation phases were planned.

The first phase consists of a questionnaire meant to assess not only the players' opinion on EVs but also their knowledge about them. After this phase, the player then plays the game, which is meant to change exactly these factors. Finally, after playing the game, the player answers some of the questions from the first questionnaire for a second time, with the goal of identifying if there is a trend in the evolution of the player base's opinion after playing the game. The surveys are available in both Portuguese and English and were carefully written with clear, although sometimes verbose, language, to ensure that the wide intended player base had no trouble understanding what was asked. Copies of the survey are present in Appendix 1 and Appendix 2.

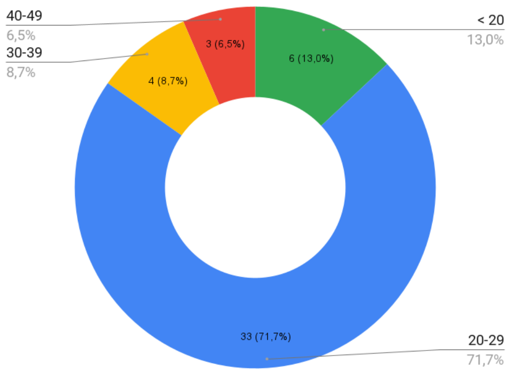
6.1 Preliminary Questionnaire

Behavioral change is a gradual process that occurs over time, and because of that, it would be impossible to thoroughly evaluate the impact of the developed game in the scope of this thesis. However, we attempted to assess the players' literacy and opinions before and after playing the game to the best degree possible. The first questionnaire gathered information on several points:

- the players' commuting habits;
- the players' opinion regarding their knowledge of EVs (i.e.: how much they think they know about the current capabilities and limitations of EVs);
- the players' opinion regarding the current viability of EVs as a mobility solution;
- the players' knowledge of the factors that impact the autonomy and functioning of EVs.

The survey was created using the Google Forms platform, and embedded on the website that was built to host the game. Google Forms is an all-purpose questionnaire builder which provides comprehensive response data, which was extremely helpful in analyzing the responses.

The survey received 170 responses, most of which were discarded due to the users not completing the activity (which involved playing the game and then responding to the second questionnaire). In total, 46 replies were maintained and analyzed. The questionnaire is present in Appendix 1.



Age Range	Participants
< 20	6 (13.0%)
20-29	33 (71.7%)
30-39	4 (8.7%)
40-49	3 (6.5%)
> 49	0 (0.0%)

Figure 6.1: Age Range of the Participants

The survey starts by inquiring about the age of the player, with the results present in Fig. 6.1. The large majority of the players (71.7%) were university students between the ages of 20 and 29 years old.

The next part of the questionnaire seeks to understand the habits of the player, as well as how interested they are in the topic of EVs. The questions are the following:

- **Q2:** "Do you believe yourself to have a solid and updated knowledge of what are the capabilities and limitations of electric cars? - Linear scale, with 1 standing for "I don't know anything about the subject", and 5 standing for "I stay updated on the most recent developments" (Fig. 6.2);
- **Q3:** "What means do you use for your daily commute?" - Multiple choice, multiple answers (Fig. 6.3);
- **Q4:** "How frequently do you travel by car?" - Multiple choice, single answer (Fig. 6.4);
- **Q5:** "How viable do you consider electric cars to be, as an everyday mobility solution? - Linear scale, with 1 standing for "Not viable at all", and 5 standing for "Perfectly viable" (Fig. 6.5);

Just from the replies to these introductory questions, we can take some conclusions already. Firstly, the population considers itself to be rather average in terms of knowledge about EVs, which favors our purpose of evaluating the game's ability to change the opinion of the average

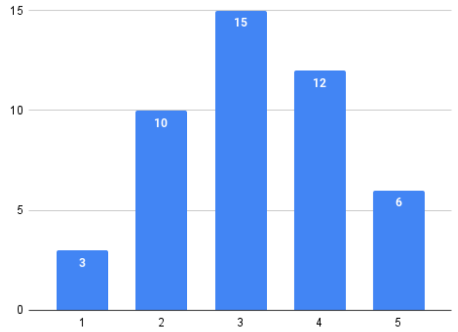


Figure 6.2: Self-assessment of the participants regarding knowledge of EVs

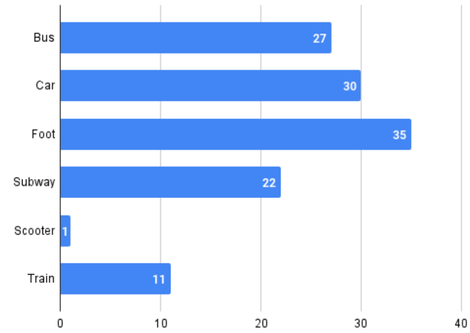


Figure 6.3: Means of transportation used by the participants in their daily life

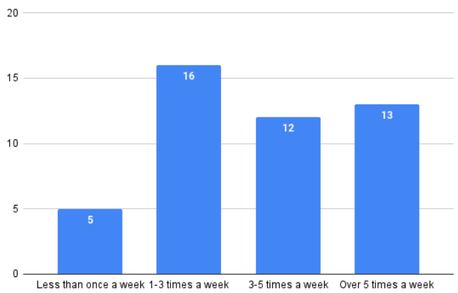


Figure 6.4: Frequency at which participants travel by car

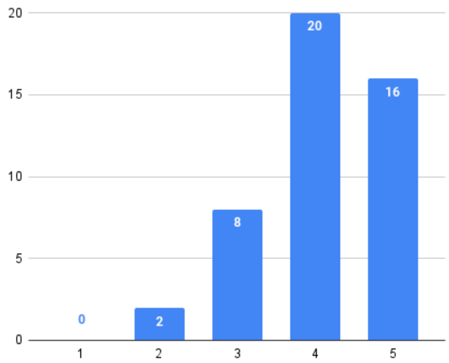


Figure 6.5: Opinion of the participants regarding the viability of EVs

person. Secondly, we understand that the majority of the population travels by car in their daily life, with about half of the population (25 out of the 46 participants) traveling by car 3 or more times a week. Finally, we can see that the population as a whole considers EVs as a fairly viable alternative, with 36 out of the 46 participants giving a positive response.

The following part tries to take a profile of the opinions of the participants, by asking questions about different factors that affect the decision to purchase (or not) an electric car. The questions are the following:

- **Q6:** "Would you purchase an electric car?" - Multiple choice, single answer (Fig. 6.6);
- **Q7:** "What is your opinion regarding the autonomy of electric cars?" - Multiple choice, single answer (Fig. 6.7);
- **Q8:** "What is your opinion regarding the purchasing cost of electric cars?" - Multiple choice, single answer (Fig. 6.8);
- **Q9:** "What is your opinion regarding the cost per kilometer of electric cars?" - Multiple choice, single answer (Fig. 6.9);

- **Q10:** ”What is your opinion regarding the environmental impact of electric cars?” - Multiple choice, single answer (Fig. 6.10).

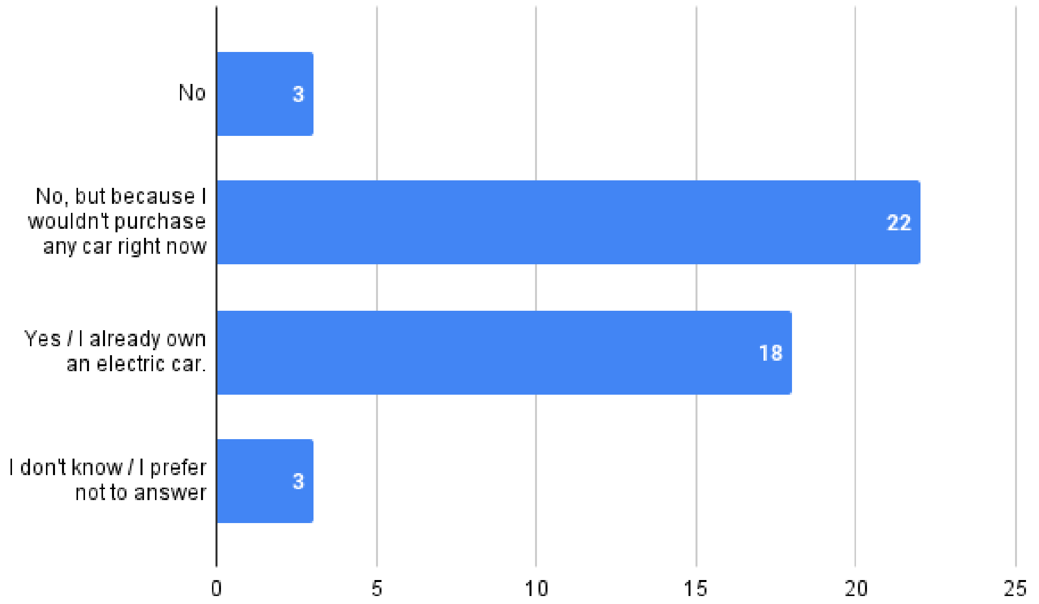


Figure 6.6: Participants’ opinion on whether they would consider purchasing an EV

We can see right away that, from the participants that are in a position where the purchase of a car is within their reach, a great majority of them would consider choosing an EV. Let’s now read into the remaining questions to understand what factors play into this collective position.

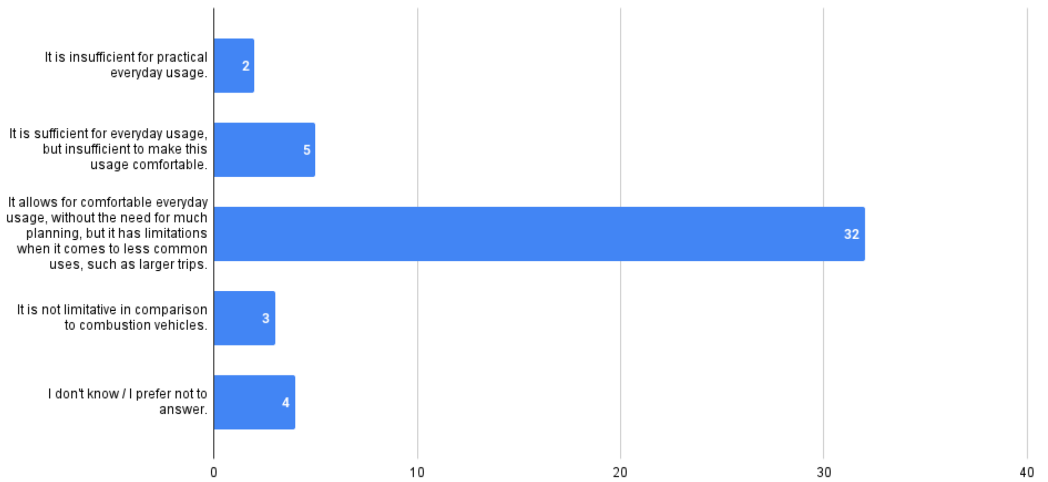


Figure 6.7: Opinion of the participants regarding the autonomy of EVs

At this point in the activity, there is a strong consensus when it comes to the matter of the autonomy of EVs. A strong majority (32 out of 46) believe that, while the EV’s autonomy is sufficient for carefree day-to-day usage, it is a limiting factor when it comes to longer trips. There is also a small, but not insignificant, minority (7 out of 46) that believes that the EV's autonomy is not enough for comfortable daily use.

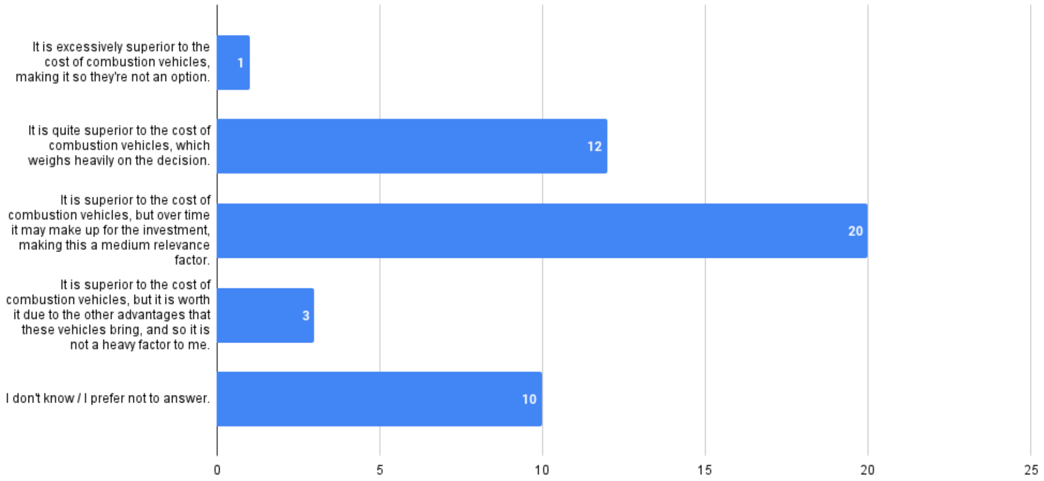


Figure 6.8: Opinion of the participants regarding the acquisition cost of EVs

In question 8 it is hard to reach any conclusions, since, apart from the fact that many participants chose not to reply, there is a big concentration on the more moderate/uncertain responses. Hence, the only conclusion we can arrive at is that the participants, in general, do not have very strong beliefs in this regard.

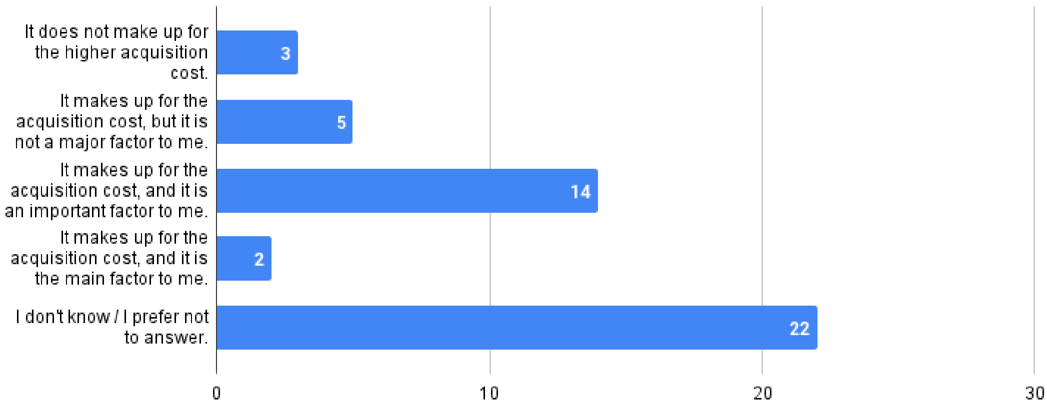


Figure 6.9: Opinion of the participants regarding the cost per kilometer of EVs

In question 9, the majority declined to answer, meaning that this is a point where the game has the potential to have a very strong impact, as the teaching process is always easier when there are no pre-existing misconceptions.

Question 10 is accompanied by a disclaimer explaining what exactly is meant by "environmental impact". One of the common arguments regarding EVs has to do with the balance between the pollution that is generated during their production, and the emissions that are saved through

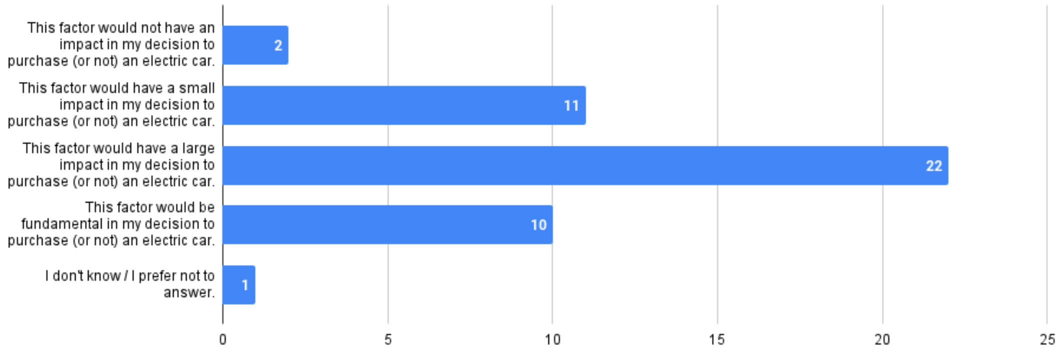


Figure 6.10: Opinion of the participants regarding the environmental impact of EVs

their usage, in opposition to a combustion vehicle. In this question, we can identify that the environmental aspect is very closely connected to EVs. As expected, for a majority of the participants, that would be an important factor in this decision.

Finally, the last section of the questionnaire concerns itself with the factors that affect the autonomy of EVs. The section is made up of a single question multiple choice grid of questions (Fig. 6.11), where the participant chooses what they think is the level of impact for three distinct categories of factors: Temperature and Weather, Driving Style, and Comfort Features (A/C, Infotainment, etc). The player can attribute the values of “Very Low”, “Low”, “Medium”, “High” and “Very High”, with an “I have no idea” option also available in the case that they don’t have any preconceived notions regarding the magnitude of those factors.

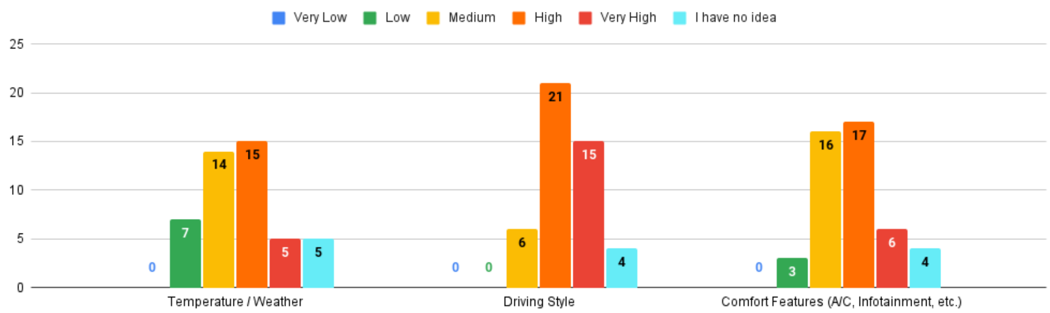


Figure 6.11: Participants’ knowledge regarding the factors that impact EV autonomy

At a first glance, we can immediately notice a wide spread of answers in the different factors, except for "Driving Style". The "High" answer is in the majority each time, which may show some reservations the users have regarding EVs. We can also see some joint awareness that the driving style is a very impactful factor in the autonomy of any car, with EVs being no exception, as a large majority believed that it would be a high impact factor.

6.2 Post-Game Questionnaire

Let us now proceed to the analysis of the second questionnaire, answered by the participants after playing the game (Appendix 2). This questionnaire starts by repeating questions 6-11 from the first questionnaire, which were answered a second time by the participants, so we could compare the responses. Afterward, the participants answered the questions present in the System Usability Scale (SUS) [19], which is the most widely used standardized questionnaire for the assessment of perceived usability [71].

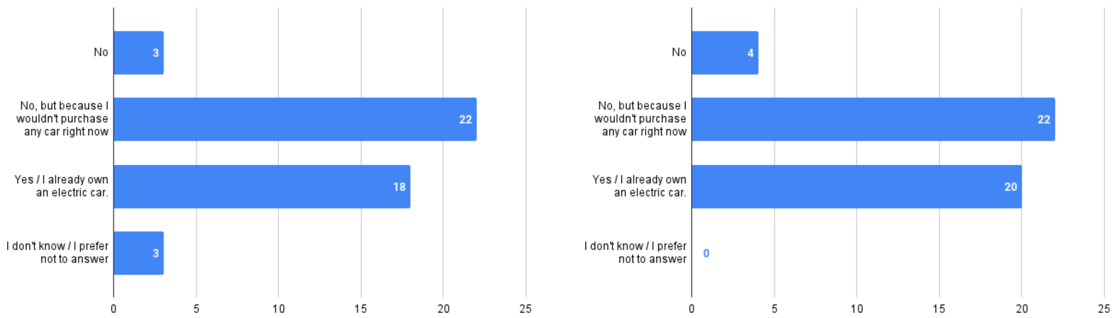


Figure 6.12: Participants' opinion on whether they would consider purchasing an EV (before and after playing the game)

Starting with question number 6 (Fig. 6.12), we can see that the undecided people were enlightened by the game experience. However, there wasn't much evolution at all in the response to this question. It can certainly be said that the age profile of the population is a factor in this, as the vast majority of the participants are at an age point where it wouldn't be common, in our society, to be capable of purchasing a car. However, to analyze if this is the whole story, or if the game just wasn't convincing in this regard, we must further analyze the rest of the questionnaire.

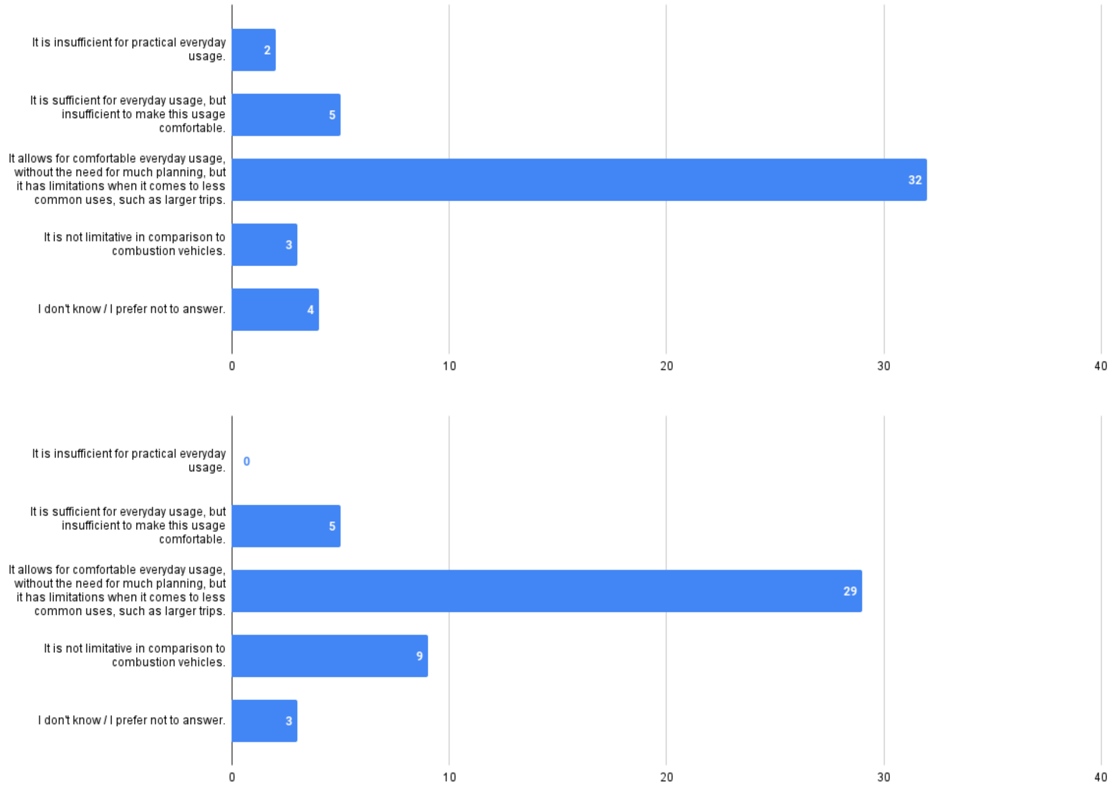


Figure 6.13: Opinion of the participants regarding the autonomy of EVs
(before and after playing the game)

In question number 7 (Fig. 6.13), regarding the autonomy of EVs, we now start to see some evolution in the responses of the players. Firstly, it is notorious that not a single person maintains the opinion that the EV's autonomy is insufficient for everyday use after playing the game. Next, we can also notice the increase (300%) in people that find the EV's autonomy a non-limiting factor. Finally, it must be noted that the vast majority maintains the belief that the EV's autonomy is great for regular use but limited in specific cases.

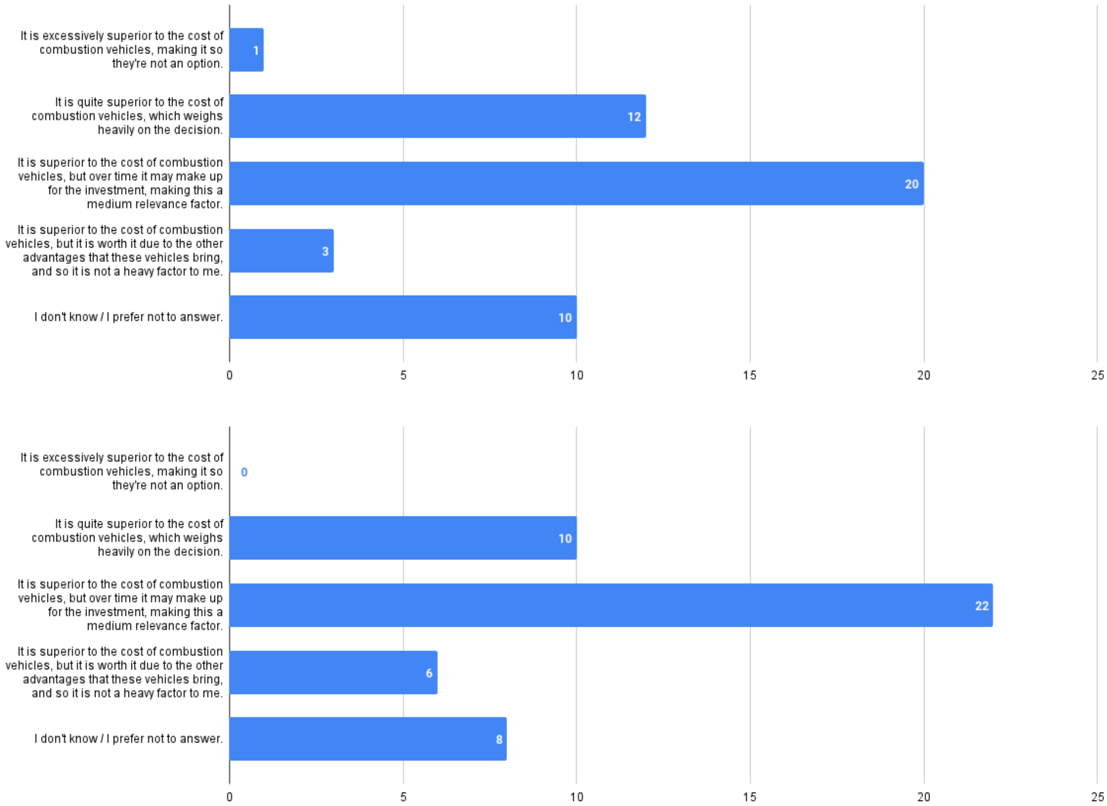


Figure 6.14: Opinion of the participants regarding the acquisition cost of EVs (before and after playing the game)

Advancing to question number 8 (Fig. 6.14), while the acquisition cost is not a factor that is addressed in the game, the fact that the cost of use is explicitly shown made the participants see the cost of acquisition from a new perspective, which is reflected in the answers. Both the answers that lean towards it being a negative factor, as well as the indecisive answer, lost votes, while the two answers that favor the EVs gained votes.

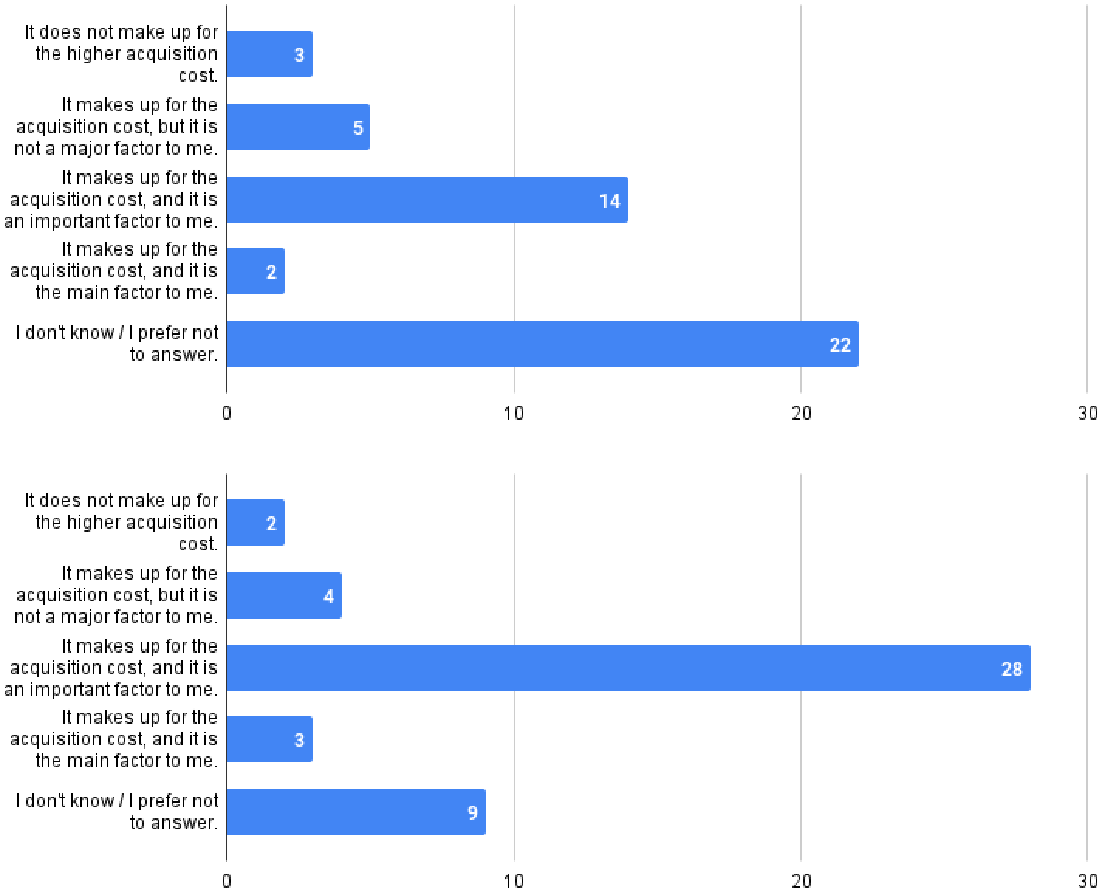


Figure 6.15: Opinion of the participants regarding the cost per kilometer of EVs (before and after playing the game)

In question number 9 (Fig. 6.15), we see a massive shift. While before playing the game the majority of the participants revealed not to be aware of this factor, after the game there was a massive majority (31 out of 46) indicating that this is an important factor. While this is still not the main factor for most of the participants, it is clear that it is a factor with much more relevance than our population would've believed at first.

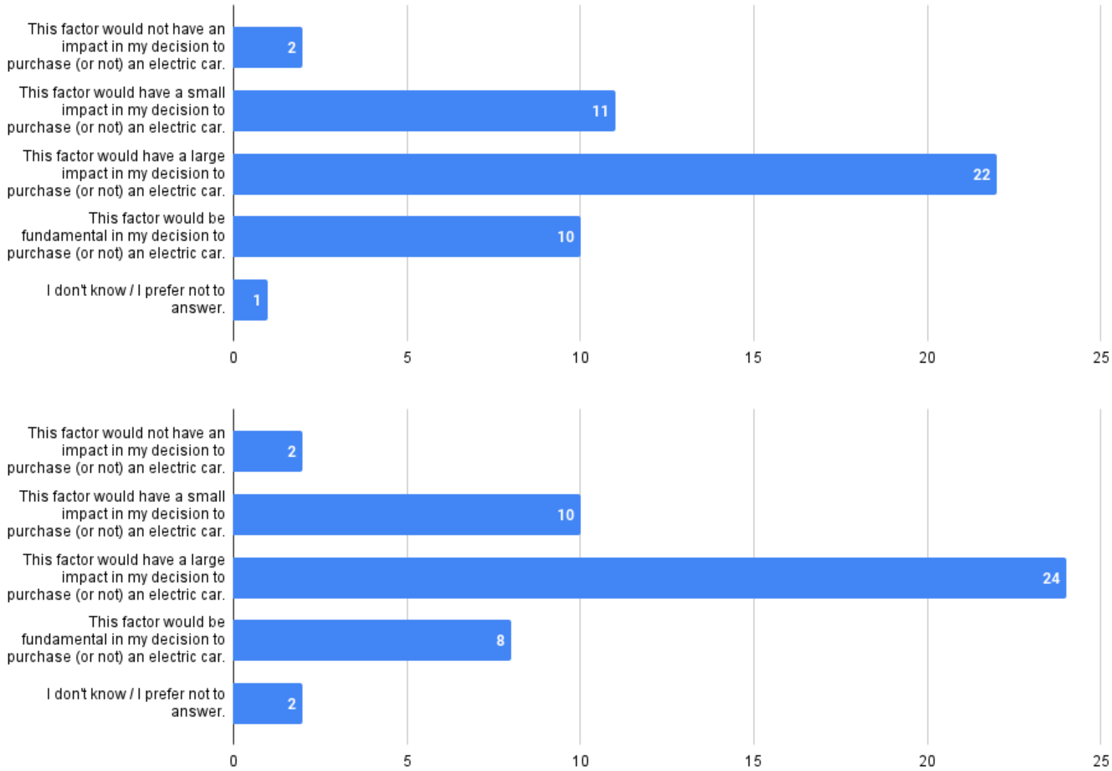


Figure 6.16: Opinion of the participants regarding the environmental impact of EVs (before and after playing the game)

In question number 10 (Fig. 6.16), which approaches the environmental impact of EVs, there is very little change, which would be expected since this is the main subject that is always associated with EVs, meaning that the opinions of the participants are more likely to have a more solid foundation. In addition, while the game addresses the amount of CO2 emissions that are saved by the use of EVs, since the pre-existing opinions were already mostly positive, that factor did not have such a big impact on this question.

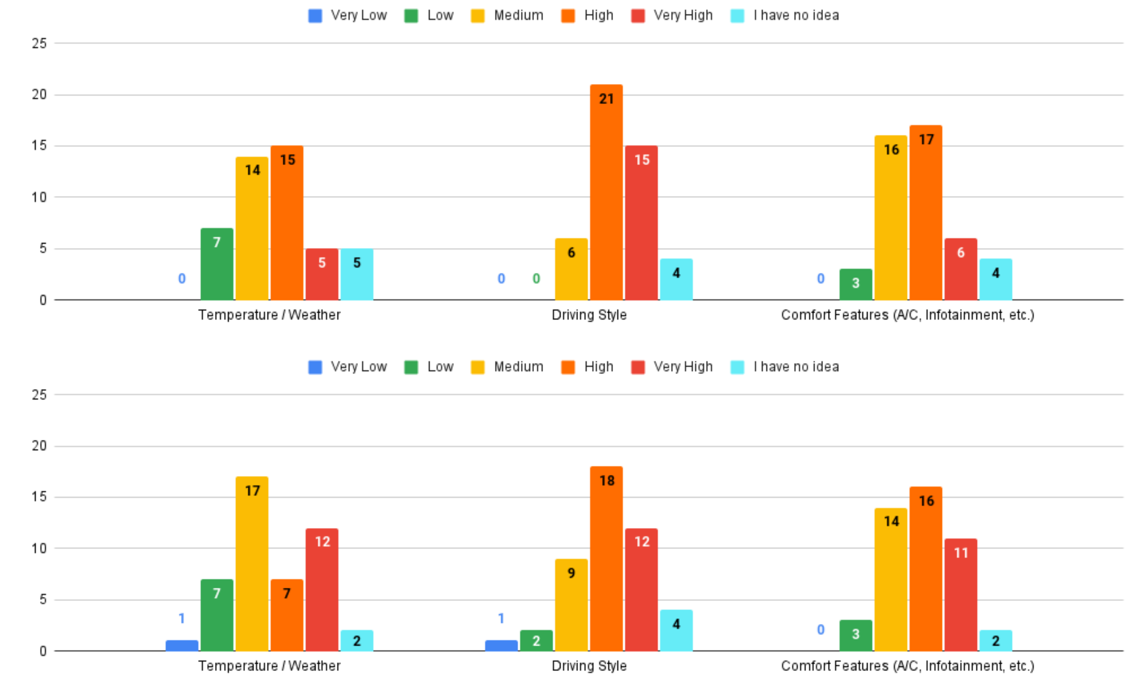


Figure 6.17: Participants' knowledge regarding the factors that impact EV autonomy (before and after playing the game)

Question 11 (Fig. 6.17) relates to the knowledge of how different factors affect the autonomy of EVs. Regarding the temperature and weather, the results were mixed, as the people who ranked that factor as "High" tended to change opinion, but not in a clear direction. In fact, both the "Medium" and "Very High" options gained votes, while the "High" option lost more than half its responses! Regarding the driving style, the fact that it is not a factor in the game caused an adverse effect, as the trend was for the opinions to go down, even though this is a major factor in the autonomy of any car, and not just EVs. Finally, regarding comfort features such as the air conditioning or infotainment units, the responses saw an increased amount of influence attributed to this factor.

In all, the results of this question are not particularly positive. This can be explained by the fact that a short game experience such as this one could not possibly achieve comprehensive coverage of exactly how all of these complex factors impact the autonomy of an EV, and so it is only natural for some, if not all, of the participants to assume that the concepts that were more present in the game had greater importance. Therefore, one of the points to improve in this project would be to find ways to connect the important factors that aren't so present to the game experience, or at the very least present them in some way.

6.2.1 System Usability Scale (SUS)

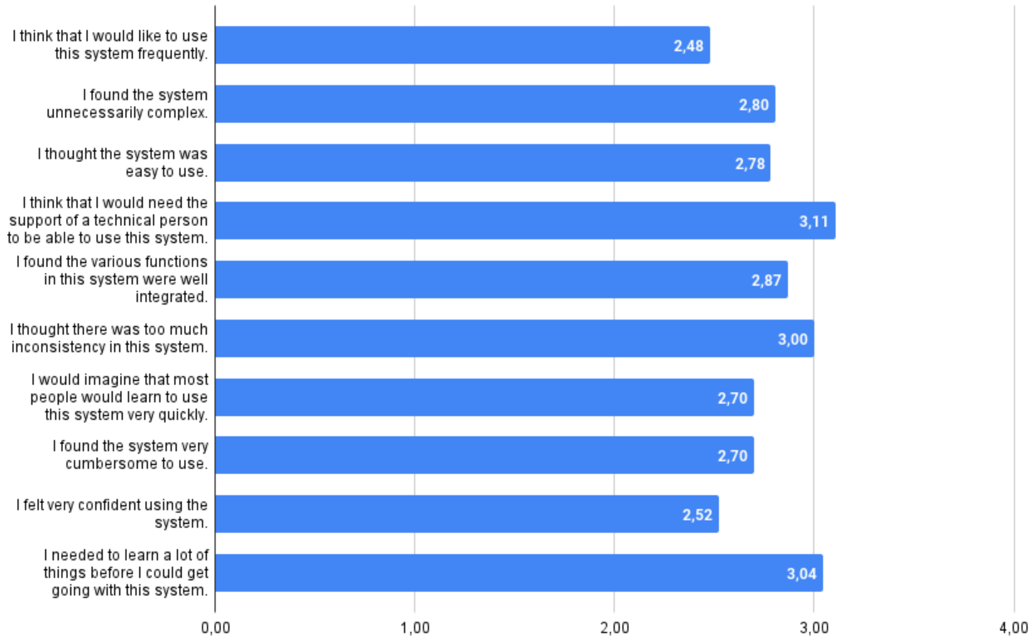


Figure 6.18: Average score for questions in the System Usability Scale

Finally, the SUS (Fig. 6.18) was filled out to finish the questionnaire. The method for calculating the score according to the SUS is the following: each question can be answered according to a five-point scale - where 1 means "Strongly Disagree" and 5 means "Strongly Agree". Then, for the odd-numbered questions, the score is obtained by subtracting 1 from the answer (effectively making this a scale of 0 to 4). For the even-numbered questions, the score is obtained by subtracting the answer from 5 (again, making this a scale of 0 to 4). Because there are 10 questions, this would make the maximum total score 40, and so the convention is to multiply the result by 2.5, to achieve a score that can reach a maximum value of 100.

A study performed by Dr. Jeff Sauro [5] showed that the average score for the SUS was around 68 points. Based on the average of the responses from our participants, Parker's Commute scored 70 points, which is a sliver above average. However, it is clear to see (Fig. 6.18) that some aspects of the scale performed much better than others. For example, the system that was developed was very strong in being accessible to an independent user, as the points that scored highest were both related to this: one of them regarding the ease of use without the assistance of a technical person, and the other regarding the need for prior learning to use the system. On the flip side, the system was not particularly enjoyable to the users, as the weakest performing categories were the following: firstly, the user would like to use the system frequently, and secondly, the user felt confident using the system.

Although the obvious solution to this would be the reorganization of the project to contemplate a multidisciplinary team that could have competent people in all areas, rather than a single person handling the different aspects of the design and implementation, a different approach could be to tweak the level acceptance parameters in a way that still encouraged exploration (e.g.: providing multiple acceptable solutions, and increasing the player's score as they find new solutions that they haven't tried yet).

6.3 Conclusions

The first stage of testing allowed for the collection of data regarding the population's prior opinions and knowledge, with the analysis showing that there was a fair amount of uncertainty about certain subjects, such as the financial aspects of the difference between EVs and combustion vehicles, or the different factors that can affect the autonomy of EVs.

The second stage of testing revealed that the game had mostly positive effects, with some exceptions being identified, as well as possible alternative approaches suggested to try and revert these results. Overall, however, the participants showed an improved understanding of the way EVs work, as well as a more favorable opinion towards their adoption.

Finally, the game's interface proved to be, at the very least, designed to an average standard, which surpassed the expectations that were in place before the development of the game.

Chapter 7

Conclusions and Future Work

This chapter goes over the main challenges and goals of the dissertation, as well as the conclusions that were reached.

Finally, some possible future directions in which this project could be developed will be explored.

7.1 Conclusions

If the initial idea seemed pretty straightforward, the conclusions reached from the literature showed from the get-go that the design process for an application like this one has endless twists and turns. Designing the game to create an engaging experience that promotes learning, through the application of these conclusions, also proved an enormous challenge. However, it was a challenge that proved rewarding, as the results were positive, and the process allowed for countless learning opportunities. I would highlight the process of integrating the game with Google Maps, on multiple levels, as a task that allowed me to learn a lot by discovery.

The game was evaluated on two fronts: firstly on its ability to fulfill its purpose, and secondly on its accessibility and ease of use. Regarding the former, the responses to the questionnaires showed a positive evolution in the participants' opinions and receptiveness towards EVs. Regarding the latter, the results of the System Usability Scale (SUS) show that the game ranks slightly above average regarding ease-of-use and intuitiveness, which we can consider a great success given the lack of any design-specific talent or experience involved in this project.

As such, we were able to verify that, through a simple application that follows a tried and tested design philosophy, it is possible to change opinions and behaviors, and ultimately make the world a better place, with just a bit of creativity.

7.2 Fulfillment of Goals

This work was meant to develop a digital game to spread literacy about the capabilities of modern EVs, by allowing the player to experience how day-to-day mobility problems could be handled using these vehicles. After the conclusions from the previous chapter, it is safe to say that this goal was achieved, to a certain degree.

To achieve this, following the literature on games applied to behavioral change, the plan was to create an engaging experience that encouraged the player to explore and reach the solution by their initiative. By allowing the user to create their own route, and giving the player no choice but to experiment with different routes in order to receive feedback, we successfully followed this design guideline, which contributed to achieving the overarching goal of the game.

7.3 Future Work

To improve on what were the perceived limitations of the game that was developed, there are multiple directions in which this project could further evolve. One obvious direction would be the implementation of more levels and power-ups, to provide information on more topics in a format that worked well in the context of this game. Another direction would be the implementation of a gameplay aspect to reflect the charging of EVs, which is an important thing to consider regarding their use in real life but is not reflected in the game in any way. Finally, the use of more specific real-life data, instead of the rough estimations based on previous years that are provided in the game, could be a path of evolution for the game. By applying the level information to known data about different EV models, the game could be transformed into a tool that assists in the choice of vehicle, more than just the teaching tool that it is. Once at this point, it would not be a great leap to compare this data to specific models of combustion vehicles, to achieve even greater decision-assisting power.

At the same time, future work could instead be directed towards developing/refactoring the integration of Google Maps with the Phaser framework, e.g. through the implementation of an extension for it. This would create a valuable tool for the development of new immersive and innovative games, which in turn would allow for easier exploration of topics such as the one approached in this dissertation.

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Appendix A

Pre-Game Questionnaire

Carros Elétricos no mundo moderno / Electric Cars in the modern world

No âmbito da Dissertação do Mestrado em Engenharia Informática e Computação na Faculdade de Engenharia da Universidade do Porto, este questionário destina-se a perceber alguns pontos de opinião quanto aos carros elétricos hoje em dia.

Esta é a primeira parte do exercício. Depois de responder, irá jogar um pequeno jogo, e depois responder à segunda parte, sendo o objetivo deste exercício avaliar o conhecimento e a opinião do público antes e depois de jogar o jogo. Assim, é encorajado que as respostas partam apenas do seu conhecimento prévio!

Se surgir qualquer dúvida, é só mandar email! up201706832@edu.fe.up.pt

In the context of the Dissertation of the Master in Informatics Engineering and Computing, in the Faculty of Engineering of the University of Porto, this questionnaire is meant to help understand some points of opinion regarding electric cars in the modern day.

This is the first part of the exercise. After answering, you will play a small game, and then answer the second part, with the objective being to evaluate the knowledge and opinion of the public before and after playing the game. Thus, it is encouraged that the questions are answered solely based on your previous knowledge!

If any questions arise, just email me!
up201706832@edu.fe.up.pt

Inicie sessão no Google para guardar o seu progresso. Saiba mais

*Obrigatório

Email *

O seu email

Idioma / Language *

- ◯ Português
- ◯ English

Faixa etária / Age range *

- ◯ < 20
- ◯ 20-29
- ◯ 30-39
- ◯ 40-49
- ◯ 50-59
- ◯ 60+

A.1 Portuguese Version

Sobre deslocações do dia-a-dia

Esta secção destina-se a perceber os seus hábitos de deslocação, assim como algumas opiniões.

Considera que tem um conhecimento sólido e atual daquilo que são as capacidades e limitações dos carros elétricos? *

	1	2	3	4	5	
Não percebo nada do assunto.	○	○	○	○	○	Mantenho-me a par dos desenvolvimentos mais recentes.

Que meios usa para fazer as suas deslocações diárias? *

- ☐ Bicicleta
- ☐ Carro
- ☐ A pé
- ☐ Autocarro
- ☐ Metro
- ☐ Comboio
- ☐ Outra: ____________

Com que frequência viaja de carro? *

- ○ Menos de 1 vez por semana
- ○ 1-3 vezes por semana
- ○ 3-5 vezes por semana
- ○ Mais de 5 vezes por semana

Quão viáveis considera os carros elétricos, enquanto solução de mobilidade para o dia-a-dia? *

	1	2	3	4	5	
Nada viáveis	○	○	○	○	○	Perfeitamente viáveis

Sobre a aquisição de carros elétricos

Esta secção tem o objetivo de perceber a fundo a sua opinião sobre os carros elétricos, a vários níveis, e principalmente como é que essas opiniões afetam/afetariam a decisão de adquirir ou não um veículo elétrico.

Compraria um carro elétrico? *

- ◯ Sim / Já possuo um carro elétrico
- ◯ Não
- ◯ Não, mas porque não compraria qualquer carro neste momento
- ◯ Não sei / Não respondo.

Qual a sua opinião sobre a autonomia dos carros elétricos? *

- ◯ É insuficiente para um uso prático no dia-a-dia.
- ◯ É suficiente para o uso diário, mas insuficiente para que este uso seja cómodo.
- ◯ Permite um uso diário cómodo, sem necessidade de grande planeamento, mas tem limitações no que toca a usos menos comuns, como viagens maiores.
- ◯ Não é limitativo em comparação com veículos a combustão.
- ◯ Não sei / Não respondo.

Qual a sua opinião sobre o custo de aquisição dos carros elétricos? *

- ◯ É excessivamente superior ao dos veículos a combustão, fazendo com que não sejam uma opção.
- ◯ É bastante superior ao dos veículos a combustão, o que tem um impacto pesado na decisão.
- ◯ É superior ao dos veículos a combustão, mas ao longo do tempo pode compensar o investimento, sendo assim um fator de importância média.
- ◯ É superior ao dos veículos a combustão, mas vale a pena pelas outras vantagens que estes veículos trazem, pelo que não é um fator pesado para mim.
- ◯ Não sei / Não respondo.

Qual a sua opinião sobre o custo por quilómetro dos carros elétricos? *

- ◯ Não compensa o custo de aquisição mais elevado.
- ◯ Compensa o custo de aquisição, mas não é um fator muito importante para mim.
- ◯ Compensa o custo de aquisição, e é um fator importante para mim.
- ◯ Compensa o custo de aquisição, e é o principal fator para mim.
- ◯ Não sei / Não respondo.

Qual a sua opinião sobre o impacto ambiental dos carros elétricos? *

Um dos argumentos comuns no que toca aos carros elétricos tem a ver com o equilíbrio entre a poluição que é gerada na sua produção e as emissões que são poupadas através do seu uso.

- ◯ Este fator não teria impacto na minha decisão de comprar ou não um carro elétrico.
- ◯ Este fator teria pouco impacto na minha decisão de comprar ou não um carro elétrico.
- ◯ Este fator teria um forte impacto na minha decisão de comprar ou não um carro elétrico.
- ◯ Este fator seria fundamental na minha decisão de comprar ou não um carro elétrico.
- ◯ Não sei / Não respondo.

Sobre o funcionamento de carros elétricos

Esta secção tem o objetivo de perceber o seu conhecimento sobre os fatores que afetam o funcionamento dos carros elétricos.

Quão forte considera que é o impacto destes fatores na autonomia do carro? *

	Muito reduzido	Reduzido	Médio	Elevado	Muito elevado	Não faço ideia
Funcionalidades de conforto (A/C, Infotainment, etc.)	○	○	○	○	○	○
Estilo de condução	○	○	○	○	○	○
Temperatura / Condições climatéricas	○	○	○	○	○	○

A.2 English Version

About daily commuting

This section is meant to understand your commuting habits, as well as some personal opinions.

Do you believe yourself to have a solid and updated knowledge of what are the capabilities and limitations of electric cars? *

	1	2	3	4	5	
I don't know anything about the subject.	○	○	○	○	○	I stay updated on the most recent developments.

What means do you use for your daily commute? *

- ☐ Bus
- ☐ Foot
- ☐ Train
- ☐ Bicycle
- ☐ Car
- ☐ Subway
- ☐ Outra: ____________

How frequently do you travel by car? *

- ○ Less than once a week
- ○ 1-3 times a week
- ○ 3-5 times a week
- ○ Over 5 times a week

How viable do you consider electric cars to be, as an everyday mobility solution? *

	1	2	3	4	5	
Not viable at all	○	○	○	○	○	Perfectly Viable

About the acquisition of electric cars

This section has the purpose of understanding your opinion about electric cars, and observing the relation between the answers to the same questions before and after the game.

Would you purchase an electric car? *

- ◯ Yes / I already own an electric car
- ◯ No
- ◯ No, but because I wouldn't purchase any car right now
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the autonomy of electric cars? *

- ◯ It is insufficient for practical everyday usage.
- ◯ It is sufficient for everyday usage, but insufficient to make this usage comfortable.
- ◯ It allows for comfortable everyday usage, without the need for much planning, but it has limitations when it comes to less common uses, such as larger trips.
- ◯ It is not limitative in comparison to combustion vehicles.
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the purchasing cost of electric cars? *

- ◯ It is excessively superior to the cost of combustion vehicles, making it so they're not an option.
- ◯ It is quite superior to the cost of combustion vehicles, which weighs heavily on the decision.
- ◯ It is superior to the cost of combustion vehicles, but over time it may make up for the investment, making this a medium relevance factor.
- ◯ It is superior to the cost of combustion vehicles, but it is worth it due to the other advantages that these vehicles bring, and so it is not a heavy factor to me.
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the cost per kilometer of electric cars? *

- ◯ It does not make up for the higher acquisition cost.
- ◯ It makes up for the acquisition cost, but it is not a major factor to me.
- ◯ It makes up for the acquisition cost, and it is an important factor to me.
- ◯ It makes up for the acquisition cost, and it is the main factor to me.
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the environmental impact of electric cars? *

One of the common arguments regarding electric cars has to do with the balance between the pollution that is generated during their production, and the emissions that are saved through their usage.

- ◯ This factor would not have an impact in my decision to purchase (or not) an electric car.
- ◯ This factor would have a small impact in my decision to purchase (or not) an electric car.
- ◯ This factor would have a large impact in my decision to purchase (or not) an electric car.
- ◯ This factor would be fundamental in my decision to purchase (or not) an electric car.
- ◯ I don't know / I prefer not to answer.

About the functioning of electric cars

This section is meant to help understand your knowledge about the factors that affect the functioning of electric cars.

How strong do you believe the impact of these factors to be in the autonomy of the car? *

	Very Low	Low	Medium	High	Very High	I have no idea
Temperature / Weather	○	○	○	○	○	○
Driving Style	○	○	○	○	○	○
Comfort Features (A/C, Infotainment, etc.)	○	○	○	○	○	○

Appendix B

Post-Game Questionnaire

Parker's Commute - Carros Elétricos no mundo moderno / Electric Cars in the modern world

🇵🇹 No âmbito da Dissertação do Mestrado em Engenharia Informática e Computação na Faculdade de Engenharia da Universidade do Porto, este questionário destina-se a perceber de que forma as opiniões levantadas na primeira parte se alteraram (ou não) após jogar o jogo Parker's Commute.

Esta é a segunda parte do questionário, e deve ser respondida imediatamente a seguir à experiência de jogo.

Se surgir qualquer dúvida, é só mandar email! up201706832@edu.fe.up.pt

🇬🇧 In the context of the Dissertation of the Master in Informatics Engineering and Computing, in the Faculty of Engineering of the University of Porto, this questionnaire is meant to help understand how the opinions gathered in the first part have changed (or not) after playing the game Parker's Commute.

This is the second part of the questionnaire, and should be answered immediately after the game experience.

If any questions arise, just email me!
up201706832@edu.fe.up.pt

Inicie sessão no Google para guardar o seu progresso. Saiba mais

*Obrigatório

Email *

O seu email

Idioma / Language *

- ◯ 🇵🇹 Português
- ◯ 🇬🇧 English

B.1 Portuguese Version

Sobre a aquisição de carros elétricos

Esta secção tem o objetivo de perceber a sua opinião sobre os carros elétricos, e de observar a relação entre as respostas às mesmas perguntas antes e depois do jogo.

Compraria um carro elétrico? *

- ○ Sim / Já possuo um carro elétrico
- ○ Não
- ○ Não, mas porque não compraria qualquer carro neste momento
- ○ Não sei / Não respondo.

Qual a sua opinião sobre a autonomia dos carros elétricos? *

- ○ É insuficiente para um uso prático no dia-a-dia.
- ○ É suficiente para o uso diário, mas insuficiente para que este uso seja cómodo.
- ○ Permite um uso diário cómodo, sem necessidade de grande planeamento, mas tem limitações no que toca a usos menos comuns, como viagens maiores.
- ○ Não é limitativo em comparação com veículos a combustão.
- ○ Não sei / Não respondo.

Qual a sua opinião sobre o custo de aquisição dos carros elétricos? *

- ◯ É excessivamente superior ao dos veículos a combustão, fazendo com que não sejam uma opção.
- ◯ É bastante superior ao dos veículos a combustão, o que tem um impacto pesado na decisão.
- ◯ É superior ao dos veículos a combustão, mas ao longo do tempo pode compensar o investimento, sendo assim um fator de importância média.
- ◯ É superior ao dos veículos a combustão, mas vale a pena pelas outras vantagens que estes veículos trazem, pelo que não é um fator pesado para mim.
- ◯ Não sei / Não respondo.

Qual a sua opinião sobre o custo por quilómetro dos carros elétricos? *

- ◯ Não compensa o custo de aquisição mais elevado.
- ◯ Compensa o custo de aquisição, mas não é um fator muito importante para mim.
- ◯ Compensa o custo de aquisição, e é um fator importante para mim.
- ◯ Compensa o custo de aquisição, e é o principal fator para mim.
- ◯ Não sei / Não respondo.

Qual a sua opinião sobre o impacto ambiental dos carros elétricos? *

Um dos argumentos comuns no que toca aos carros elétricos tem a ver com o equilíbrio entre a poluição que é gerada na sua produção e as emissões que são poupadas através do seu uso.

- ◯ Este fator não teria impacto na minha decisão de comprar ou não um carro elétrico.
- ◯ Este fator teria pouco impacto na minha decisão de comprar ou não um carro elétrico.
- ◯ Este fator teria um forte impacto na minha decisão de comprar ou não um carro elétrico.
- ◯ Este fator seria fundamental na minha decisão de comprar ou não um carro elétrico.
- ◯ Não sei / Não respondo.

Sobre o funcionamento de carros elétricos

Esta secção tem o objetivo de perceber o seu conhecimento sobre os fatores que afetam o funcionamento dos carros elétricos.

Quão forte considera que é o impacto destes fatores na autonomia do carro? *

	Muito reduzido	Reduzido	Médio	Elevado	Muito elevado	Não faço ideia
Temperatura / Condições climatéricas	○	○	○	○	○	○
Estilo de condução	○	○	○	○	○	○
Funcionalidades de conforto (A/C, Infotainment, etc.)	○	○	○	○	○	○

Questões sobre experiência de jogo, usabilidade e acessibilidade.

Esta secção tem o objetivo de avaliar o protótipo de jogo que foi criado, em termos de usabilidade e acessibilidade.

Escala de Usabilidade do Sistema *

A Escala de Usabilidade do Sistema (EUS) é uma maneira simples de obter a opinião do utilizador sobre a usabilidade de um sistema, ajudando a determinar a sua efetividade, eficiência e satisfação.

	Concordo Fortemente	Concordo	Neutro	Discordo	Discordo Fortemente
Acho que gostaria de usar este sistema frequentemente.	○	○	○	○	○
Achei o sistema desnecessariamente complexo.	○	○	○	○	○
Achei o sistema fácil de usar.	○	○	○	○	○
Acho que precisaria do apoio de uma pessoa técnica para ser capaz de utilizar o sistema.	○	○	○	○	○
Achei que as várias funções deste sistema foram bem integradas.	○	○	○	○	○
Achei que havia demasiada inconsistência neste sistema.	○	○	○	○	○
Imagino que a maior parte das pessoas aprenderia muito rápido a usar este sistema.	○	○	○	○	○
Achei este sistema muito incómodo de usar.	○	○	○	○	○
Senti-me muito confiante a usar este sistema.	○	○	○	○	○
Precisei de aprender muitas coisas antes de arrancar no uso deste sistema.	○	○	○	○	○

B.2 English Version

About the acquisition of electric cars

This section has the purpose of understanding your opinion about electric cars, and observing the relation between the answers to the same questions before and after the game.

Would you purchase an electric car? *

- ◯ Yes / I already own an electric car
- ◯ No
- ◯ No, but because I wouldn't purchase any car right now
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the autonomy of electric cars? *

- ◯ It is insufficient for practical everyday usage.
- ◯ It is sufficient for everyday usage, but insufficient to make this usage comfortable.
- ◯ It allows for comfortable everyday usage, without the need for much planning, but it has limitations when it comes to less common uses, such as larger trips.
- ◯ It is not limitative in comparison to combustion vehicles.
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the purchasing cost of electric cars? *

- ◯ It is excessively superior to the cost of combustion vehicles, making it so they're not an option.
- ◯ It is quite superior to the cost of combustion vehicles, which weighs heavily on the decision.
- ◯ It is superior to the cost of combustion vehicles, but over time it may make up for the investment, making this a medium relevance factor.
- ◯ It is superior to the cost of combustion vehicles, but it is worth it due to the other advantages that these vehicles bring, and so it is not a heavy factor to me.
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the cost per kilometer of electric cars? *

- ◯ It does not make up for the higher acquisition cost.
- ◯ It makes up for the acquisition cost, but it is not a major factor to me.
- ◯ It makes up for the acquisition cost, and it is an important factor to me.
- ◯ It makes up for the acquisition cost, and it is the main factor to me.
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the environmental impact of electric cars? *

One of the common arguments regarding electric cars has to do with the balance between the pollution that is generated during their production, and the emissions that are saved through their usage.

- ◯ This factor would not have an impact in my decision to purchase (or not) an electric car.
- ◯ This factor would have a small impact in my decision to purchase (or not) an electric car.
- ◯ This factor would have a large impact in my decision to purchase (or not) an electric car.
- ◯ This factor would be fundamental in my decision to purchase (or not) an electric car.
- ◯ I don't know / I prefer not to answer.

About the acquisition of electric cars

This section has the purpose of understanding your opinion about electric cars, and observing the relation between the answers to the same questions before and after the game.

Would you purchase an electric car? *

- ◯ Yes / I already own an electric car
- ◯ No
- ◯ No, but because I wouldn't purchase any car right now
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the autonomy of electric cars? *

- ◯ It is insufficient for practical everyday usage.
- ◯ It is sufficient for everyday usage, but insufficient to make this usage comfortable.
- ◯ It allows for comfortable everyday usage, without the need for much planning, but it has limitations when it comes to less common uses, such as larger trips.
- ◯ It is not limitative in comparison to combustion vehicles.
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the purchasing cost of electric cars? *

- ◯ It is excessively superior to the cost of combustion vehicles, making it so they're not an option.
- ◯ It is quite superior to the cost of combustion vehicles, which weighs heavily on the decision.
- ◯ It is superior to the cost of combustion vehicles, but over time it may make up for the investment, making this a medium relevance factor.
- ◯ It is superior to the cost of combustion vehicles, but it is worth it due to the other advantages that these vehicles bring, and so it is not a heavy factor to me.
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the cost per kilometer of electric cars? *

- ◯ It does not make up for the higher acquisition cost.
- ◯ It makes up for the acquisition cost, but it is not a major factor to me.
- ◯ It makes up for the acquisition cost, and it is an important factor to me.
- ◯ It makes up for the acquisition cost, and it is the main factor to me.
- ◯ I don't know / I prefer not to answer.

What is your opinion regarding the environmental impact of electric cars? *

One of the common arguments regarding electric cars has to do with the balance between the pollution that is generated during their production, and the emissions that are saved through their usage.

- ◯ This factor would not have an impact in my decision to purchase (or not) an electric car.
- ◯ This factor would have a small impact in my decision to purchase (or not) an electric car.
- ◯ This factor would have a large impact in my decision to purchase (or not) an electric car.
- ◯ This factor would be fundamental in my decision to purchase (or not) an electric car.
- ◯ I don't know / I prefer not to answer.