Bachelor Thesis

Assessing the impact of a future full e-mobility scenario at the University of Twente

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Bachelor Program Creative Technology

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Abstract

In the upcoming years, a large increase in electric vehicles (EVs) is predicted. With the prospect of future e-mobility, the need and relevancy for adequate infrastructure to support the transition to EVs becomes increasingly more important. This research investigated if there is a need for expansion or optimization of the University of Twente (UT) EV infrastructure by assessing the current infrastructure, exploring existing options, and with those, providing recommendations to cope with a full e-mobility scenario. From the literature, it was found that performing a grid impact analysis would give an accurate indication of how much an increase in EV penetration rate would impact the electricity grid of the UT. Furthermore, it was found that utilizing the Monte Carlo Method would yield more accurate results. Therefore a model was created that uses several distribution samples including car arrival time, initial state of charge, and battery capacity. The first sample was obtained from the Amperapark at the UT, the second from a study, and the third from the top 10 registered EVs in the Netherlands. The analysis simulated several EV penetration rate scenarios, The UT consumes a lot of electricity daily, and from their energy platform the highest electricity consumption day of 2023 was obtained, which could be described as the worst-case scenario. Using the available parking spaces, a full e-mobility scenario is estimated to be an increase of approximately 1000 EVs. The UT has a contracted capacity of 7.5MW, which will result in hefty fines if passed. By adding the results to the worst-case scenario the impact on the electricity grid of the UT was found. These results indicate that an increase of an EV penetration rate of 25% results in passing the 7.5MW limit. Higher penetration rates will leave an even bigger impact on the electricity grid of the UT. There is not enough room on the electricity grid of the UT for such a large increase in energy consumption, therefore the UT would not be able to cope with a full e-mobility scenario. The results were incorporated into a data physicalization to educate others on the impact of EVs on the electricity grid of the UT in a playful and immersive manner. The UT should consider looking into their EV charging infrastructure and making concrete plans to ensure that they are adequately prepared for the transition to EVs.

Acknowledgment

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Chapter 1 – Introduction

In recent years, the growth and development of electric vehicles (EVs) have been rapidly increasing, with EV sales having tripled in the last three years, and are projected to increase even more over the next decade [1]. In 2023 the European Union (EU) passed a law to prohibit the sale of CO2-emitting cars such as petrol and diesel cars by 2035, further encouraging the development of the EV market and higher EV penetration rates [2]. The EU has set a goal of achieving climate neutrality in 2050, the aforementioned law was passed to ensure that the transport sector can achieve climate neutrality by 2050 [3].

Such growths introduce their own set of new problems. When EV penetration rates increase, the need for sufficient infrastructure increases along with it. In the Netherlands, the electricity grid in big cities has already gotten increasingly congested due to phenomena such as the transition from gas to electric in-house heating and gas to induction cooking [4]. With higher EV penetration rates, the grid will become even more strained, leading to more congestion. These higher congestion rates can cause problems, such as an increased amount of power failures during peak consumption hours.

If the Netherlands wants to achieve climate neutrality by 2050, big changes to the Dutch electric infrastructure need to be made such as the expansion of the high/medium/low-voltage Dutch electricity grids. According to a report from Energiekompas2050, a 40-45% increase in transformers, a 20-30% increase in the number of cables, a 35-45% expansion of the middle-voltage electricity grid, doubling/tripling the number of connection stations, and more is needed to facilitate the new energy demand [5]. Most of the work should be carried out in the coming 10 years because the largest growth is happening in that period. Expansions of the grid till 2050, in preparation for the electricity transition can cost up to 100 billion euros [6].

With the prospect of future e-mobility scenarios, the need and relevancy for adequate infrastructure to support the transition to EVs becomes increasingly more important. To ensure proper EV adaptation and integration, changes need to be made not only on a national scale but maybe also on a local scale. This research investigates if there is a need for expansion or optimization of the UT EV infrastructure while considering the impact on the electricity grid. In this way, the UT can prepare adequately for future e-mobility scenarios.

If there is a need for improvements, the UT should be inclined to take action. As a technical University, UT strives to be progressive with a *People-first* mindset, in line with a *High Tech Human Touch*-philosophy, focussing on being sustainable by responsibly managing technology in a continually changing society [7]. Therefore, leading with EV charging infrastructure would be in line with the philosophy of the UT as EVs are a key step in achieving climate neutrality in the transport sector.

This report focuses on current charging infrastructure, grid limitations, and EV charging strategies with a focus on University campuses and related scenarios. To ensure that the electricity grid can handle the power and energy requirements of future full e-mobility scenarios at the UT the current infrastructure will be critically assessed and optimization options will be discussed along with existing solutions incorporating charging management strategies. The goal of this report is to assess the current EV charging infrastructure at UT, look at existing solutions, and provide suggestions for the UT to cope with a 100% e-mobility scenario.

1.1 Research questions

This research aims to assess the impact of future e-mobility scenarios at the University of Twente (campus). This leads to the following research question:

"*What are the extents of the impact of different electric vehicle penetration rate scenarios at the University of Twente?"*

To answer the main research question, the following sub questions have been derived.

Subquestion 1: "What are the power and energy requirements for a future full e-mobility scenario at the University of Twente, and how would this impact the electricity grid?"

Subquestion 2: "What strategies can be devised to optimize the electric vehicle charging infrastructure at the University of Twente?"

Subquestion 3: "What implications arise with the electrification of the University of Twente personnel vehicles?"

Subquestion 4: "How could awareness be created within the community of the University of Twente about the impact of electric vehicles on the University of Twente? "

Chapter 2 – Background Research

2.1 Electric Grid

The electric grid is responsible for transporting and distributing electricity. The Dutch electric grid consists of a hierarchical structure that can be divided into four main net categories. These are the interconnection net, transport net, regional distribution net and the local distribution net [8]. These consist of three different operating levels, the high voltage grid, the medium voltage grid, and the low voltage grid with each operating level having its own functions [9]. In between the different nets, there are transformer stations that lower the voltage levels.

The interconnection net is part of *the high-voltage grid,* it operates at 110kV up to 150kV and is responsible for transporting electricity over long distances at very high voltages.

The transport net is also part of *the high-voltage grid* with operating voltages of 50,110 and 150kV and is responsible for transportation at a regional level.

The regional distribution net is part of *the medium-voltage grid* which operates at 3kV up to 10kV and resides underground. It is responsible for distributing electricity to different substations and transformer stations.

The local distribution is part of the *low-voltage grid* which operates at 230V and 400V and is responsible for distribution to end consumers and households.

2.1.1 Grid Congestion

Transmission networks and distribution grids become congested when they are unable to distribute power according to load demand [10]. Grid congestion can lead to damage to power systems and can cause problems such as blackouts. The Dutch electricity grid is reaching its maximum capacity in large parts of the country due to increased amounts of congestion, consequentially new large-scale consumers and new housing areas cannot get new electricity connections [11]. This increase can largely be ascribed to increasing demand and the increase of electricity that is delivered back to the grid by consumers and enterprises due to increasing amounts of renewable energy being generated [12].

2.2 General electrical vehicle information

2.2.1 Electrical Vehicle Concept

The concept of an EV is very simple at its core. An EV consists of a rechargeable battery, an electric motor, and a controller. The controller can control the car's speed by controlling how much power is supplied from the battery to the electric motor. It can do this forward and backward, it is called a two-quadrant controller [13]. If it can also brake forwards and backward, it is called a four-quadrant controller. This utilizes a useful aspect of EVs, which is regenerative braking, where the EV regains a bit of energy by increasing the resistance of the motor. The EV battery can typically be recharged with a plug at a charging station [14].

2.2.2 Electrical Vehicle Types

There are different types of EVs available on the market. The different types are: fully electric, hybrid, and fuelled EVs. There are more types of EVs such as line-powered, solar-powered, hydrogen-powered, and more. However, these are in their development phases and whilst sales are increasing globally, they are yet to be fully adopted in the Netherlands [15], [16].

Fully electric cars are described as above, only utilizing a battery to be powered. Hybrid EVs however, work the same but also make use of a fossil-fueled motor. Such cars can accommodate longer distances since EVs usually aren’t able to travel long distances. There are also fuelled EVs, which cannot be charged, it is similar to a hybrid car, except that this type charges its battery with a fossil-fuelled motor.

2.2.3 Battery

When designing an EV, choosing a battery is an important task. The battery types that are predominantly used in EVs are; Lead-Acid, Nickel-Metal Hydride, and Lithium-ion batteries [17]. These are all rechargeable battery types, with different characteristics. Lead-acid batteries were the first widely used battery type for EVs due to their characteristics such as cost-effectiveness and reliability [18]. However, due to the limitations of Lead-Acid batteries and the invention of Nickel-Metal hybrid batteries, Lead-Acid batteries stopped being the battery standard for EV batteries. However Lead-Acid batteries are still used in modern EVs to power the car on standby [19]. The Nickel-Metal Hydride batteries offered higher energy density and longer driving ranges, however, they did not become the new battery standard for EVs. This is due to the invention of the Lithium-ion batteries (LIB). Nickel-metal hybride batteries are mainly used in most hybrid cars [20].

Due to its characteristics, most current EVs make use of LIBs. This is the same type of battery that can be found in consumer products such as smartphones and laptops.

2.2.3.1 Battery Aging

A substantial disadvantage of LIBs is that they suffer from aging [21]. There are multiple types of aging but they can be categorized into three main categories. Calendar aging, cyclic aging, and reversible aging. Calendar aging is the gradual degradation of the battery over time, with or without use. The State of Charge (SoC) and temperature are mainly responsible for calendrical aging. The SoC describes the percentage of a battery that is charged. In general, higher temperatures and a higher SoC negatively impact the total battery life [22]. Cyclic aging is the deterioration of the battery after use. Reversible aging are reversible aging mechanisms that can increase battery lifetime such as the anode overhang.

2.2.3.2 Improved Charging Method LIB

To minimize the negative impact of battery aging on LIB batteries, specialized charging strategies can be implemented. One study investigated the impact of State of Charge (SoC, temperature, and amount of cycles on the battery capacity [23]. This was done by testing different temperatures: 10/25/40°C, on different SoC levels: low/medium/high SoC for 500 charging cycles. They found that at lower SoC, very low temperatures (10°C) lead to the least relative battery capacity that is lost. However, at a higher SoC, higher temperatures (25°C) lead to the least relative battery capacity loss while temperatures (10°C) lead to the most relative battery capacity loss. However, the most important discovery was that lithium plating was the most impactful regarding the relative battery capacity, which mainly depended on the charging rate.

By creating awareness on how EV batteries work and why they degrade, users can make better-informed decisions regarding this matter, which could prolong their EV battery life. Therefore, creating awareness about this subject could be a relatively easy method to lengthen the lifespan of batteries and increase general battery utilization. It could also be utilized in charging strategies by prompting users to charge at slower rates or only till a certain percentage to reduce their battery degradation. However, as battery charging can be a very complex process. More research is needed on specific strategies when actually considering to implement such a strategy.

2.2.4 Charging types

Different charging types are commonly used, most of them use conductive charging and can be split into three main types which are described in *table 1*.

Charging Type	Charging method	Charging speed
Type 1: Wall outlet Relatively slow but accessible	Uses **AC** current and onboard converter	3.6 kW to 7.2 kW
Type 2: AC Fast charging	Uses **AC** current and onboard converter	3.6 kW to 22 kW
Type 3: DC Fast Charging	Uses **DC** current and offboard converter	50 kW to 350 kW

Table 1: Different charging types

There are more alternative charging methods that could potentially be utilized next to conductive charging. These methods include inductive charging and off-board charging. Inductive charging is a wireless charging method where the energy is transferred with the use of magnetic fields. This method removes the hurdles and danger of having to handle high voltages when plugging a charger into an EV. However, this method is currently not efficient, as it introduces high power losses. It could potentially be used in the future for concepts such as roadway electrification where an EV can be charged while it drives [24].

Off-board charging is a method that utilizes the concept of swappable batteries. By charging batteries beforehand, car batteries can be quickly changed to get a full battery quickly. This removes the need to wait for the car to be charged. It is a very efficient method since there is no energy loss when swapping the battery, and there are lots of benefits such as minimizing power loss, renewable energy integration, removing charging times, and minimal management cost [25]. However, it also does come with its drawbacks, additional batteries are needed to be stored and charged and when all these batteries are empty, no batteries can be swapped. Additionally, it needs significant investments in infrastructure as swapping stations need to be built, and batteries need to be built/bought. However, the most challenging part is that standardization is necessary for this method to succeed.

2.2.5 EVs in the Netherlands

The cars that are being used in the Netherlands give a representation of what cars are being used by UT employees and visitors. In the Netherlands, currently (march 2024) the most registered EV model is the Tesla Model 3. Out of all the registered vehicles, 5.2% (473.000) are electric and 3.2% (296.000) are hybrid [16]. Consequently, the Dutch EV penetration rate is currently still under 10%, meaning the electrification of vehicles is in its early stages.

EV sales are predicted to increase in the Netherlands over the coming years, resulting in higher EV penetration rates [26], [27]. In table x, the averages of the top 10 most registered EVs in the Netherlands are displayed to give an estimation of the general specifications of the average EV in the Netherlands [28].

	Capacity EV	Energy Usage	Range
Lowest	52.0 kWh	0.139 kWh/km	285 km
Average	59.5 kWh	0.160 kWh/km	361 km
Highest	65.4 kWh	0.182 kWh/km	415 km

Table 2: General specifications regarding capacity, energy usage, and range calculated from the top 10 commercially available EVs in the Netherlands

2.2.6 EV Charging Infrastructure in the Netherlands

The EV charging infrastructure of the Netherlands indicates what the infrastructure of the UT should at least measure up to. As of April 2024, there are almost 700.000 charging stations in the Netherlands, 537.000 of these are household charging stations and 99.000 are public charging stations [16]. Additionally, there are around 54.000 semi-public charging stations and almost 5.000 fast charging stations.

Comparing these numbers to the number of registered EVs, it can be seen that there are around 1.1 EVs/hybrids per charging station when including household charging stations. Moreover, there are around 7.9 EVs/hybrids per public charging station and around 4.9

EVs/hybrids when also including semi-public charging stations. This means that there are almost 8 times as many EVs'/hybrids as public charging stations and 5 times as many when including semi-public charging stations.

2.2.7 Charging Ecosystem

To establish and maintain a proper EV charging infrastructure there are multiple parties involved [29]. There are EV manufacturers and charging station manufacturers who produce EVs and EV charging stations. To supply the charging stations with electricity, there are electricity providers and utility companies to maintain the grid. Most prominently there are EV charging companies that build and maintain the charging networks, such companies are also in control of the apps that users interact with to charge their cars. The software that manages everything is made by EV charging software companies. Additionally, governments play a role by providing funding, other incentives, and regulations. The end users are the EV drivers who mainly interact with the EV charging companies and their provided software and charging stations.

2.3 Current situation at UT

To asses if the infrastructure of the UT is sufficient for future e-mobility scenarios, the current infrastructure needs to be mapped out in order to be assessed. Firstly, currently, no research has been done on future full e-mobility scenarios at the UT nor on its current infrastructure. Neither are there any plans of the UT in place to deal with future full e-mobility scenarios. Therefore there seems to be a gap in the research of this field. This research aims to fill this gap by providing an inventorisation, assessment, and recommendations.

This chapter describes the current state of all the relevant factors of the UT EV infrastructure. It includes the electrical infrastructure, the charging infrastructure, and the UT energy usage. This information is collected from public websites, information that is stated that is not available online is collecefted though an interview with an expert which is an UT employee that deals with electricity contracts at the UT [30].

2.3.1 Electrical Infrastructure

The electrical infrastructure is the foundation of an EV charging infrastructure. Therefore information about the infrastructure of the UT is crucial for the assessment process. However, unfortunately, the specific details of the infrastructure of the UT are not publicly available. Therefore a simplification of the actual system will be described. This information was acquired through the expert interview [30].

The UT has its own electrical network with a power contract that provides 7.5MW over a cable that supports up to 10MW with a voltage of 10KV [30]. This cable comes from a 110KV station. However, this 7.5MW capacity should not be exceeded at any time, otherwise it will result in hefty fines for the UT. To ensure the UT does not exceed this 7.5MW capacity, the cooling of the cold circle [31] can be turned off or reduced as a final measure. The cooling of the cold circle can take up to 1MWh during warm months such as June.

The UT has around 20-30 transformer stations, which are spread around the campus in rings. In this way, the buildings can always be supplied with power from two ways, so that if there is a power issue somewhere, the other side can still provide power. These rings also ensure the distribution of the available power. The capacity of these transformer stations varies depending on the demand of the buildings. Unfortunately, this is private information and therefore cannot be used. This can affect the placement distribution of new charging stations.

When placing new charging stations, one has to think about the capacity of the transformer stations, there may be enough capacity on the total grid of the UT but this capacity is distributed throughout the campus. Therefore, this fact needs to be taken into consideration and will need further research when trying to implement it. Another option could be to estimate the capacity of the transformers considering the energy data of each building and comparing this to the maximum values.

2.3.2 Charging Infrastructure

Currently, the EV charging infrastructure of the UT consists of multiple charging stations spread over the UT, consequently distributing the load throughout the campus. When considering a 100% EV penetration rate scenario, the amount of parking spaces can give an indication of what the maximum parking capacity might be and therefore how much cars entail a full e-mobility scenario.

There are 3 main public parking areas at the UT which have a combined total of 1066 parking spaces and 32 public charging stations [32, p. 2]. These charging stations have charging speeds of 4x11 kW,18x13 kW, 2x21 kW, and 6x22 kW respectively. If all these stations were occupied and drawing energy at full capacity, around 450kW could be drawn maximally.

The aforementioned charging stations are on the UT and owned by the UT, however, they are operated by third-party aggregators, namely Shell [33] and Theeforce [34]. Shell only operates charging stations that they produce whereas Theeforce also operates charging stations that are produced by other manufacturers, therefore offering more flexibility. Since the UT purchased the charging stations, they are able to determine the prices of the charging stations [30]. Furthermore, they have the ability to incorporate charging management strategies if desired.

There are some other charging stations at the UT that are not publicly available, however, there is no public information available on these charging stations, and are therefore not taken into consideration. In addition to this, there is also a PV-fed charging station from AmperaPark [35].

2.3.3 UT Employees and EV Penetration Rate

In 2022, the UT had 3.933 employees out of which 3540 work fulltime, about 55% of the staff is academic staff and 45% is supporting staff. From the academic staff 40% is permanent and 88% of the supporting staff is permanent.

A survey that was distributed 8 years ago (2016) researched smart commuting at the UT [36]. It had a sample size of 435 UT employees and 1.367 other employers that travelled to the UT. These results indicate that a larger number (65%) of the UT employees travelled to the UT by bike, out of which a big part (42%) always travel by bike and the rest (23%) sometimes travel by bike. The other employers have slightly more people that sometimes come by bike.

To add to this, less than half (42%) of the UT employees travels by car at least once per week whereas about half (52%) of the other employees travel by car at least once a week. Some employees travel by train, bus, walk or use a different method of transport. As this is an relatively old survey, the amount of people that travel to the UT by bike might have increased as the UT incentives employees to travel by bike or e-bike [37]. Additionally, from 2025 and onwards the UT will 100% compensate any non CO2 emitting business travel which can increase the amount of employees travelling by EV [37].

Considering that these numbers may have changed, these estimations may be off, however they can still be used to make a relative estimation of how much people visit the UT by car every week. If around 42% of the staff travels to work by car at least once a week and there are 3933 employees, this would mean around 1650 employees travel to the UT at least once per week by car. Additionally there are lots of visitors and clients that travel to the UT by car which increases this number.

Alternatively, the amount of of parking spaces as a maximum amount of EVs for a full e-mobility scenario can be considered. This can give a better estimate of the maximum capacity of the UT. With these numbers an estimation can be made on the current amount of EVs. For such scenarios, it is decided to assume that the EV penetration rate of the UT follows the average penetration rate of the Netherlands. However, the pentration rate might be higher at the UT, this could be researched with the help of a survey.

By assuming that the UT has around 1000 cars parked daily and that the EV penetration rate is 5.2% [16], there would be around 50 EVs parked daily. By assuming there around 1650 employees that travel by car at least once a week, there would be around 86 EVs coming in at least once every week.

2.3.3 Energy Usage

The UT is transparent in its energy usage. Their energy usage is measured and reported on its energy platform [38]. Yearly, the buildings on the UT campus (excluding UT buildings in the city) use around 30.000.000 to 33.000.000 kWh of electricity which can be seen in figure 1.

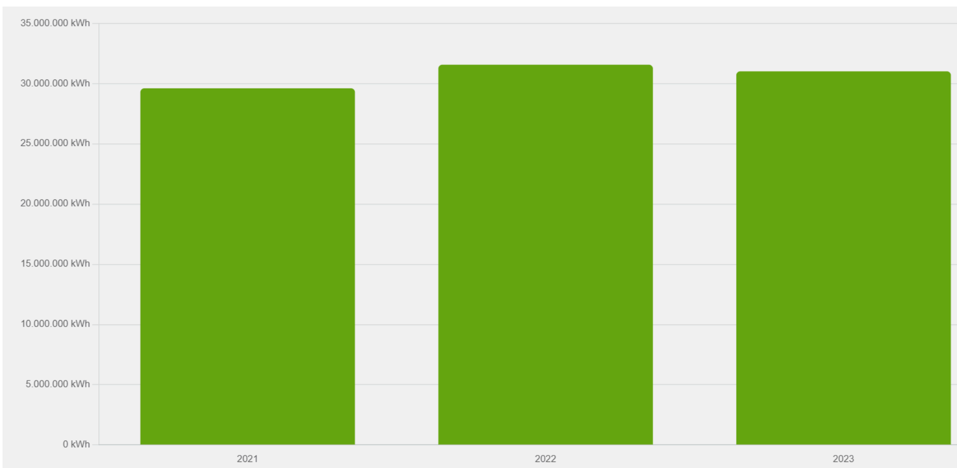


Figure 1: UT electricity consumption of all the campus buildings per year in 2021-2023, displayed in kWh

The highest demanding months of 2023 were June and September, with a combined consumption of almost 3.000.000 kWh in June and almost 2.900.000 in September, the monthly consumption can be seen in figure 2. Since June is during the summer, during this period, the average temperature is higher increasing the need for cooling. As cooling requires lots of electricity, the electricity consumption increases. On the other hand, during the summer the sun is more active, which is beneficial for PV-energy generation. September is during autumn, there is generally less sun than in the summer months, meaning less potential for PV-energy generation.

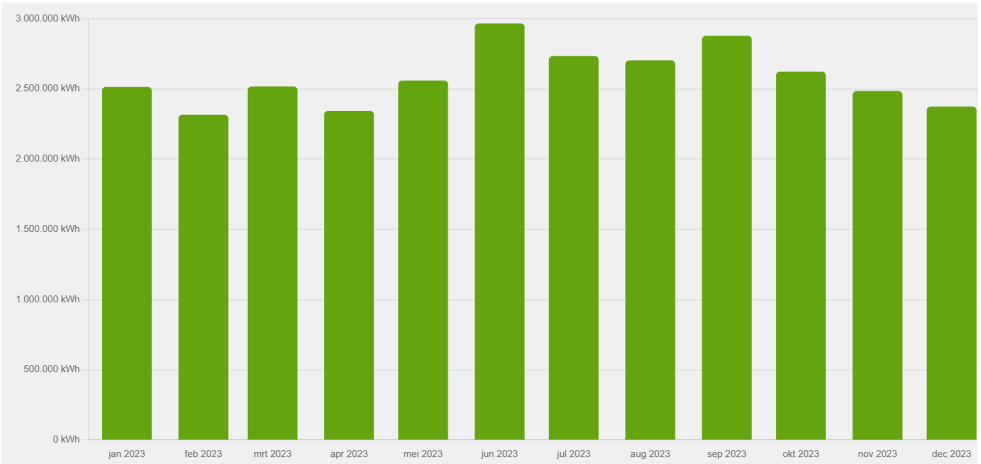


Figure 2: UT electricity consumption of all the campus buildings per month of 2023, displayed in kWh

When considering the hourly rates in figure 3. It can be observed that the highest registered hourly values are 7000kWh, there are only a couple of occurrences where this 7000kWh was reached during the year, these occurred during June and September, the aforementioned highest consumption months. The 7000kWh is already close to the maximum contracted energy limit of 7.5MW, and therefore at peak consumption times, there is not much room for additional load on the grid.

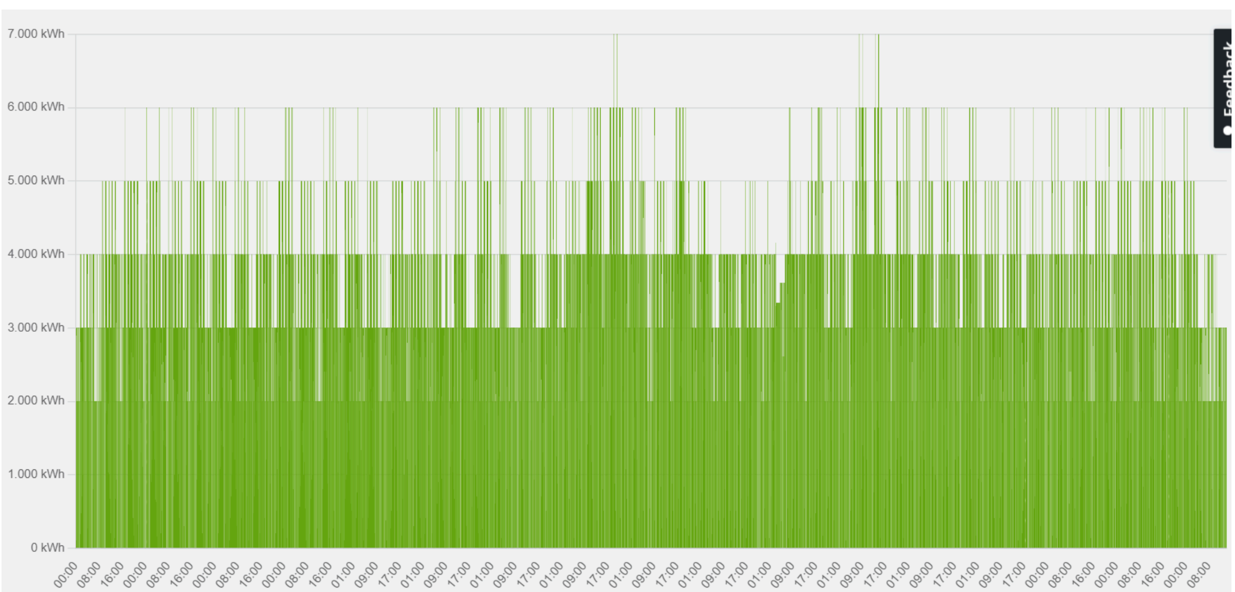


Figure 3: UT electricity consumption of all the campus buildings per hour in 2023, displayed in kWh

2.3.4 Worst-case scenario

On high-demand days, there may be limited capacity on the electricity grid. Figure 4 displays the electricity consumption of the University Campus on 07/09/2023. This is the consumption of one the highest demanding consumption day in 2023, which could be considered as a “worse case scenario”.

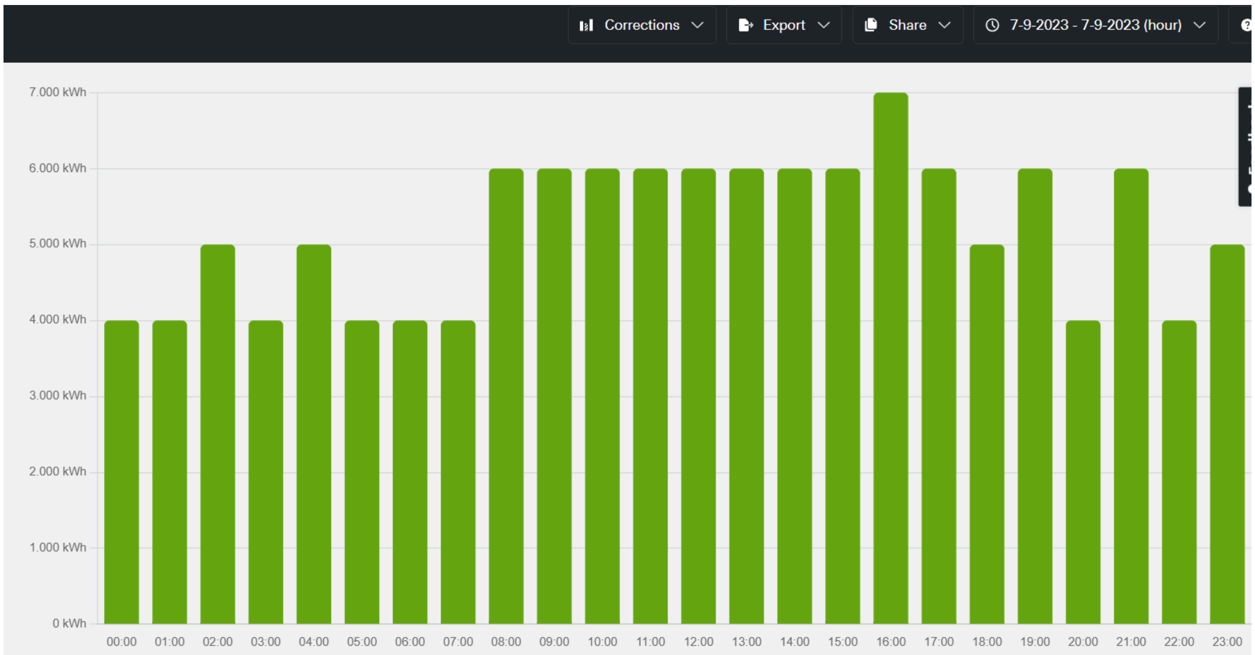


Figure 4: UT electricity consumption of all the campus buildings per hour on 07/09/2023, displayed in kWh

It can be observed that throughout the day, the hourly consumption was around 6000kWh and peaked at 7000kWh at 15:00. Even after 18:00, the hourly consumption was still around 5000kWh. This means that during the day, when UT employees usually are at the UT with their car parked (between 8:00-18:00), there is not a lot of room for more electricity consumption. Even if the load could be perfectly spread throughout the day, there is still a limited amount of electricity available. This is indicates that there is not enough room for extra energy consumption on the UT electricity grid.

In April however, the electricity consumption is the lowest of all months, one day is displayed in figure 5. There is a lot more electricity available throughout the day. In lower consumption months, there would be more capacity for EVs on the UT grid. However, since EVs need to be charged throughout the whole year, the maximum capabilities of the charging infrastructure at the UT are reflected by its worst case scenario. Exceeding this capacity on such a day will cause problems for the UT, since it results in hefty fines from the electricity provider. Therefore, one should take the worst case scenarios into consideration when examining such an infrastructure.

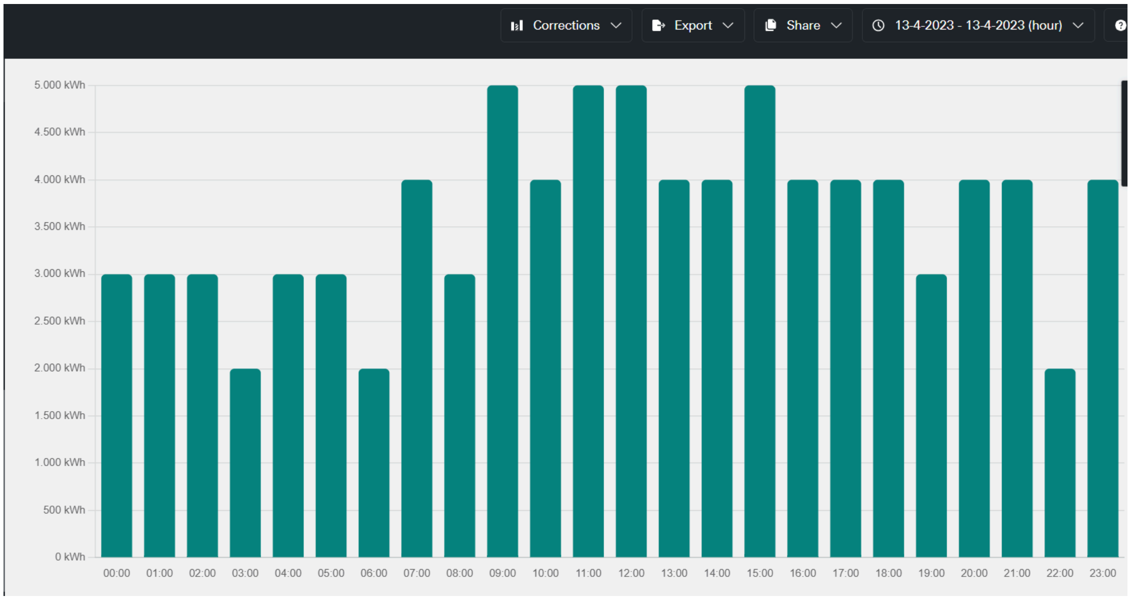


Figure 5: UT electricity consumption of all the campus buildings per hour on 13/04/2023, displayed in kWh

In this project, the worst case scenario will be used in the simulations to show what the electricity impact would be on such days. It would be possible to install more charging stations during the lower consumption months and not use them during the higher consumption months. However, this solution is not efficient nor affordable.

2.3.5 Responsibility UT EV charging infrastructure

Currently, the UT is providing charging stations to visitors/employees. As mentioned in the charging infrastructure section, they set the price of these stations whilst letting a third party operate them. They do not have a reduced electricity tariff for employees, only for UT vehicles. In the future, they might face the problem of having to choose if they want to expand their charging infrastructure or not. Depending on the necessity, the UT could decide against expanding if it the benefit of providing EV charging stations to their employees is not worth the investment.

An important factor to consider for future e-mobility scenarios is the entity that ensures that there is a proper EV infrastructure. As discussed in the charging ecosystem section, there are multiple entities involved in the process, the entity responsible for ensuring there are enough charging stations is the government. As the Netherlands is part of the European Union, it adheres to their rules and therefore to the European Energy Performance of Buildings Directive [39]. Therefore, in the Netherlands, there are some rules for installing charging stations. When renovating a commercial building, 1 out of 10 parking spots must have a charging point [40]. When a new commercial building is built, 1 out of 5 parking spots must have a charging point. Additionally, from 2050 and onwards, all commercial buildings with more than 20 parking spots are obliged to have at least 1 charging point.

However, the crux is that the ones placing the charging stations are not always the ones that reap the benefits. Should the companies that produce these cars install and maintain these charging stations, should the government do it, should employers do it, or should consumers do it themselves at home? This question is also important when considering the infrastructure at the UT. Why should the UT even provide charging stations in the first place if people can charge their cars at home or somewhere else? These are questions that arise from doing research into this matter. This is a complex consideration that the UT needs to decide on when a scenario arrises that in which the UT might not want to expand their infrastructure.

2.3.6 Limitations and Possible Implementations at the UT

2.3.6.1 Charging Infrastructure

Considering the energy contract and the grid capacity, if the UT wants to expand its infrastructure, either by consuming more or generating more electricity, it will most likely face some problems. Since the cable of the UT supports up to 10MW [30] it could be a possibility to expand their energy contract. However, if the UT wants to incorporate renewable energy into the grid, the infrastructure might also need to be upgraded due to the increased electricity that needs to be transferred on the local grid.

Currently, the charging stations that are deployed at the UT are type 2 charging stations. There are no type 3 charging stations at the UT yet. This means that there is no possibility for DC fast charging at the UT. Fast charging stations could be a nice addition for visitors who have to travel long distances are not staying for a long time and need to charge their EVs quickly.

Additionally, the charging infrastructure of the UT does not have V2G capabilities. This could be a possibility for future implementations. Its merits and some strategies will be discussed in the next section.

2.3.6.2 Charging Strategies

Battery swapping could only be a viable option for the UT if the UT or local companies decide to make significant investments in off-board charging infrastructure. Special charging strategy ideas such as battery swapping, on-road charging, and others are far from being realized and not applicable to the UT and therefore will not be considered.

2.4 State of the Art: Grid management

Smart grid management entails using strategies for managing the grid that can be applied to maintain a stable electric grid. Such strategies aim to efficiently divide available electricity, balance supply and demand, integrate renewable energy, and more [41]. To achieve effective grid management in the case of a University campus, a criterion needs to be derived to asses if a measure is beneficial. The criterion in this case should be feasibility since this is the limiting factor of future e-mobility scenarios. The feasibility can be evaluated by assessing the impact on the electric grid. This impact can be defined as the amount of extra electricity that is needed to accommodate for the different penetration rates of EVs and their corresponding electricity needs.

2.4.1 Grid Impact

A grid impact study indicates the feasibility of a scenario by considering new electrical sources in an existing grid. Therefore, to assess to what extent higher EV penetration rates are feasible at the UT, a grid impact study needs to be performed. To find a suitable approach, multiple studies are discussed. One study researched an approach to assess the impact of plug-in EVs on the Unisa campus electricity net and used the Monte Carlo method to simulate the EV charging profiles according to their vehicle patterns [42]. “Monte Carlo simulation uses random sampling and statistical modeling to estimate mathematical functions and mimic the operations of complex systems” [5, p. 1]. These profiles were used to assess the minimum/average/maximum daily charging profiles. Using these profiles, grid power usage and node voltages could be used to determine the impact of the EVs on the grid.

In the literature, the Monte Carlo method is often utilized in grid impact analyses [44], [45], [46]. Most grid impact analyses in the literature focus on scenarios that differ from University Campuses. However, there are also studies that use this method for a University Campus scenario. One study researched the effect of different EV penetration levels on the electricity grid of a University campus in Ireland [47]. They also used the Monte Carlo method to simulate different penetration rate situations. In their test situation, it was found that 27.3% of their transformers were underrated and that 23.3% of their power lines were congested. These results indicate that either their infrastructure needed improvement or that further research was needed for different optimization solutions, such as to optimize the charging schedules. These papers suggest a useful method to approach grid impact on a University campus, utilizing the Monte Carlo method.

2.4.2 Smart Grid

Making a grid, a ‘smart grid’ is the key to more effective grid management. The electrical grid can become ‘smart’ by incorporating systems that can monitor the grid in real time. This introduces new possibilities for managing the grid, such as real-time information, two-way communication, integration of renewable energy, higher efficiency, and more [48]. With these management possibilities, grid efficiency can be increased. Additionally, this is of importance to the charging of EVs, since this introduces the possibility of gaining control over the charging process, which allows for the use of Demand-side management strategies [49]. Moreover, a smart grid also supports the integration of EVs into the grid with the use of the smart grid technology called vehicle-to-grid (V2G) [50]. V2G facilitates bi-directional energy exchange between EVs and the grid, improving power operation, this process utilizes the battery capacity of EVs.

2.4.3 Backup Batteries for Stability

Similar to V2G techniques, battery packs can also be used to stabilize the electricity net. In smart grid environments, a backup battery can contribute to stability in the system, as well as storing excess renewable energy and reducing strain on the grid. In the literature, a range of studies have explored the possibilities of integrating batteries and renewable energy into the grid [51], [52], [53]. Such solutions can be useful in a campus environment, especially for a campus with PVs. Similarly, a situation was discussed in a study on a College campus in India, where a scenario with a PV-powered charging station that is connected to the grid and includes a backup battery was simulated [54]. It was found that the backup battery allowed for uninterrupted charging of the EVs by utilising bidirectional electricity transmission, the sharing of the sources and loads was satisfactory. This study demonstrates the feasibility of a small-scale application of a backup battery in a PV-fed EV charging station. In a study on a University Campus in Pakistan [55], a similar scenario was researched, namely a hybrid EV charging station that charges employing PV, grid, and battery. However, this station charges based on availability and price per kWh instead. Since these papers present small-scale applications, scalability issues might be introduced when working with infrastructures that include more charging stations and PVs. Additionally, these studies did not discuss how backup batteries help maximize the utilization of PVs and the ability to spread the electric load.

2.4.4 Economic Viability Solar Energy

The grid is not the only factor that needs to be accounted for when considering feasibility. Adequate resources are necessary when building a charging infrastructure. In a study on the King Fahd University campus, a study was conducted on the techno-economic feasibility of generating solar energy to meet the energy demands of an academic campus and EV charging. Comparisons were made on different simulated scenarios using HOMER: simple grid, photovoltaic(PV), simple grid+PV, and smart grid+PV. It was found that the combination of using a smart grid + PV resulted in being the most economically viable [56]. However, this study did make use of net metering. Since regulations, availability, and viability of net metering differ between countries, it may not apply to other situations such as University campuses in the Netherlands.

2.4.5 EV Grid Integration

EVs can be integrated into the grid using vehicle-to-grid (V2G) technology that can positively impact the grid with factors such as power management [57]. V2G technology allows for a bidirectional energy flow between an EV and the grid. By utilizing the battery capacity of EVs, EVs can receive power and deliver power back to the grid. In this way, an EV can act as a temporary energy storage system. By taking advantage of the bidirectional capabilities, techniques such as peak load shaving, load leveling, voltage regulation, spinning reserve and more can be used [58]. Effective use of these techniques can lead to increased grid stability, additionally, this can lead to lower costs for EV users if they are compensated for their provided services to the grid. However, V2G requires significant investments as equipment that supports V2G can be very expensive. Moreover, it also leads to substantial battery degradation due to frequent charging and discharging cycles [50].

Next to possibilities such as vehicle to grid, EVs can be charged based on active power transfer cooperation between different EVs. This method is called vehicle-to-vehicle(V2V) and is investigated in a Chinese Study [59]. It introduces a flexible energy management protocol using V2V algorithms to match users' EV energy demand and surplus. The study found that their proposed charging strategies were feasible and could reduce network energy consumption.

2.5 State of the Art: EV Charging Management

EV charging management strategies aim to increase the efficiency of dividing and using electricity among several EVs. The goals of such strategies are, balancing the load on the electric grid, maximizing the utilization of available resources, and reducing total charging times. In the literature, many different charging strategies that can be employed with optimization techniques and algorithms have been explored. This section discusses the two main charging frameworks, strategies for the respective frameworks, and the phenomenon of overstay.

In a smart grid environment, coordinated EV charging can be achieved in two ways. With a centralized charging framework and a decentralized charging framework [60]. In both these frameworks, there is an aggregator involved, this is an agent that manages charging activities between the EV consumer and the distribution network operator [61]. The aggregator has the interest of both parties at heart. In a centralized framework, the aggregator is responsible for the charging decisions, in a decentralized framework, the EV customer is responsible for the charging decisions [57]. In a centralized framework information is processed centrally, it provides an optimal global solution whilst considering grid constraints and the preferences of users but it introduces computational complexity, which makes it less flexible and scalable [62]. On the contrary, a decentralized framework relies on the decisions of individual EV customers, a globally optimal solution depends on user input and user reliability which leads to less computational complexity, more flexibility, and more scalability. Since the charging is not directly in the control of the aggregator, the charging behavior of users can only be steered, which can be done with incentives such as dynamic pricing.

2.5.1 Centralized Charging and Scheduled/coordinated Charging

Charging schedules can be optimized by using algorithms and user input. This is a possibility when using a centralized charging infrastructure, however, this does require some form of cooperation from the user. This is because users need to give some data/input beforehand in order for the charging schedules to be made. Such a situation was explored in a study on the Damietta University campus. They researched the effect of using optimized charging schedules on EV users' charging behavior. This study was performed with a simulation using MATLAB simulating 50 EVs and 3 charging stations. It was found that by scheduling the charging behavior of EV users based on traveling distance to a charging station, queuing time, and needed energy consumption, the total charging cost can be reduced [63].

The actual efficiency of a scheduled situation relies on the execution of the schedule, in a scenario with autonomous vehicles, this execution does not rely solely on human input anymore. Such a scenario was researched in a study that utilized simulations incorporating real-world parking statistics from Hamburg Airport and the City of Braunschweig [64]. It explored the possibilities of coordinated charging strategies with autonomous EVs in parking places. This was done by exploring multiple strategies, the used algorithm strategies were: Earliest deadline first(EDF), Greedy, Shifting, Flexible, and Scanning. It was found that the scanning strategy was the best-suited scheduler strategy. It yielded high utilization rates whilst minimizing charging station overhead. By simplifying the charging process, charging comfort and utilization rates can be increased. These papers demonstrate the potential of centralized charging with high utilization rates. Moreover, simpler coordinated or scheduled strategies can also be utilized for high utilization rates.

2.5.2 Decentralized Charging and Demand-Side Management

Demand-side management strategies (DMS) can be incorporated to gain more real-time command and control over the electric grid. This could be implemented in a decentralized charging infrastructure since electricity supply and demand constantly fluctuate and usually peak during the day at peak consumption hours. In a study on the Ahsanullah University campus, DMS strategies were investigated. One of these strategies was to have grid-connected solar PV-powered electric vehicle charging stations with battery energy storage and apply a standard tariff [65]. In this study, PV energy generation is present during the day, peaking around the afternoon, the EV energy demand also peaks during the day but remains present during the night. In this case, there is a disparity between the EV energy demand and the PV energy generation. According to this study, by applying grid charging rates, using a backup battery, and supplying the excess energy back to the grid, it is possible to reduce the charging cost for EV owners and reduce peak-hour grid pressure. In a different study, various dynamic pricing charging strategies were reviewed, including real-time pricing (RTP), time of use (ToU), critical peak pricing (CPP), and peak time rebates (PTR) [60]. It was found that RTP is the most covered charging strategy in the literature. RTP is a form of dynamic pricing where pricing is based on real-time electricity prices. This encourages EV users to charge at off-hours, improving grid stability and enabling flexible charging patterns that are aligned with grid demand. Alternatively, PTR schemes can also be used to prevent overloading the grid at peak hours. These strategies do require advanced communication infrastructure to be applied effectively. Such decentralized strategies allow for the charging of EVs without coordination and overloading the grid. However, the effectiveness relies on the awareness of the EV user and its response to incentives.

2.5.3 EV Parking Space Management

Overstay of EV charging stations leads to lower utilization rates. This phenomenon is an often overlooked aspect in EV charging management research. To deal with this problem, incentives can be introduced to remove the car on time. Such incentives can either be positive, encouraging the user to pick up their car, or negative, punishing the user for not picking up their car. A Chinese study explores the option of using different penalty models which include: dynamic, non-linear, and fixed penalties, with the intent of increasing utilization rates. It was found that a fixed-penalty model led to the highest utilization rate [66]. However, the study also suggests that after EV users have gotten used to the fixed-penalty model, the dynamic-penalty model can be introduced to improve the satisfaction of the EV users. Another study researched a completely different approach to this problem. A differentiated pricing based on deadlines, where users agree to a prespecified amount of energy was introduced. The longer the users are willing to extend their deadline, the lower the energy price presented to the consumer. By extending the time a car is in the charging station, the charging load can be spread over longer periods, introducing the ability to incorporate renewable energy and load spreading. It was found that marginal cost pricing, combined with EDF algorithms scheduling, can lead to an efficient equilibrium that maximizes suppliers' profit and social welfare [67]. These papers discuss useful methods to deal with the overstay phenomenon.

2.5.4 Fast Charging

One Spanish study discussed the possibilities of a university-based EV-sharing system utilizing a fast-charging infrastructure [68]. This study simulated charging and driving scenarios around the university campus area to test the technical design aspects, feasibility, and efficiency of such a shared system. The shared system is based around several charging stations spread across the Spanish city of Bilbao. The distances that were covered in the study were up to 30km, comparing this to the UT, 30km could bring users to a lot of the surrounding villages and cities.

The yielded results showed that the designed model could suffice the mobility needs of a University Campus. Such a shared system could be a possibility at the UT which could be considered if there are enough employees who live close by and do not want to commute every day by car or do not want to invest in a car.

Chapter 3 – Methodology

This research follows the principles of the Creative Technology Design Process by Mader and Eggink which is displayed in figure 6 [69]. This approach gives structure to the process that leads to a final product in a stepwise manner. It allows for a wide and rational approach to iteratively work out ideas and optimize them. As the final result often differs from the initial design, this approach has room for reiterations when needed throughout the whole project.

The Creative Technology Design Process usually consists of four phases, a brainstorming phase, a specification phase, a realization phase, and an iteration phase. First ideas are made, then this idea is fit to requirements, then the idea is brought to life, and finally, the product is evaluated and improved.

This project will deviate a bit from the steps taken in the Creative Technology Design Process.

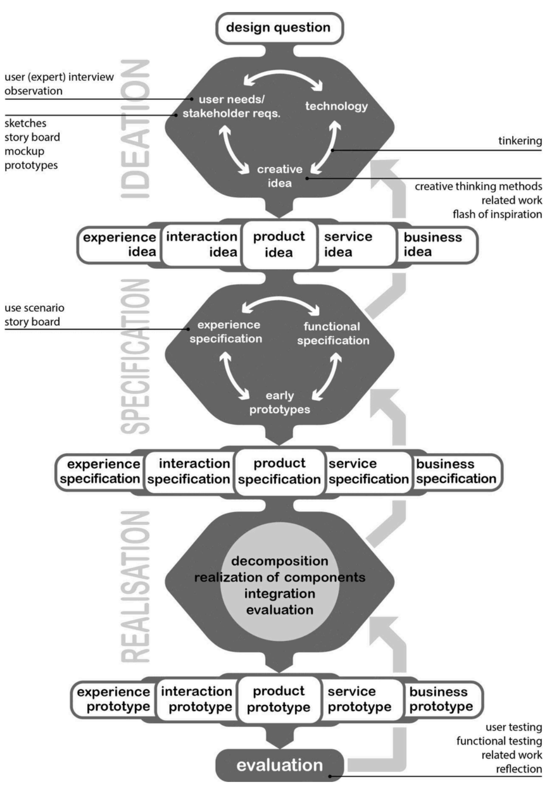


Figure 6: Creative Technology Design Cycle

Before ideating, it is important to have an understanding of the field and the current situation. Therefore there is a need for research on EVs, charging, charging infrastructure and the current situation regarding these topics at the UT. To achieve these objectives, information will gathered with the help of websites, existing literature, data and books. Information regarding the UT that cannot be found online will be acquired through expert interviews.

3.1 Analysis Methodology

After conducting the background research and gaining insights and an understanding of the field, a way to achieve the main objective of this report needs to be found. As the main objective is assessing the impact of future e-mobility scenarios, this assessment of impact needs to be defined in order to be excecuted.

The background research concluded that the impact can be defined as the amount of extra electricity that is needed to accommodate for the different penetration rates of EVs and their corresponding electricity needs.

Since this research aims to give grounded recommendations for possible strategies that can be implemented to optimize the UT infrastructure to prepare for future e-mobility, scenarios. It is necessary to define a criterion that allows to assess if a measure is beneficial. Feasibility is therefore chosen, as this is the limiting factor of future scenarios.

In several studies discussed in the background research that were on similar situations to that of the UT, namely University campuses, the impact was measured by performing grid impact analyses. These analyses were used to assess the feasibility of future e-mobility scenarios. Therefore, to give grounded recommendations and assess the impact of increased EV penetration levels on the UT infrastructure and electric grid an impact analysis will be performed. This analysis will simulate different scenarios using the Monte Carlo method [43]. This analysis will be performed with the use of Python software, and will run on an Intel I5.

This simulation will be run based on different variables. The data that will be used is going to be collected with the help of a survey which can be found in Appendix Section 1 aswell as other available online sources. This questionnaire is going to be spread through word of mouth, email, and via a QR code. The aim is to reach a as much people as possible. This questionnaire will be used to gain insights into several aspects such as arrival and departure time, willingness to extend charging time and charging frequency.

Additionally data that has been collected in an experiment on the solar park at the UT [70] and data from the UT energy platform and the results of some studies will be used in the analysis. The data is planned to be used can be found in table 3.

Amount of parking spaces	1066 places
Maximum electricity capacity	7.5MW contracted (cable supports up to 10MW)
The current amount of personnel that come by car	Estimate with the help of the questionnaire
Current EV penetration rate	Estimate with the help of the questionnaire
EV charging demand + The reasoning behind this demand	Estimate with the help of the questionnaire
Keenness on future EV integration	Estimate with the help of the questionnaire
Stage of charge (SoC)	Estimate with available Amperapark sample + use questionnaire
Occupancy rate: Average arrival time Average departure time	Estimate with available Amperapark sample + use questionnaire
Average electricity usage	UT energy platform

Table 3: Relevant data for assessment

After running the simulations, an assessment will be made on different scenarios. Would the UT be able to deal with the increase of EVs with its current charging infrastructure or are different strategies and optimizations required in order to be feasible? Or, is it not even feasible to charge all the new EVs at the UT? In this case, different solutions have to be found as well.

With this assessment, potential solutions and strategies that can used will be determined. If possible, the simulations will be run again incorporating these strategies or solutions to assess their effectiveness.

Finally, after gathering all the assessments, the gathers will be incorporated into a final prototype. The prototype that will be made is discussed in the ideation chapter.

Chapter 4 – Ideation

There are several possible directions that this project could venture into. The general directions that can be taken are; AI/Algorithms, data visualization, data physicalization, user experience, and tool development. For this project, the direction of data physicalization was chosen as this is an interesting way of displaying the found results in a way that aligns with the Creative Technology mindset and with personal preferences.

The physicalization should convey a message or have some form of goal. To determine this goal, the potential stakeholders of this project are considered. The most important stakeholders are the University of Twente itself which can be seen in table 4. It is important that the design keeps the goals and needs of the UT in mind. Additionally, potential users of the EV charging infrastructure are considered, which include the UT personnel, clients, and visitors.

Important → Least important

Who	University of Twente	University of Twente Personnel	Visitors and clients	University of Twente students and close proximity residential area
Why	The UT is the most important stakeholder as it regards its infrastructure. The effects of their infrastructure will affect them.	The UT personnel are the ones that benefit from the EV charging infrastructure because can charge their cars at work	Visitors/clients can charge their EVs on the University terrain when visiting the UT, they benefit from the EV charging infrastructure They sometimes drive long distances to visit the UT, and also need to recharge their car. They are not present at the UT as long as employees and therefore may require faster charging speeds	With the increased electricity demand for EVs, electricity problems can be introduced, its effects can affect those in close proximity to the UT. Additionally, resources that are spent on EV charging infrastructure cannot be spent on the UT their primary function: being an Educational Institute. Lastly, some students may drive an EV, therefore benefitting from the EV charging infrastructure

Table 4 : Stakeholder analysis

To determine what factors to physicalize and how to do this, a brainstorm was performed, this was done by writing down all the factors that could be potentially be visualized. After this, multiple methods were written down for each factor which can be seen in figure 7.

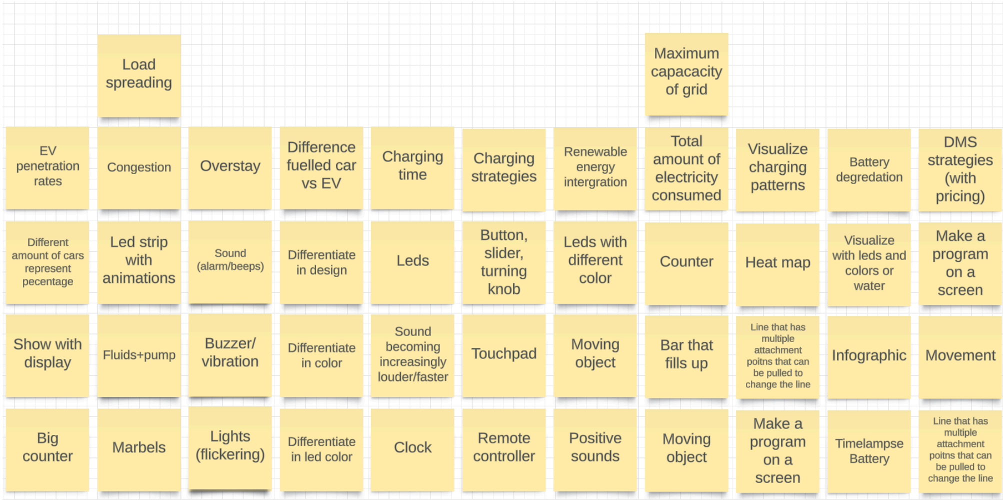


Figure 7: Brainstorm factors

From this, factors were chosen based on their interestability, feasibility, and personal interest.

4.1 Final Concept

The final idea consists of the physicalization of the effect of different scenarios on the electric grid. The prototype consists of a parking lot, in this parking lot multiple cars can be parked/placed. When inserting a car, the car will start charging, this can be seen with an LED bar. The car represents the amount of EV penetration. For example, if there are 5 cars in total, putting 5 cars in the parking lot represents a 100% EV penetration rate. The idea is visualized in figure 8.

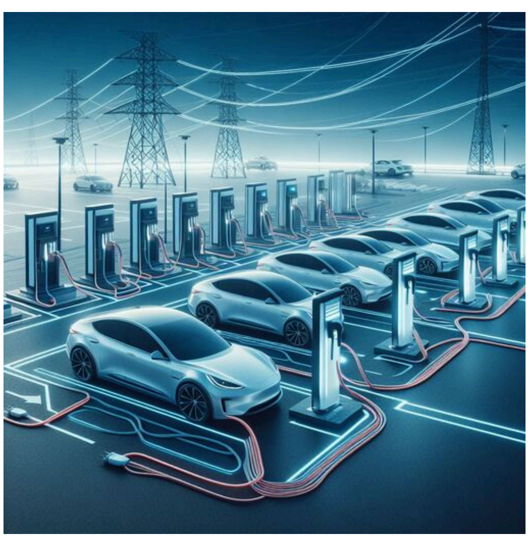


Figure 8: AI generated image of final concept, generated with Microsoft AI

Chapter 5 - Grid Impact Analysis

5.1 Overview

This grid impact analysis calculates the average energy consumption per hour for a certain amount of EVs and charging speed utilizing the Monte Carlo method. It utilizes multiple distributions and probabilities to calculate the charging time per car, energy consumption per EV, and the total required energy to charge the total amount of EVs. These calculations are sorted into the average consumption per hour and represented in a graph. As for the Monte Carlo Method, the calculations are iterated 1000 times and averaged in order to get accurate results. The simulations have been run in the program *Python* (version 3.10.9), the code that has been used for these simulations can be found in Appendix Section 3.

5.1.1 Probabilities and Distributions

The probability P_a of incoming vehicles' arrival time T_a, in 15-minute intervals, is taken from a dataset of the Amperepark at the UT [35] as well as the initial state of charge distribution D_{SoC} with the probability P_{SoC} which was found in a study that created realistic EV profiles using real data of 221 EVs [71]. The capacity C_{Bat} is based on the probability P_{Bat} of the top 10 registered EV models in the Netherlands [16].

5.1.2 Used Data

The distribution that has been used in the grid impact simulation to model the incoming vehicle times is displayed in figure 9. It visualizes the incoming cars in 15-minute intervals.

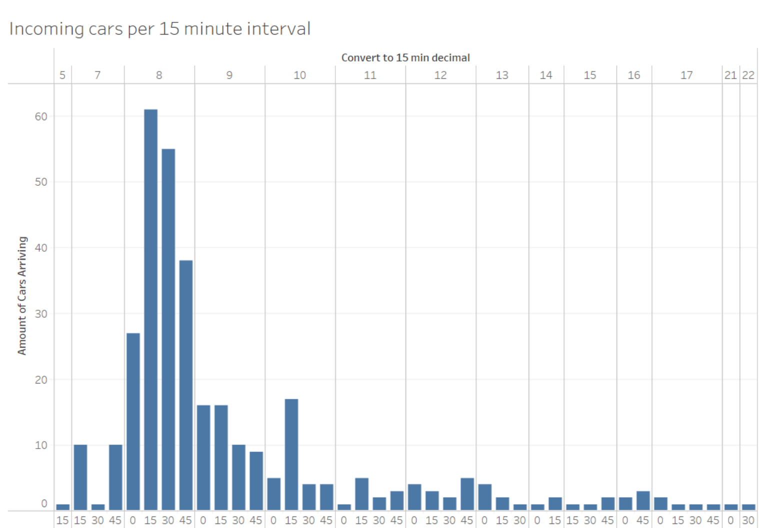


Figure 9: Graphical representation of the number of cars arriving on the y-axis and the time in hours split into 15-minute intervals on the x-axis, made with the help of the software "Tableau"

The initial state of charge probability distribution that has been used in the grid impact simulation can be seen in figure 10 [71]. These numbers are the average initial state of charge states of two charging events in a week during weekdays. Weekdays were chosen since these are working days. The average values of the first and second charging events are used in the simulation.

Units (% battery)	1st	2nd
0 (0.00)	0.58	0.96
1 (8.33)	3.57	4.18
2 (16.66)	8.51	7.41
3 (25.00)	11.77	9.75
4 (33.33)	11.93	9.67
5 (41.66)	11.05	9.53
6 (50.00)	11.75	11.34
7 (58.33)	12.36	10.63
8 (66.66)	9.48	8.58
9 (75.00)	6.54	6.91
10 (83.33)	5.80	7.41
11 (91.66)	3.88	7.02
12 (100.00)	2.78	6.61

Figure 10: Probability distribution of the initial state of charge considering time dependency

The distribution of battery capacity is calculated with the top 10 registered EVs in the Netherlands and can be seen in figure 11 [16]. The probability is based on the number of registered models and their corresponding capacity. By using the most popular EVs in the Netherlands, the model can give a good representation of the current used vehicles which is a good indication of what vehicles will be registered in the coming years.

Brand	Model	Amount	Capacity	
Tesla	Model 3	48.565	57.5	kWh
Kia	Niro	25.205	64.8	kWh
Tesla	Model Y	23.570	57.5	kWh
Volkswagen	ID3	21.339	58.0	kWh
Skoda	Enyaq	18.265	58.0	kWh
Hyndai	Kona	18.237	65.4	kWh
Peugot	208	15.780	48.1	kWh
Volkswagen	ID4	14.790	77.0	kWh
Renault	Zoe	14.413	52.0	kWh

Figure 11: Table Top 10 registered EVs in the Netherlands, the number of registrations per model, and their corresponding capacity

5.2 Calculations

Every calculation is executed N_i amounts of times, this is the number of iterations, the higher this number gets, the longer the program will run, and the higher the accuracy of the calculations will be. It was chosen to run the program for 1000 iterations, which is twice as high as the convergence of the factor of safety which is 500 iterations [72]. This amount of iterations provides accurate results with a low deviation in calculating the mean value while retaining a relatively short program run time.

Additionally, a set charging speed S_{Charge} of 13kW was chosen as this was the most common charging speed found at the UT charging stations and a set charging speed helps to retain simplicity in the model

Firstly, the initial battery capacity of the car is calculated with Equation **(1)** using the possible battery capacities C_{Bat} , the number of cars N_C , and the probability P_{Bat}.

$$Bat_i = rand\,(C_{Bat}, N_c, p = P_{Bat}) \qquad \textbf{(1)}$$

Afterward, the initial state of charge SoC_i is calculated with Equation **(2)** with the probability P_{SoC}, number of cars N_c , and distribution D_{SoC}.

$$SoC_i = rand\,(\,P_{SoC}, N_c, p = \frac{D_{SoC}}{\sum D_{SoC}}) \qquad \textbf{(2)}$$

Then, the required energy to charge each car E_{req} is calculated with Equation **(3)** with the previously calculated initial battery capacity Bat_i found in Equation **(1)** and the initial state of charge SoC_i found in Equation **(2)** .

$$E_{Req} = Bat_i \times (1 - SoC_i) \qquad \textbf{(3)}$$

$$E_{Total} = \sum E_{Req} \qquad \textbf{(4)}$$

Next, the arrival time T_{Arr} is calculated with Equation **(5)** with the probability P_{Arr}.

$$T_{Arr} = rand\,(T_{Arr}, p = P_{Arr}) \qquad \textbf{(5)}$$

After that, the charging time T_{Charge} is calculated with Equation **(6)** with the required energy E_{req} found in Equation **(3)** and the charging speed S_{Charge}.

$$T_{Charge} = \frac{E_{Req}}{S_{Charge}} \qquad \textbf{(6)}$$

Finally, the average energy consumption per hour $\overline{E}_{Con}$ and the total energy required to charge all the vehicles are calculated $\overline{E}_{Mtot}$ with Equation **(7)** and **(8)** using the amount of iterations N_i.

$$\overline{E}_{Con} = \frac{E_{Con}}{N_i} \qquad \textbf{(7)}$$

$$\overline{E}_{Mtot} = \frac{E_{Mtot}}{N_i} \qquad \textbf{(8)}$$

5.3 Results

To give a clear overview of the impact of the added EVs, the output of the calculations is displayed in graphs, and added to the UT worst-case scenario of energy consumption that was mentioned in the background research. The worst-case scenario is used to give an overview of what the infrastructure of UT should be able to cope with as such scenarios can occur.

Since there is a lack of data that could give any indication about the percentage of UT employees that travel to the UT by car or EV and the frequency of this occurrence, an assumption will be made on the amount of EVs that represents a 100% penetration rate based on the amount of parking spaces. Because the UT currently has around 1060 public parking spaces and the percentage of cars in the Netherlands that are EVs is around 5.2%, the assumption will be made that a 100% penetration rate means that there are around 1000 EVs added.

This analysis considers that every EV can immediately charge after arrival meaning there is always a charging station available, additionally, the EV immediately leaves after being fully charged. Issues such as the overoccupancy of charging stations will be taken into consideration in the discussion, however they are not included in the analysis.

Furthermore, the following added EV scenarios are displayed and discussed: 20%, 25%, 40%, and 100% penetration rate.

5.3.1 Scenario 1: 20% penetration rate; 200 added EVs

In the graph displayed in figure 12, the energy consumption of 200 EVs is displayed at a charging rate of 13 kW. It can be seen that there is a peak around 8:00-11:00, which reaches its maximum value around 9:00 at 1440 kWh. The total extra EV energy consumption is around 5.900 kWh, and 112 chargers are needed to cover the peak of the energy consumption.

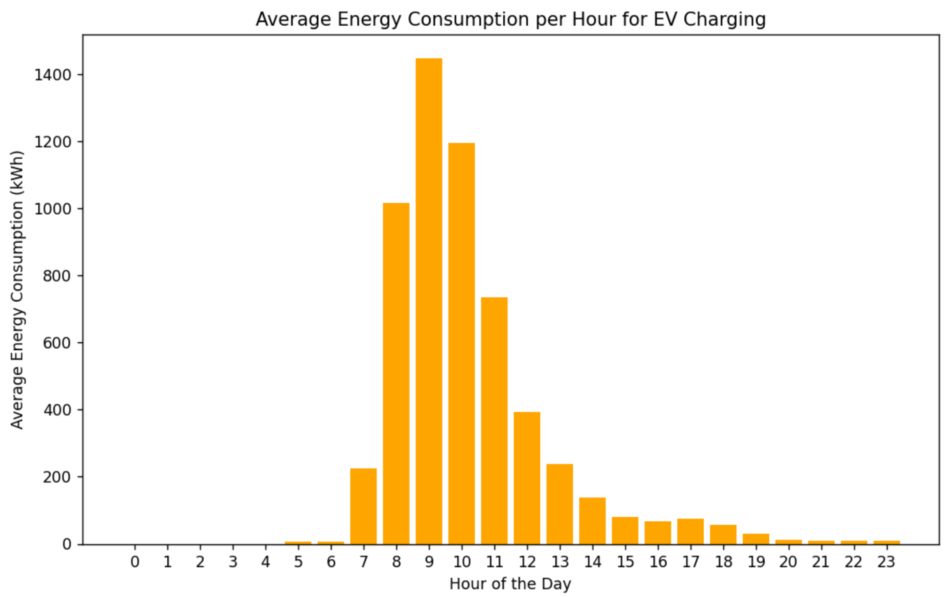


Figure 12: Graph with Average Energy Consumption (kWh) on the y-axis and the hours of the day on the x-axis scenario: 200 added EVs and 13 kW charging speed, obtained through Python and iterated 1000 times

When adding this EV energy consumption to the UT worst-case scenario, it can be seen that the University grid will be at its limits but can still manage the extra consumption, see figure 13. However, there is not a lot of room for extra consumption.

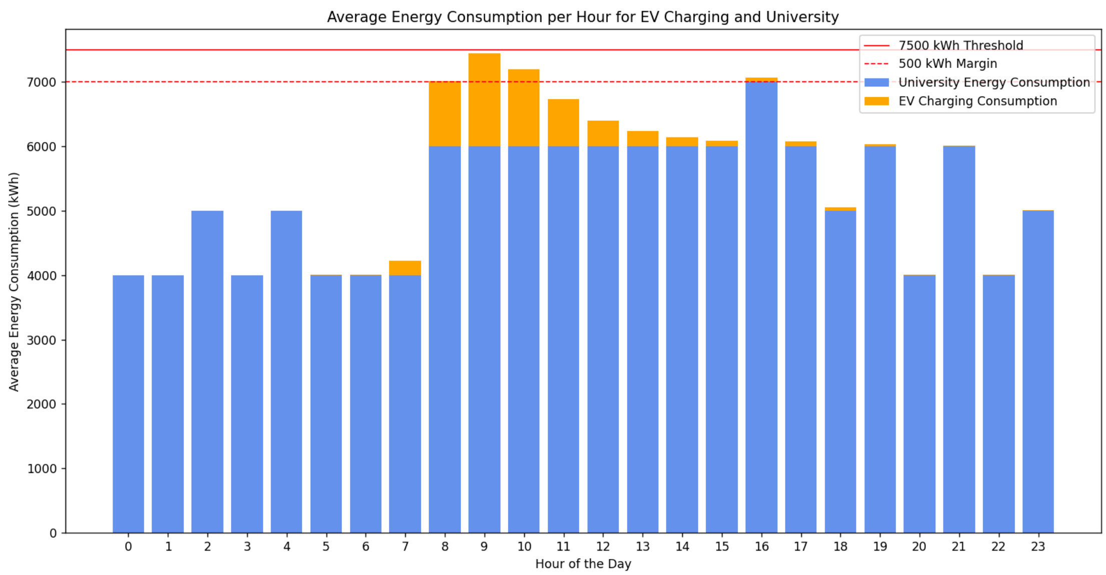


Figure 13: Graph with Average Energy Consumption (kWh) on the y-axis and the hours of the day on the x-axis scenario: 200 added EVs and 13 kW charging speed with UT "worst-case" energy consumption, obtained through Python and iterated 1000 times

Taking the working hours 8:00-18:00 into consideration, there would be hypothetically room for around 16.500 kWh extra consumption, however since 7.500 kWh is a set limit that cannot be passed, a 500 kWh margin is taken into account as the upper limit to be on the safer side. By taking this 500 kWh margin into account, there is around 11.000 kWh capacity left spread over 8:00-18:00.

5.3.2 Scenario 2: 25% penetration rate; 250 added EVs

By increasing the number of EVs by 50, the 500 kWh margin is passed on multiple occasions and the peak exceeds the 7500 kWh limit, this can be seen in figure 14. Subsequently, the peak average energy consumption increases with the increased number of EVs. The energy peaks around 1800 kWh, 139 chargers are needed to cover this peak, and the total added energy consumption is around 7200 kWh, see figure 15.

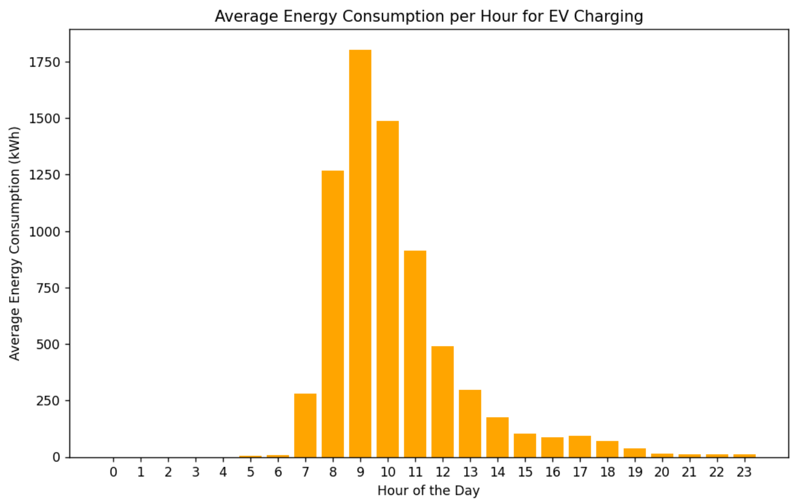


Figure 14: Graph with Average Energy Consumption (kWh) on the y-axis and the hours of the day on the x-axis scenario: 250 added EVs and 13 kW charging speed, obtained through Python and iterated 1000 times

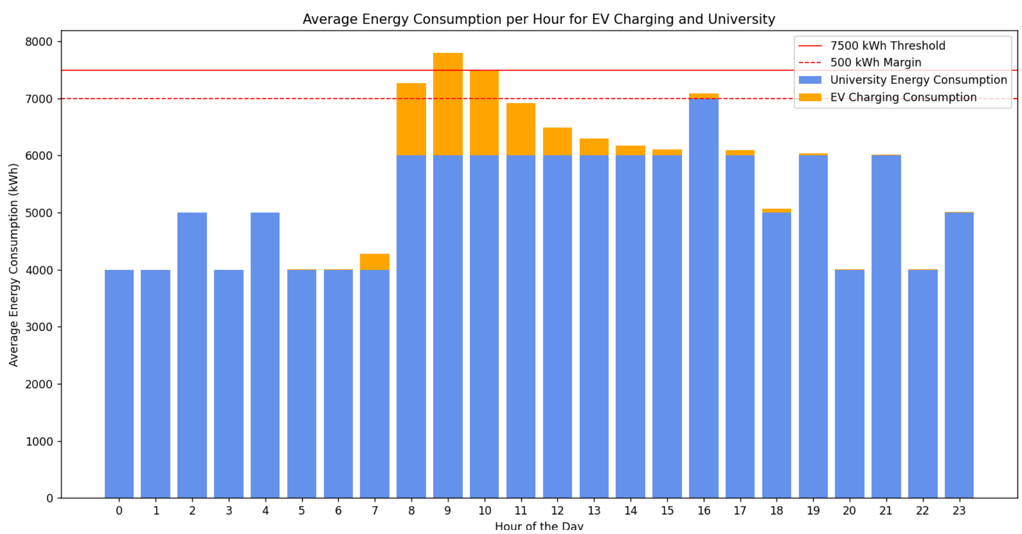


Figure 15: Graph with Average Energy Consumption (kWh) on the y-axis and the hours of the day on the x-axis scenario: 250 added EVs and 13 kW charging speed with UT "worst-case" energy consumption, obtained through Python and iterated 1000 times

5.3.3 Scenario 3: 40% penetration rate; 400 added EVs

The added energy consumption in the 400 EV scenario will be around 11.500 kWh with a peak of around 2900 kWh, 223 chargers are needed to cover this peak.

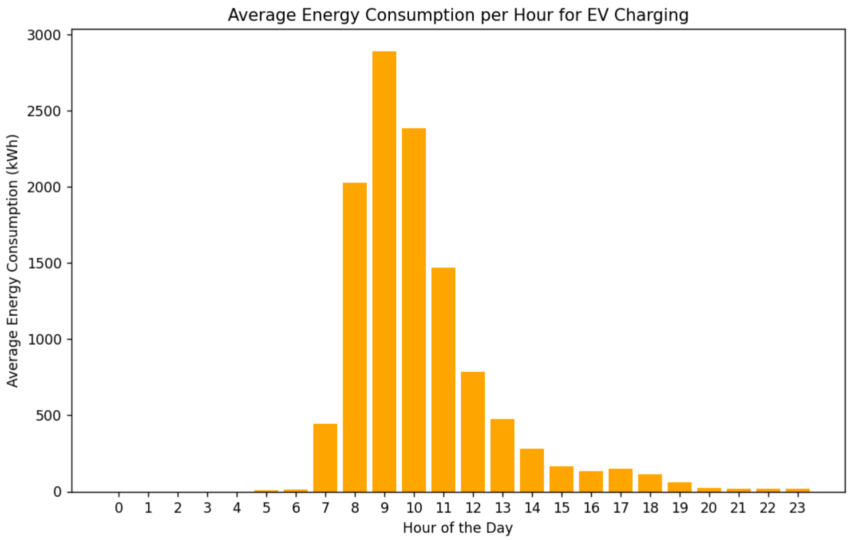


Figure 16: Graph with Average Energy Consumption (kWh) on the y-axis and the hours of the day on the x-axis scenario: 400 added EVs and 13 kW charging speed, obtained through Python and iterated 1000 times

The effects of the increased amount of EVs on the UT grid can be seen in figure 16 and 17. In this scenario with 400 EVs and without applying charging strategies, the energy consumption will exceed the 7500 kWh threshold on multiple occasions.

In a hypothetical scenario where this extra consumption could be spread perfectly over the whole working day (8:00-18:00), there still would not be enough room left for additional consumption if the 500 kWh margin is adhered to. The increase in energy (11.500 kWh) is larger than the left room for energy consumption (11.000 kWh).

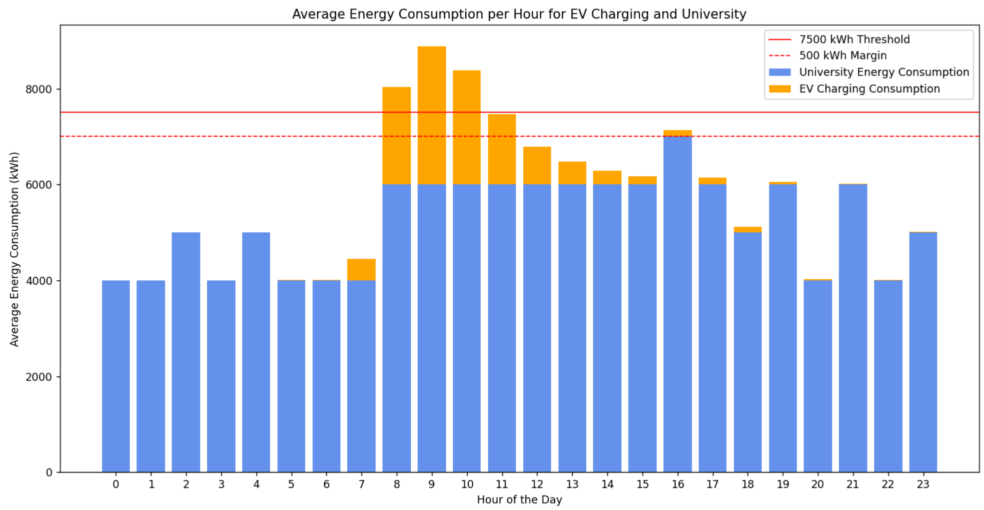


Figure 17: Graph with Average Energy Consumption (kWh) on the y-axis and the hours of the day on the x-axis scenario: 400 added EVs and 13 kW charging speed with UT "worst-case" energy consumption, obtained through Python and iterated 1000 times

However, spreading the load can still be a viable option. To demonstrate this effect, for this scenario, the charging speed is reduced from 13 kW to 5 kW which is a 61.5% reduction, this can be seen in figure 18 and 19. Ideally for load spreading, the charging speed can be reduced during peak consumption hours and increased at lower consumption hours. As this model does not support a variable charging speed, a fixed reduction is used.

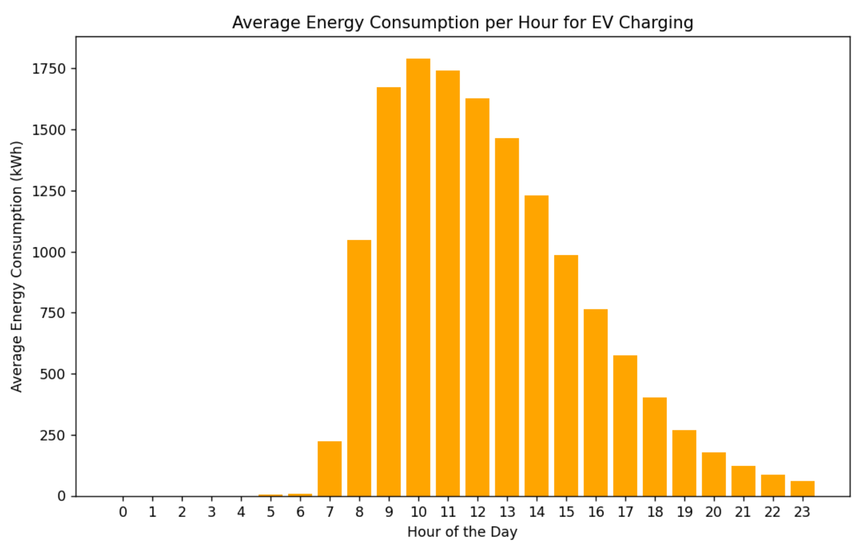


Figure 18: Graph with Average Energy Consumption (kWh) on the y-axis and the hours of the day on the x-axis scenario: 400 added EVs and 5 kW charging speed, obtained through Python and iterated 1000 times

As a result of this reduction, the previous peak from 9:00 gets spread out over the following hours. Consequently, the peak energy consumption gets drastically reduced from 2800 kWh to 1750 kWh, which is a reduction of 37.5%. However, this increases the amount of charging stations that are needed to cover the peak from 223 to 288, which is an increase of 29.1%. These results showcase the potential effects of loadspreading. It can be seen in graph x that even with the lower charging speed, with 400 extra EVs, there is barely enough electric capacity at the UT without taking the 500 kWh margin into account.

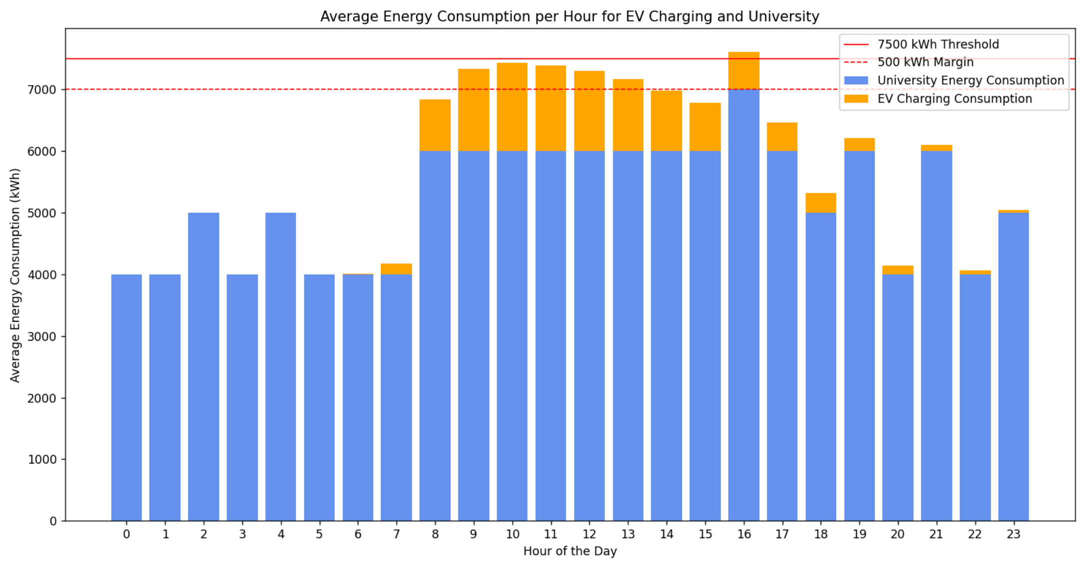


Figure 19: Graph with Average Energy Consumption (kWh) on the y-axis and the hours of the day on the x-axis scenario: 400 added EVs and 5 kW charging speed with UT "worst-case" energy consumption, obtained through Python and iterated 1000 times

5.3.4 Scenario 4: 100% penetration rate; 1000 added EVs

In this 100% penetration scenario with 1000 EVs added the total amount of increased energy consumption is around 28.700 kWh peaking at around 7200 kWh needing 556 chargers to cover this peak, see figure 20. When considering such high numbers of added EVs, it can be observed in figure 21 that the electricity grid of the UT cannot withstand such high amounts of EVs.

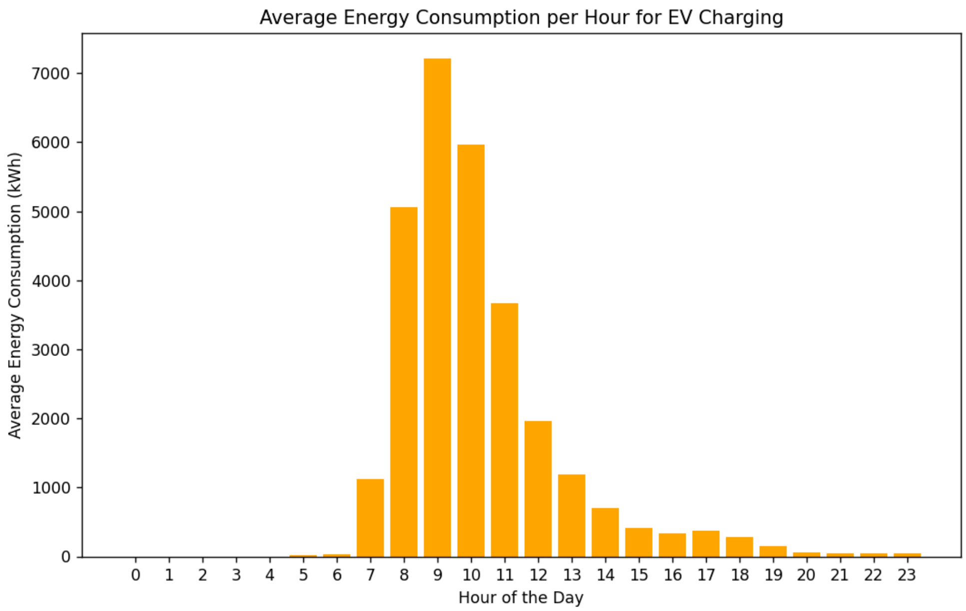


Figure 20: Graph with Average Energy Consumption (kWh) on the y-axis and the hours of the day on the x-axis scenario: 400 added EVs and 13 kW charging speed, obtained through Python and iterated 1000 times

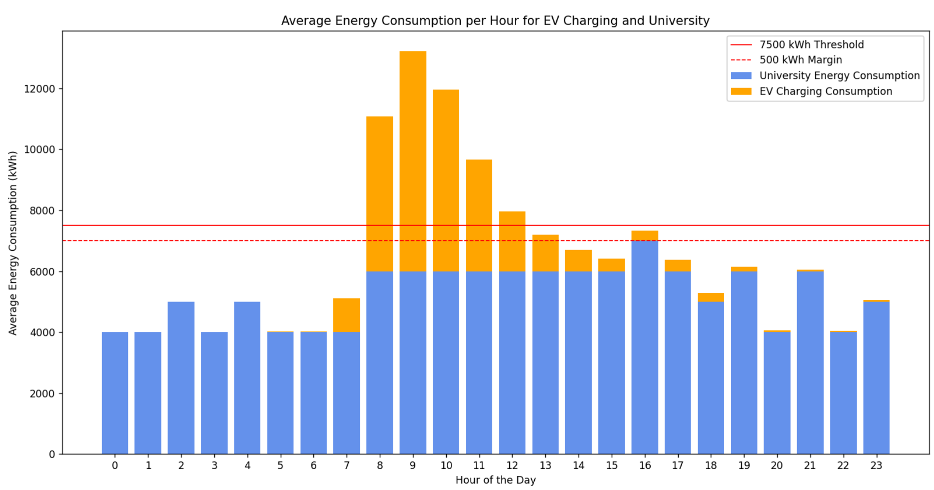


Figure 21: Graph with Average Energy Consumption (kWh) on the y-axis and the hours of the day on the x-axis scenario: 1000 added EVs and 13 kW charging speed with UT "worst-case" energy consumption, obtained through Python and iterated 1000 times

In table 5, an overview can be seen of the result all the scenarios.

Scenario Number	Penetration rate	Added EVs	Charging Rate	Peak/ Maximum Value	Required Chargers (peak)	Total Added Energy Consumption
1	20%	200	13kW	1.440 kWh	112	5.900 kWh
2	25%	250	13kW	1.800 kWh	139	7.200 kWh
3	40%	400	13kW	2.900 kWh	223	11.500 kWh
3	40%	400	5 kW	1.750 kWh	288	11.500 kWh
4	100%	1000	13kW	7.200 kWh	556	28.700 kWh

Table 5: Overview of the grid impact analysis results of the different scenarios

5.4 Survey Results

The survey has a sample size of 77 people, out of which 73,9% own a car, 51,7% visit the UT by car on either a regular or irregular basis, and out of those people, 9 drive an EV and 6 a hybrid car. The results of the survey can be found in Appendix Section 2.

5.4.1 Arrival and Departure Times

The survey results indicate that most employees arrive between 8:00 and 9:00, this aligns with the used arrival distribution. However, while most of the peak of the arrival rate is between 8:00-9:00, a lot of employees arrive at 9:00 as well therefore the peak found in the survey may be shifted between 15-30 minutes later and lasts longer. Additionally, the results suggest that most employees leave the UT between 17:00 and 18:00, this means the electric load could potentially be spread between 8:00 and 18:00.

5.4.2 Charging Frequency

Out of the 15 employees that drive an EV/hybrid, 53% have never charged their car at the UT before, and the remaining 47% charge their car at the UT occasionally, sometimes, or on a regular basis. Out of this 47%, only 2 employees charge their car at the UT once or multiple times per week. The most common reason (60%) is that the employees prefer charging their car at home.

5.4.3 Charging Flexibility

Of the EV and hybrid car owners, 84,6% indicated that they do not mind how long their car charges, as long as it is full at the end of the day. Out of the non-EV car owners, 73,7% indicated that if they would own an EV, they would not mind how long their car charges. By performing a small statistical analysis, it can be concluded that the first group shows that this is a significant trend with a 95% confidence interval between 0.650 to 1.0421. This suggest that the true proportion is likely between 65.0% and 104.2%. The second group shows a significant trend with 95% confidence interval between 0.539 to 0.9350 which suggests that the true proportion is likely between 65.0% and 104.2%.

Additionally, 54% of the EV and hybrid car owners would be willing to charge their car at a later time for a lower charging price.

Although the sample size of this survey is relatively small, these results might indicate a general trend that most employees do not mind how long their car charges. Furthermore, as the results indicate that about half the employees would be willing to delay their charging start time for a lower charging price, therefore it can be concluded that there may be willingness of some employees to delay their charging start time. In practice, these results should be validated with a larger sample size to make well-grounded conclusions.

5.5 Discussion and Recommendations

This section discusses potential options the UT has, considering their EV infrastructure and the potential approaches/strategies the UT could take/utilize to deal with the increasing EV penetration rates. This discussion is based on the background research, the grid impact analysis, and the survey results.

5.5.1 Future Scenario

One study predicts that in the Netherlands in 2030 out of all the registered vehicles, 26% will be EVs [26]. This is about five times higher than the current share of EVs (5.2%), meaning that the UT will have to deal with five times the amount of current EVs in 6 years.

Assuming the UT has around 1000 cars parked daily, this would mean that there are about 50 EVs parked. This would mean that by 2030, there will be an increase of around 250 EVs. As seen in the analysis, the UT could cope with this increase if the load is spread throughout the day, but the grid is already nearing its maximum capacity. The penetration rate will increase more in the years following 2030, meaning that the UT has to take some action regarding its infrastructure to cope with the increasing penetration rate. This can be done by optimizing the charging process, cutting back on energy consumption in certain areas, increasing its own energy generation, investing in energy storage, or expanding its energy contract, the last option seems unlikely as the UT lies in an area where according to Netbeheer Nederland, there is no transport capacity available for large consumers or companies [73].

5.5.2 Centralized or Decentralized Charging

Decentralized charging strategies often rely on user responsiveness on price incentives. When relying on such dynamic pricing strategies users are incentivized to charge at off-hours as mentioned in the background research, however, such strategies may not be as effective in the setting of the UT. Most employees arrive in the morning, leaving their cars to charge during the day. Employees may not respond to the dynamic pricing because it means they have to move their EV during the day or want to ensure that their EV is charged and therefore let it charge immediately after arrival. The survey results can not conclude a definite trend that indicates that UT employees are willing to move their cars at a later moment in exchange for a lower charging price.

In a centralized charging framework, potentially scarce resources can be distributed among vehicles where the aim is to reach a globally optimal solution. As seen in the background research, there are multiple approaches in a decentralized framework, one could utilize historical data, individual EV charging patterns, make use of scheduling to optimize the overall charging process, and more. In general, a centralized charging framework is a good approach to optimize resource distribution where the capacity of the grid can be fully exploited [74].

Considering the advantages of a centralized charging framework, this approach seems to be suitable for the situation of the UT. However, one should mind the limitations of centralized charging frameworks as they tend to be less flexible than a decentralized charging framework, and also require a robust communication infrastructure

First of all, centralized charging frameworks benefit from predictability as aggregators have the responsibility to participate in the electricity market, they need to minimize the deviation between their expected demand and the actual demand [75]. In a situation such as the UT, personnel generally visit the location regularly and usually arrive around the same time. Such situations have less variation in the people that occupy the parking places and the times that these are occupied than for example at a public parking spot. This in turn leads to more consistency and predictability in terms of charging behavior.

Secondly, insights into charging data can lead to optimization of the overall charging process at the UT, therefore the EV users' acceptance of sharing their data should be considered [75]. The willingness of UT employees to share their data might be higher than the average user of a public charging point because the UT as an employer can be seen as trustworthy. Currently, UT employees charging data is already being collected at the AmperaPark, under specific agreements [35].

Lastly, when opting for a centralized charging infrastructure a complex and expensive communication infrastructure is needed [74]. The complexity of the infrastructure increases with the number of EVs, it can be expensive to invest in such an infrastructure.

5.5.3 Load Spreading

The results of the analysis indicated that the EV charging energy demand is the highest during the morning after most of the UT employees arrive. This energy demand peak becomes very high around 9:00-10:00, this is problematic because this large increase will result in a big temporary increase in energy demand. Ideally, this demand could be spread throughout the day when there is more energy available therefore spreading the load over longer periods. This can be achieved in multiple ways: peak shaving, load shifting, or utilizing V2G possibilities.

The survey indicates a trend that most UT employees do not mind how long their car charges. This indicates that a variable charging speed to spread the load over longer periods might be a viable option.

5.5.4 Solar Energy

Generating more energy is the most straightforward solution for making up for an energy deficiency. Among the most common methods to generate electricity, the most suitable method for the UT is Photovoltaic panels (PVs). PVs generate electricity and therefore provide a return on investment in the long term. As PVs are a renewable energy source, investing in PVs adds to the sustainable status of the UT. Although PVs generate electricity, there is a large investment cost and it will take some time to generate enough electricity to make a profit on the PVs.

Additionally, a different factor that needs to be taken into consideration, is the fact that new PV technology could be invented in the upcoming years. This could increase their efficiency immensely as most current PVs are only between 15-20% efficient [76]. PV manufacturers are constantly trying to improve efficiency in their solar panels setting new records for efficiency with the panels reaching up to 24.1% efficiency [77]. Therefore, current PVs might become outdated in the near future.

Furthermore, the energy generation of PVs is time-dependent, since the sun mainly shines during the day. This factor cannot be controlled and since electricity generated by PV either needs to be used or stored a new problem is introduced, the electricity demand and supply need to be matched. To give an indication of how this might affect the placement of PVs at the UT, an energy generation curve of a cluster of PVs in Enschede on an average sunny day in March is displayed in the graph in figure 22 [78].

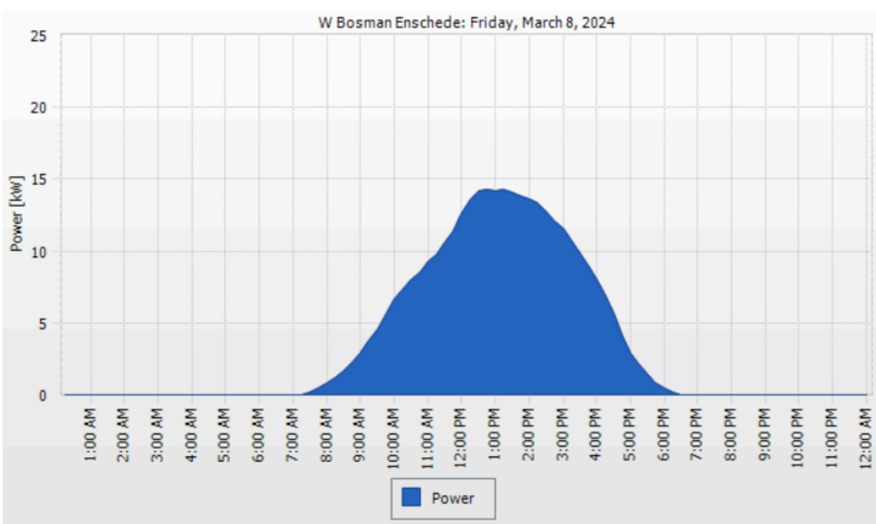


Figure 22: PV energy generation curve on an average sunny day, generated by a cluster of PVs in Enschede on 8/03/2023

This graph displayed in figure 22 was chosen as it represents an energy generation curve that is expected of an average sunny day. PV-energy generation can differ a lot depending on the weather, therefore such energy generation curves can differ from the one found in this graph. In the graph, it can be seen that the energy generation of the PVs peak around 12:00/13:00. As seen in the aforementioned distribution graph in figure 9, the arrival rate is the highest during the morning around 8:00-9:00, which results in a peak energy demand for EV charging around 9:00-10:00 in case no charging strategies are applied. Therefore, there is a disparity between the two peaks. When the PV-generated energy generation is at its highest, the EV charging demand is already fairly low, since PV-generated energy is expensive to store, it is difficult to charge the cars with PV-generated energy without applying other charging strategies. Consequently, such charging strategies seem to be necessary to charge EVs with PV-generated electricity.

In the background research, such a setup where excess PV-generated electricity was delivered back to the grid, was found to be economically viable. However, the Dutch government may put a halt to the delivery of PV energy back to the grid for small users in 2027 [79]. Depending on the nuances of these measures, this may also apply to the UT and is, therefore, an unreliable factor for the future. However, since the UT consumes a lot of electricity during the day, if feasible, the electricity can be supplied back to its own grid instead. A different option would be to store the excess energy in batteries, this will be discussed later.

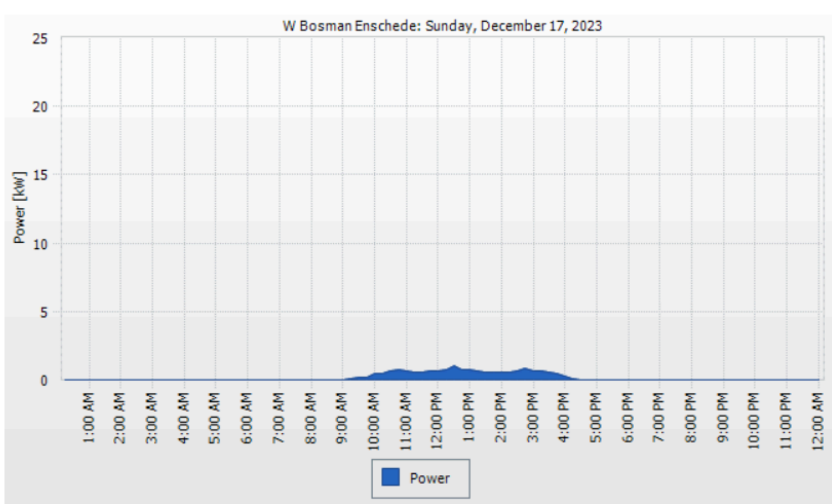


Figure 23: PV energy generation curve on an average winter day, generated by a cluster of PVs in Enschede on 17/12/2023

Additionally, limiting factors need to be considered when installing PVs. PVs can only be installed in some places, the orientation of the panels in relation to the direction of the sun has a lot of impact on the amount of energy the PVs [80]. Moreover, not every roof is suitable for the installation of PVs, the roof should first be evaluated by an architect or a structural engineer

[81]. One downside that needs to be considered is the PV-energy generation, which is a lot lower around the winter months (October - February) [82], [83]. In figure 23, the energy generation curve of an average winter day is displayed. Around the summer months (May-August) the energy generation can be 5 times as high as the generation around the winter months. Considering this and the fact that the worst-case scenario used in the grid impact analysis occurred in September, the effectiveness of PV energy generation to cover the electricity consumption during September may be limited and should be taken into account when investing in PVs.

5.5.6 Batteries

Investing in energy storage can be expensive, when considering to invest in energy storage the energy capacity is not the only factor to consider, the charging rate is also important. Batteries with higher energy density can store more energy at a smaller size, a higher charging rate means that a battery can charge and discharge at a higher speed [84]. High-charging rate batteries can supply electricity at a high rate, introducing the possibility for various implementations. One study proposed using a stationary $LiFePO_4$ battery pack as an energy buffer in an ultra-fast charging station [84].

One rather expensive and difficult-to-implement solution could be to invest in a large amount of energy storage. These large energy storages could act as a large energy buffer, being able to temporarily store large amounts of energy and use them when energy demand is high. In combination with a variable energy contract, these large batteries could take advantage of lower electricity prices and low energy demand during the night. The batteries could be charged at night by the grid and be used at higher demand hours. With storage that is large enough to buffer the additional EV energy demand, this solution could hypothetically work. However, this solution could be seen as a “band-aid” solution as it solves the problem by shifting it from one moment to another. It does not give a return on investment in the long term as it does not create any type of revenue. Additionally, such a strategy would struggle to be economically viable. One study researched the possibilities of a grid-connected battery system that could take advantage of off-hour electricity rates [85]. It was found that such a system was not profitable.

A better solution would be to combine energy storage with PVs as described in the background research. Battery energy storage could resolve the energy disparity problem of PVs as it allows for temporary storage that can shift the energy load. Excess PV-generated energy can be stored and its consumption can be postponed until needed. Additionally, the aforementioned strategy of storing grid-supplied energy at lower prices could also be applied, but then on a smaller scale. This could be a viable option around the winter months when there is less PV-generated energy available and the precedence of additional backup energy is needed.

5.6.7 Grid Integration

In the background research it was found that by integrating vehicles into the grid, one can enhance grid stability. Therefore, the UT electricity grid could become more stable and flexible by utilizing such V2G possibilities and it opens up the opportunity for several techniques such as peak load shaving, load leveling, voltage regulation, spinning reserve, and more [58]. However, as there are currently no charging stations at the UT that allow for a bidirectional energy flow, there are no possibilities for V2G options at this moment. Because such charging stations are expensive, it would require large investments in the UT charging infrastructure to introduce such possibilities. Therefore before deciding on such matters, it is important to consider if it really is beneficial for the UT and ergo worth the investment.

As the survey indicated a trend that most people do not mind how long their car charges, this could indicate that it would be possible to have a lot of cars that stay stationary for long periods. This is beneficial for V2G techniques, with more stationary EVs there is a larger total capacity that can be utilized for the different V2G techniques.

Before considering the implementation of V2G services, willingness to participate in these services needs to be considered. Since V2G faces several technical challenges in the short and long term that can influence its success, users, in this case, UT employees, may not be open to taking part in such practices. The greatest impediment V2G faces is that V2G services can accelerate battery degradation, which reduces total battery capacity [86], [87], [88], [89]. Additionally, security and privacy issues can be concerns to users, for V2G to succeed, these technical barriers need to be resolved [90].

Chapter 6 – Realisation

6.1 Overview

Having completed the discussion on the results of the grid impact analysis and the survey results, the subsequent step is incorporating these results into a working prototype. As discussed during the ideation, the prototype is a physicalization of different factors.

To incorporate the results of this project into the final prototype, the physicalization uses data from the performed grid impact analysis.

6.1.1 Prototype Goal

The aim of this physicallization is to inform stakeholders of the possible future EV scenarios at the UT. To achieve this goal, the meaning of the important factors needs to be conveyed to the user of the prototype. By translating these factors from data into something tangible, the data is displayed in a more immersive and creative way, offering a different perspective. This can make it more interesting and understandable for the user.

6.1.2 Hardware and Software

In order to make a prototype that can attain the intended features, microcontrollers are used to power and control actuators with the help of sensors. The used microcontrollers are an Arduino Mega 2560 [91] and an Arduino Uno [92], and the actuators used are three WS2812B ledstrips [93], additionally a potentiometer, a push button, and a 4-digit LED display [94]. The code that is used on the 2 Arduinos can be found in Appendix Section 4

6.1.3 Data Physicallization

The main factors that need to be displayed are the hourly electricity consumption of the UT and the added electricity consumption of the added EVs. Contexts need to be given to be able to interpret this information, the importance of the amount of added electricity consumption should be clear to the user. Therefore there should be a noticeable difference between the different types of electricity consumption as well as an indication when too much electricity is being consumed.

The data is displayed by an LED strip that lights up a certain amount of LEDs based on the amount of electricity consumed. Next to this LEDstrip, there is a bar that gives contextual information on the consumption by providing numbers next to the LEDstrip. The LEDs light up in different colors depending on the type of energy consumption, after too much energy is consumed, the LEDs will turn red to indicate the size of the electricity surplus. The point maximum amount of energy that can be consumed will also be indicated on the bar.

This physicalization entails a simulation in which the user is allowed to influence the outcome. By incorporating multiple inputs that the user can select, the outcome will differ based on the input. The prototype is shown in figure 24.

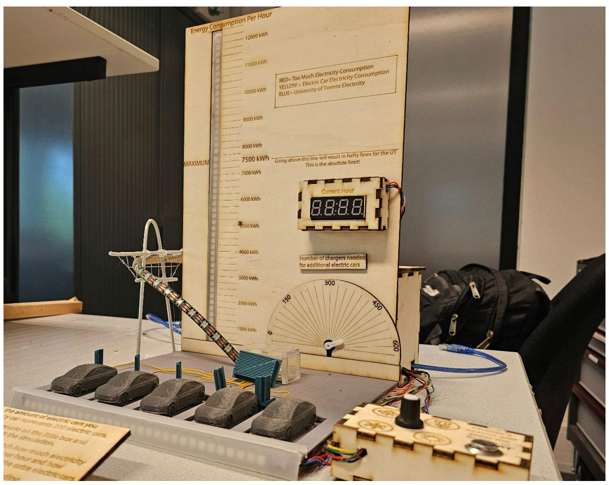


Figure 24 : Prototype Turned Off

6.1.4 Inputs

Firstly, the user can select the amount of added EVs by placing down tangible cars into slots that represent parking spots. For every added car, 200 EVs will be added to the simulation, this represents a 20% increase in the EV penetration rate. When all 5 cars are added, the simulation results will incorporate a 100% EV penetration rate scenario. The effect of placing down the cars can be seen immediately, several LEDs will light up yellow depending on the amount of cars that are placed down.

Secondly, the user can select a season; spring, summer, fall, and winter, see figure 25. For every season, there is one worst-case scenario of the daily electricity consumption pattern of the UT. By selecting the scenario, it will be incorporated into the simulation.

Figure 25 : Prototype Season Selection Panel

6.2 Simulation

Afterward, the user can start the simulation by pressing a button. There are several outputs, namely 3 different LED strips a servo motor, and a digital time display. The simulation is split in 24 hours, every 2 seconds, a new hour will be displayed. The current time will be indicated by a digital time display. Depending on the season, a certain amount of LEDs will turn blue, based on how much electricity is consumed in that hour by the UT. Depending on the amount of cars that are placed down, a certain amount of LEDs will turn yellow on top of these blue LEDs. If too much electricity is consumed, the additional LEDs will turn red instead of yellow. The other LED strip that indicates how many cars were placed down will slowly turn green depending on how much EVs have been charged at that point. Additionally, depending on how many EVs have been placed down the servo changes position on a scale to indicate how much chargers are needed to charge the additional EVs.

6.3 Process

During the realization of the prototype, several factors have been changed, tweaker or added. During the testing of the functionality, it was found that servo motors and LEDstrips can interfere with each other in certain situations and therefore a second Arduino was added with the help of serial communication to reduce this interference. Moreover, initially, the servo motor was intended to indicate the time, however, as this was not very clear, a digital display was used instead. The wire detection system was originally intended to be built solely with wires, however as the area of these wires is not that large, this was not working effectively. Therefore a material with a larger conductive area was needed, copper tape was the ideal solution as it was a thin material with a large conductive area.

Additionally, there was one extra feature in the physicalization that aimed to shed light on an often overlooked problem in EV charging. After EVs have been fully charged, they are often not removed immediately, thereby unnecessarily occupying a charging station and decreasing its utilization rate. To show this in the physicalization, a random event is incorporated into the simulation that can activate anywhere during the simulation. This event pauses the simulation, a buzzer will turn on and and LEDs will blink red next to a certain car. This indicates that this EV is fully charged and needs to be removed to continue the simulation. After removing the car, the simulation will continue.

However, it was decided not to implement this feature as its implementation caused errors that were too complicated to solve in this timespan.

Chapter 7 – Evaluation

7.1 Overview

The user evaluation aims to evaluate the prototype with the following measures; how well the prototype can achieve its goals, and the usability of the system. As the goal of the prototype is to inform stakeholders of possible future e-mobility scenarios, the main findings of the grid impact analysis should be conveyed in a clear way to the user. Therefore, the evaluation investigates how well the users understand the prototype and its intended purposes. Apart from that, the System Usability Scale(SUS) is utilized to evaluate the usability of the system [95]. This method was chosen since it is a quantitative measurement that can measure how well the prototype works. The questions that were used in the evaluation can be found in Appendix Section 5, the consent form template in Section 6 and the System Usability Scale template in Section 7.

7.1.1 Setup and Process

Before starting the evaluation, the user is asked to read the consent form and give their consent to participate in this study, this form can be found in Appendix Section 6. After receiving consent, the user receives a short oral explanation of the prototype. The user can then try out the prototype in the way they want to. After a couple of minutes of trying out the prototype, the user is asked to fill in a short questionnaire that includes the SUS. After the questionnaire is filled in, the user is thanked for their participation, which concludes the evaluation.

7.1.2 Ideal User Group

Ideally, the user group would consist of a mix of stakeholders including those with different amounts of knowledge about electric vehicles and different amounts of prior experiences with data physicalizations.

7.2 Results

The written notes of the short interviews can be found in Appendix Section 5.

7.2.1 User group

Since the time of this project was limited, it was not achieved to arrange an ideal group of users. In reality, the participant group that evaluated the prototype consisted of students. A sample size of 12 people was used to evaluate the prototype. Most participants have had previous experience with data physicalizations, lots of participants also made one themselves, while there were some who had limited to no experience with data physicalizations. The participants' knowledge of EVs varied from 3 to 9 on a scale of 1-10, with most participants rating their knowledge between 3 and 6 with a mean of 5,3.

From the 12 participants an average SUS score of 79,8 was found with a median of 82,5, this can be classified as good, almost reaching an excellent score which is reached at around 80,3 - 80,7 [95], [96]. This suggests that the prototype has good usability. However, one should consider that most participants already had previous experiences with data physicalizations, and therefore the usability could potentially be lower in a user group with people who do not have any experience with data physicalizations. In future evaluations, it could be considered to try to find participants without any previous experience with data physicalizations.

7.2.2 Comments, feedback and suggestions

Almost all participants found the prototype aesthetically pleasing and overall well put together and also easy to interpret after explanation. Moreover, a lot of participants liked the various inputs and outputs such as the ledstrip and the interactivity by being able to place down the cars and choosing a season. Many participants had positive comments about the understandability of the prototype. However, most participants also commented that it would probably be difficult to understand the prototype without a short oral explanation. Therefore multiple participants suggested making a detailed explanation or an explanation poster. Multiple participants also misinterpreted the blue lights at the beginning as they found it difficult to understand what the University Energy Consumption exactly entails. This could be explained more clearly on the prototype.

Additionally, multiple participants also thought they could change scenarios during the simulation which is a feature that is deliberately locked as it could create confusion during the simulation and break the continuity of the simulation. This feature either could be changed or it should be indicated before using the prototype.

Some participants also suggested that they would prefer it if they could control time itself so they could easily go to the interesting parts of the simulation that they wanted to see by for example a scrolling wheel. This suggestion could be implemented by introducing a separate mode or removing the timer and introducing this scrolling function. However, this would change the idea of the prototype which is to showcase the impact of the EVs, not only on a specific moment but on the whole day in general.

7.2.3 Prototype Intended Goal

All participants indicated that they learned something from the prototype. Most participants did not know that the University consumes so much electricity in general and did not expect that EVs would need so much electricity to be charged. Additionally, most participants did not expect that EVs would have such a big impact on the electricity grid and did not know that there was not that much room left for additional electricity consumption. Several participants also commented that the UT should carefully choose when and how to charge the EVs. These comments indicated that the experience with the prototype was informative and educative as most participants learned something new. Since a lot of participants were surprised about ny the newly learned information, the prototype seems to be able to spread awareness on this topic. Therefore the prototype seems to achieve its intended goal.

Chapter 8 – Discussion & Future Work

8.1 Discussion

The rate of vehicle electrification in the Netherlands is predicted to increase rapidly in the coming years [26], to cope with this, the Dutch government has to take action. However, the Dutch government is not the only one that will feel the consequences, the whole country will have to consider the impact of the increase in EVs. The UT in particular as a research institute and employer of many people, will have to consider partial or full e-mobility scenarios in the near future and its consequences.

This research project has focused on researching the impact of EVs on the electric grid, particularly on scenarios that were similar to the UT. First and foremost, with an expert interview it was found that the UT has 7.5MW contracted energy contract, this is an upper limit that when passed will result in hefty fines for the UT. With the performed grid impact analysis, it was found that in a worst-case scenario, the infrastructure of the UT would not be able to cope with a 25% EV penetration rate increase without applying any strategies as this surpasses the 7.5MW limit. To combat this problem, there are several options that the UT can take. These include optimizing the charging process, cutting back on energy consumption in certain areas, increasing its own energy generation, investing in energy storage, or expanding its energy contract.

8.1.1 Solutions

Additionally, it was found that a centralized charging framework would be the most fitting framework for the UT their charging infrastructure. However at higher EV penetration rates, the problems become more pronounced, and solutions that most likely come accompanied by large investments, need to be found to cope with such high rates. Investing in PV panels seems to be the most straightforward solution, however, this also comes with its limitations as PV-energy generation is weather, season, and time-dependent. Additional technical limitations also further increase the difficulty of implementing PV panels. Therefore more nuanced options may be needed that can operate in different circumstances. Additionally, charging strategies can optimize the charging process and can introduce the possibility of load spreading. As the survey results indicate there is a significant trend in the willingness of users to charge their car over longer periods of time, therefore it could potentially be a viable strategy.

Using the grid impact analysis, it was also found that even with charging strategies where one would be able to perfectly spread the additional load, there still would not be enough room left for increased amounts of EV charging electricity consumption. At a 40% EV penetration rate there is already bearly enough room to spread the additional load, when considering a full e-mobility scenario there is not enough room to spread the additional load.

8.1.2 Survey

The conducted survey had a sample size of 75. However, of these people, only a small percentage owned an EV or hybrid vehicle. This limits the amount of conclusions that can be derived from the survey. Therefore a bigger sample size would be beneficial, however since the amount of people who own an EV is still relatively small, it is also normal that it is hard to find people who own an EV to participate in a survey.

The results of the survey indicated that some people do not charge their car at the UT despite owning an EV, with the main reason being that they prefer to charge at home. For future implementations, the rationale behind this could be explored.

As discussed in the grid impact analysis results, insights into charging data can lead to optimization of the overall charging process at the UT, therefore the EV users' acceptance of sharing their data should be considered [75]. The users' willingness to share their data could be polled with the help of a widespread survey, consequently, this might lead to more research opportunities.

8.1.3 Limitations

This study also comes with some limitations, first off all it is important to consider that the grid impact analysis makes use of multiple estimations. Therefore, as the results are predictions that consider the most important factors, they will never be fully accurate as the reality is more nuanced. It will however give a representative estimation of what the actual situation could look like.

The analysis uses a linear 13kWh charging speed. In reality, there are several charging stations with different amounts of charging speeds at the UT, the model could potentially include different charging speeds as well as fast charging stations. Higher charging speeds lead to higher energy consumption in a shorter time span, resulting in higher energy consumption peaks. Additionally, the charging station availability and travel time are not considered in the analysis. If charging stations are occupied due to overstay, the utilization rates of the charging stations decrease, which could potentially decrease the energy consumption of the simulations. Furthermore the travel time that potentially increases as more charging stations are occupied, due to increased searching time and travel distance, can potentially lead to a small increase in energy consumption and lower utilization rates. However, depending on the placement of the charging stations, this would have a minimal impact on the simulation outcome. Another factor that is not considered in the analysis is the efficiency of the charging stations, as charging equipment can introduce energy losses which in some cases can be up to 32% [97], [98], [99]. This further increases the amount of energy that is needed to charge the EVs. This differs per charging station and in practice this could be measured to get an even more accurate estimation of the required energy to charge the EVs.

Another factor that has not been taken into account is the placement of the charging stations, it has not been considered in the analysis neither has it been considered in the rest of the report. This can be ascribed to the fact that no concrete information about the transformer stations at the UT could be acquired. As the electric load also needs to be distributed throughout the campus, one cannot place all the charging stations in one spot without considering the transformer stations. Therefore when planning on installing more charging stations, the placement of these stations should be considered carefully.

Moreover, the background research on grid and charging management was limited in its scope since mostly only situations similar to the UT were considered. More charging strategies exist that are applicable to different situations but, these are outside the scope of this project.

8.5 Future implementations

For future implementations, it could be considered to ask the participants about their willingness to make use of V2G technologies. This can be an interesting topic to research when V2G technologies have developed so much that it could be considered a viable option for the UT.

Other future possibilities that could be researched include V2G technologies, alternative charging methods, fast charging, and informing users about battery life. These options were briefly explored in this report but could yield results that could improve grid stability and reduce electricity demand. Additionally one different interest aspect that could also be researched is the optimal ratio of charging stations to electric vehicles, this could be helpful when deciding on investing in more charging stations.

Furthermore, another future possibility would be to research charging management strategies specifically on the situation of the UT. One option would be to incorporate charging management strategies into the used grid impact analysis to see how the strategy influences the simulation.

Chapter 9 – Conclusion

This report focussed on assessing the impact of a full e-mobility scenario at the University of Twente. This was done by critically assessing the UT its current EV charging infrastructure, exploring different existing solutions, and with those solutions providing suggestions for the UT to cope with a full e-mobility scenario. It was found that an EV penetration rate of 25% and higher would have a large impact on the UT which could result in the UT being fined by their electricity provider.

To get an indication of how much energy a full e-mobility scenario would require, a grid impact analysis was performed. A full e-mobility scenario is estimated to be an increase of around 1000 EVs, this would lead to an increase of around 28.700 kWh in electricity consumption to charge all these EVs. Moreover, the results of the analysis also give an indication on the impact on the electricity grid of the UT as the results indicate that without applying any strategies the UT would currently not be able to cope with an increase of 250 EVs. As the impact of a full e-mobility scenario would be four times as large, the UT would currently not be able to cope with a full e-mobility scenario.

To find suitable charging strategies for the UT, research has been conducted on similar scenarios to the UT such as University Campuses. It was found that a centralized charging framework would be suitable for the UT as it is a good approach to optimally distribute the available resources of the grid. On top of that, with such a framework the UT could optimize its charging process with methods such as utilizing historical data, researching individual EV charging patterns, scheduling, and more.

Moreover, solutions were explored that could help the UT to cope with the increased EV charging energy demand. It was found that investing in PV panels is a viable option for the UT to generate electricity to adhere to the increased energy demand whilst being profitable in the long term. However, as PV-energy generation is undependable as it relies on the activity of the sun, other solutions are needed to ensure grid reliability. Such options include investing in battery storage to temporarily store PV energy, optimizing the charging process, cutting back on energy consumption elsewhere, and using loadspreading techniques. Additionally, the survey results indicated a significant trend; most UT employees do not mind how long their car charges, as long as it is full before they leave. Smart charging techniques utilizing variable charging speeds could potentially be implemented.

To educate the UT community and create awareness on the impact of EVs on the electricity grid of the UT, a prototype was made to convey the main results in fun and immersive way. This was achieved by making a data physicalization. With the evaluation of the prototype it was found that the prototype was effective at achieving its intended goal; educating people about the impact of the EVs on the UT its electricity grid.

This report sheds light on an important issue, namely, the large impact that EVs can have on the electricity grid of the UT. In the literature, there are different studies that have explored the impact of EVs on the grid. Research has been done on similar situations, such as university campuses in different countries. However, there is currently no existing research in the case of UT, which makes the research of this report novel. As EV charging infrastructure is currently an ongoing issue in the Netherlands this report researches a relevant topic. The UT will not be the only one that will have to deal with these kinds of issues. Other universities and companies might run into the same types of problems.

Moreover, this report contributes to the existing research by providing insight into the specific case of the UT. This report can also be of importance to the UT as it spreads awareness of a problem that may currently be overlooked. It warns the UT about possible future scenarios with higher EV penetration rates. Furthermore, this report could act as a starting point for further research on the UT EV charging infrastructure possibilities. As mentioned in the discussion several interesting options can be explored which can be relevant to the UT.

All in all, taking the results of this report into account, the UT should consider looking into their EV charging infrastructure and making concrete plans to ensure that they are adequately prepared for the transition to EVs.

Appendix

1: Survey Questions

Section 1 of 12

Quick Survey Electric Cars UT

I am a student at the University of Twente from the faculty of EEMCS. I'm currently working on my bachelor thesis project, which aims to asses the impact of future e-mobility scenarios; what will happen when the UT personnel will start driving electric cars. This survey is intended for UT personnel and the survey aims to estimate factors and gain insights into topics that are related to electric cars at the UT.

The data you provide will remain **anonymous**, be stored for a few months, kept private (it will not be published) and will be used to estimate some variables that can be used for a general analysis. You can **always resign** from this survey at any given moment. The survey might take around **1-3 minutes** to complete. Please contact me if you have any questions by sending an email to: *j.j.schondorff@student.utwente.nl*

Do you consent to your data being used anonymously in this research? *

- ◯ Yes
- ◯ No

Section 2 of 12

Verification UT Employee

Description (optional)

Are you an employee at the UT (researcher, PhD, supporting staff, etc.) *

Student jobs are **excluded**

- ◯ Yes
- ◯ No

Section 3 of 12

Insights on current car population at the UT

Description (optional)

Do you own a car? *

- ◯ Yes
- ◯ No

Section 4 of 12

Insights on current car population at the UT

Description (optional)

Do you usually come to the UT by car? *

- ◯ Yes
- ◯ No
- ◯ Sometimes
- ◯ Other...

Section 5 of 12

Insigths on arrival and departure times

Description (optional)

Is your car electric? *

- Yes
- No
- Hybrid

Around what time do you usually arrive at the UT? *

(You can give an indication around which half hour/hour you arrive at the UT on a normal workday, for example: **8:30 or 9:00**.. etc.)

Time

Around what time do you usually leave the UT? *

(You can give an indication around which half hour/hour you usually leave the UT on a normal workday for example: **8:30 or 9:00**.. etc.)

Time

Section 6 of 12

Insigths on arrival and departure times

Description (optional)

Around what time do you usually arrive at the UT? *

(You can give an indication around which half hour/hour you arrive at the UT on a normal workday, for example: **8:30 or 9:00**.. etc.)

Time

Around what time do you usually leave the UT? *

(You can give an indication around which half hour/hour you usually leave the UT on a normal workday for example: **8:30 or 9:00**.. etc.)

Time

Section 7 of 12

Insights about the charging frequency and EV charging infrastructure usage

Description (optional)

How often do you charge your car at the UT? *

- I have never charged my car at the UT before
- Occasionally (multiple times in a year)
- Sometimes (around once a month or more)
- Often (around once a week or more)
- Frequent (multiple times per week)

Section 8 of 12

Insights on energy requirements

Description (optional)

How low does your car's battery typically get before you plug it in to charge at UT *

- ◯ Less than 25%
- ◯ Between 25% and 50%
- ◯ Between 50% and 75%
- ◯ More than 75%
- ◯ Other...

Section 9 of 12

Insights on energy requirements

Description (optional)

Why are you not charging your car more often at the UT? *

- ☐ The charging prices are too high at the UT
- ☐ There are not enough chargers
- ☐ There are not enough parking spaces
- ☐ I prefer charging my car at home
- ☐ Other...

Section 10 of 12

Insights on user preferences and flexibility

Description (optional)

Do you care about how long your car would take to charge when you're at work at the UT? *

- No, as long as it is full before I leave
- Yes, I want my car to be charged quickly as I'm not staying long
- Yes, I would like to have it charged quickly (in case I want/need to leave earlier)
- Sometimes (I occasionally want/need to leave earlier)
- Other...

Would you be willing to charge your car at a later time for a lower charging price? *

- Yes
- No

Section 11 of 12

Insights on user preferences and flexibility

Description (optional)

If you would have an electric car, would you care about how long your car would take to charge when you're at work at the UT? *

- ◯ No, as long as it is full before I leave
- ◯ Yes, I want my car to be charged quickly as I'm not staying long
- ◯ Yes, I would like to have it charged quickly (in case I want/need to leave earlier)
- ◯ Sometimes (I occasionally want/need to leave earlier)
- ◯ Other...

Section 12 of 12

Thank you for participating

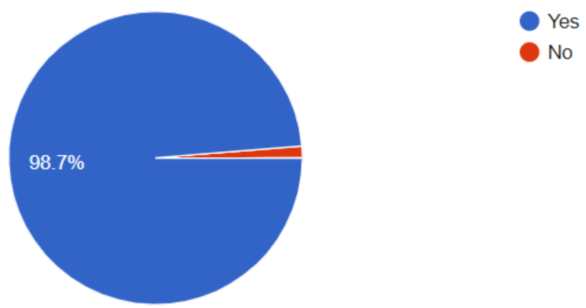
Thank you for participating in this survey. Your answers will be stored anonymously and kept for 1.5 months. Afterwards they will be deleted. In case you want your answers to be removed or in case you have any questions, you can contact me at *j.j.schondorff@student.utwente.nl*

2: Survey Results

Do you consent to your data being used anonymously in this research?

Copy

77 responses

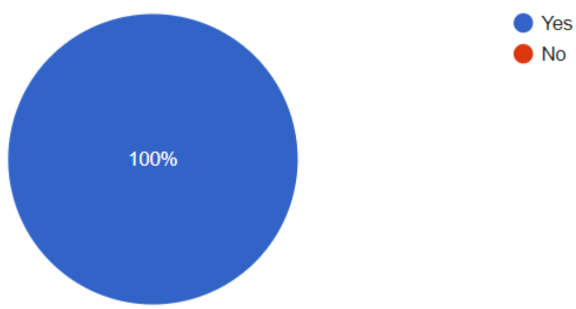


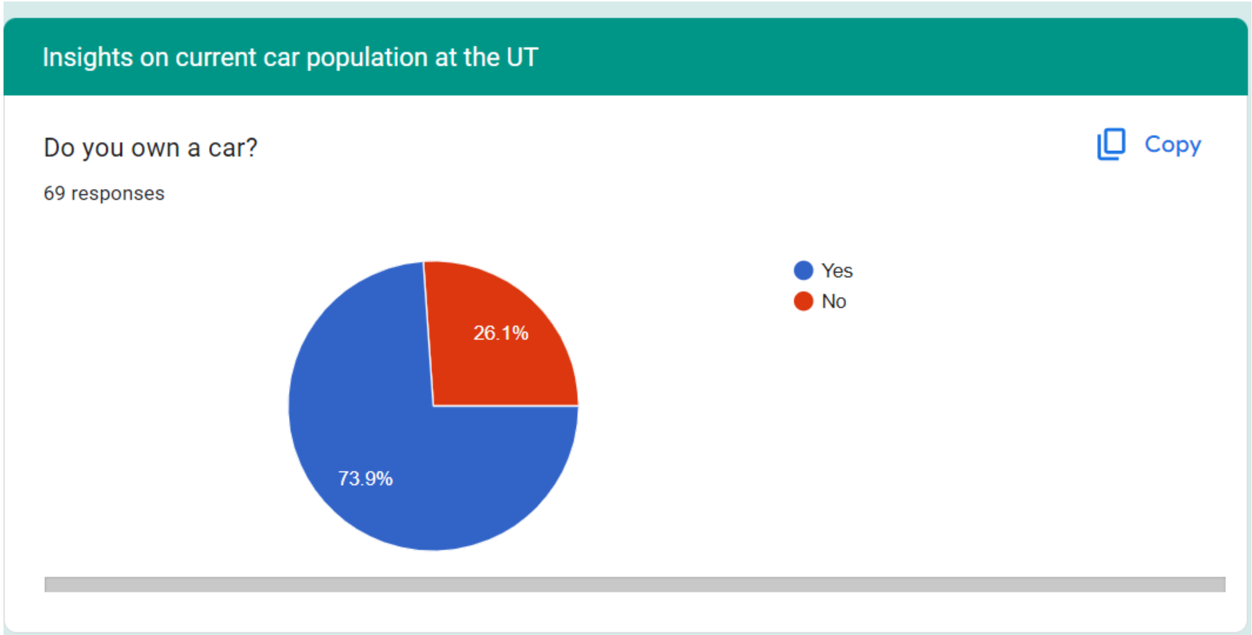
Verification UT Employee

Are you an employee at the UT (researcher, PhD, supporting staff, etc.)

Copy

76 responses



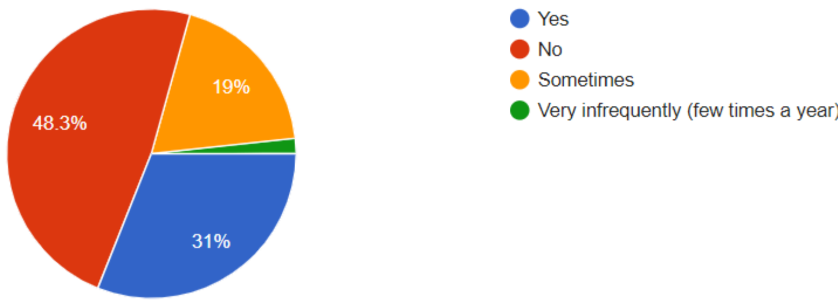

Insights on current car population at the UT
Do you own a car?
Copy
69 responses
26.1%
73.9%
Yes
No

Insights on current car population at the UT

Do you usually come to the UT by car?

Copy

58 responses

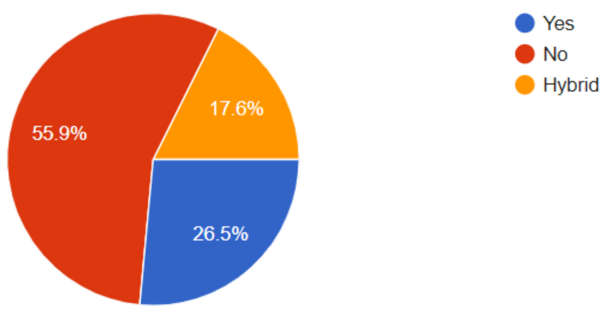


Insigths on arrival and departure times

Is your car electric?

Copy

34 responses



Around what time do you usually arrive at the UT?

34 responses

07 : __ AM	7:30 AM; 7:45 AM
08 : __ AM	8:00 AM 4; 8:15 AM 2; 8:20 AM 2; 8:25 AM; 8:30 AM 6; 8:45 AM 3; 8:50 AM
09 : __ AM	9:00 AM 6; 9:15 AM; 9:30 AM 4
10 : __ AM	10:00 AM 2

Around what time do you usually leave the UT?

34 responses

01 : __ PM	1:00 PM
04 : __ PM	4:00 PM; 4:30 PM 3
05 : __ PM	5:00 PM 9; 5:10 PM; 5:15 PM 4; 5:30 PM 9
06 : __ PM	6:00 PM 4
07 : __ PM	7:00 PM
11 : __ PM	11:00 PM

Insigths on arrival and departure times

Around what time do you usually arrive at the UT?

42 responses

07 : __ AM	7:30 AM 2
08 : __ AM	8:00 AM 5; 8:15 AM; 8:20 AM; 8:30 AM 7; 8:45 AM 4; 8:55 AM
09 : __ AM	9:00 AM 16; 9:30 AM 4
10 : __ AM	10:00 AM

Around what time do you usually leave the UT?

42 responses

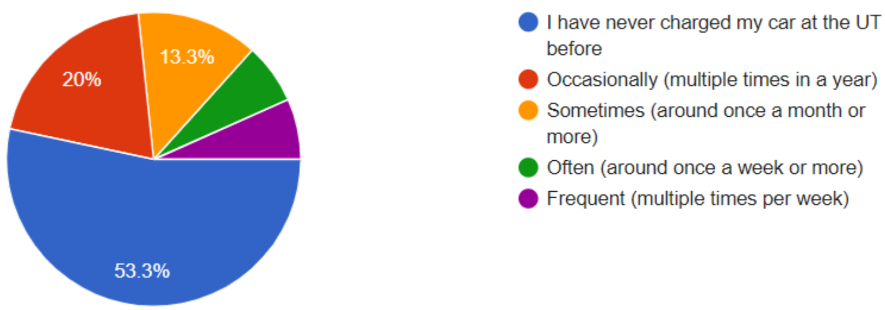
01 : __ PM	1:30 PM
03 : __ PM	3:30 PM
04 : __ PM	4:00 PM 4, 4:30 PM 3, 4:45 PM 2
05 : __ PM	5:00 PM 13, 5:15 PM 2, 5:30 PM 8, 5:45 PM 4
06 : __ PM	6:00 PM 3, 6:30 PM

Insights about the charging frequency and EV charging infrastructure usage

How often do you charge your car at the UT?

Copy

15 responses

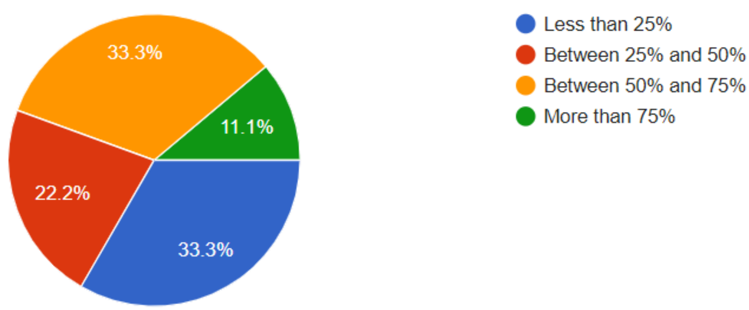


Insights on energy requirements

How low does your car's battery typically get before you plug it in to charge at UT

Copy

9 responses

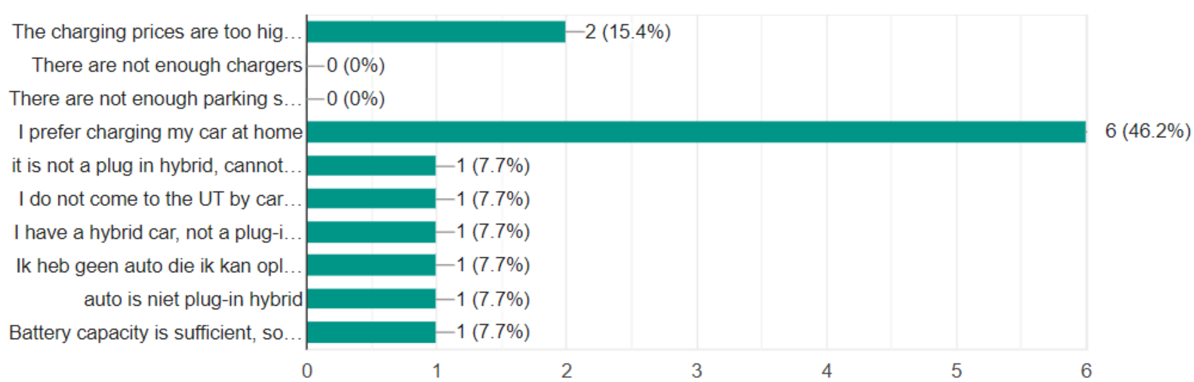


Insights on energy requirements

Why are you not charging your car more often at the UT?

Copy

13 responses



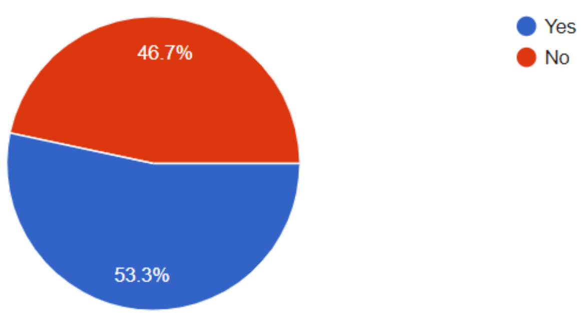
Insights on user preferences and flexibility

Do you care about how long your car would take to charge when you're at work at the UT?

15 responses

Would you be willing to charge your car at a later time for a lower charging price?

15 responses



Insights on user preferences and flexibility

If you would have an electric car, would you care about how long your car would take to charge when you're at work at the UT?

Copy

19 responses

3: Python Code: Grid Impact Analysis

```
import numpy as np
import matplotlib.pyplot as plt
# Seed for reproducibility
# np.random.seed(42)

# Given data
soc_distribution = [0.77, 3.875, 7.96, 10.76, 10.83, 10.29, 11.545, 11.945, 9.02, 6.725, 6.605,
5.365, 4.695]
soc_percentages = np.array(
    [0, 8.33, 16.66, 25.00, 33.33, 41.66, 50.00, 58.33, 66.66, 75.00, 83.33, 91.66, 100.00]) /
100
battery_capacities = [48.565, 57.5, 64.8, 57.5, 58.0, 58.0, 65.4, 48.1, 77.0, 52.0]
battery_probabilities = [0.19, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.05, 0.1, 0.06]

# Arrival times and their probabilities
arrival_times_data = [
    ('05:15', 1), ('07:15', 41), ('07:30', 1), ('07:45', 10), ('08:00', 27),
    ('08:15', 62), ('08:30', 55), ('08:45', 38), ('09:00', 16), ('09:15', 16),
    ('09:30', 10), ('09:45', 9), ('10:00', 5), ('10:15', 17), ('10:30', 4),
    ('10:45', 4), ('11:00', 1), ('11:15', 5), ('11:30', 2), ('11:45', 3),
    ('12:00', 4), ('12:15', 3), ('12:30', 2), ('12:45', 5), ('13:00', 4),
    ('13:15', 2), ('13:30', 1), ('14:00', 1), ('14:15', 2), ('15:15', 1),
    ('15:30', 1), ('15:45', 2), ('16:00', 2), ('16:45', 3), ('17:00', 2),
    ('17:15', 1), ('17:30', 1), ('17:45', 1), ('21:00', 1), ('22:30', 1)]
arrival_times = np.array([int(t.split(':')[0]) + int(t.split(':')[1]) / 60 for t, _ in
arrival_times_data])
arrival_probabilities = np.array([p for _, p in arrival_times_data])
arrival_probabilities = arrival_probabilities / arrival_probabilities.sum()

# Charging station speed (kW)
charging_speed = 13
# Number of cars and iterations
num_cars = 1000
num_iterations = 1000

# Simple Calculation
soc_choices_simple = np.random.choice(soc_percentages, num_cars, p=np.array(soc_distribution) /
sum(soc_distribution))
battery_choices_simple = np.random.choice(battery_capacities, num_cars, p=battery_probabilities)
energy_required_simple = [(1 - soc) * battery for soc, battery in zip(soc_choices_simple,
battery_choices_simple)]
total_energy_simple = sum(energy_required_simple)
print(f"Total energy required to charge x cars (Simple Calculation): {total_energy_simple:.2f}
kWh")
```

```
# Monte Carlo simulation
total_energy_monte_carlo = 0
energy_consumption = np.zeros(24)

for _ in range(num_iterations):
    for _ in range(num_cars):
        # Randomly select battery capacity
        battery_capacity = np.random.choice(battery_capacities, p=battery_probabilities)

        # Randomly select initial SoC
                initial_soc  =  np.random.choice(soc_percentages,  p=np.array(soc_distribution)  /
sum(soc_distribution))

        # Calculate energy needed to charge
        energy_needed = battery_capacity * (1 - initial_soc)
        total_energy_monte_carlo += energy_needed

        # Randomly select arrival time
        arrival_time = np.random.choice(arrival_times, p=arrival_probabilities)
        arrival_hour = int(np.floor(arrival_time))
        arrival_minute_fraction = arrival_time - arrival_hour

        # Calculate charging time in hours
        charging_time = energy_needed / charging_speed

        # Update energy consumption for each hour of charging
        start_time = arrival_time
        end_time = arrival_time + charging_time

        start_hour = int(np.floor(start_time))
        end_hour = int(np.ceil(end_time))

        if start_hour == end_hour:
            energy_consumption[start_hour] += energy_needed
        else:
            # Energy for the first partial hour
            first_hour_energy = (1 - arrival_minute_fraction) * charging_speed
            if first_hour_energy > energy_needed:
                first_hour_energy = energy_needed
            energy_consumption[start_hour] += first_hour_energy
            energy_needed -= first_hour_energy

            # Energy for the intermediate full hours
            for hour in range(start_hour + 1, end_hour):
```

```
                if hour < 24:
                    if energy_needed > charging_speed:
                        energy_consumption[hour] += charging_speed
                        energy_needed -= charging_speed
                    else:
                        energy_consumption[hour] += energy_needed
                        energy_needed = 0

            # Energy for the last partial hour
            if end_hour < 24 and energy_needed > 0:
                last_hour_energy = (end_time - end_hour) * charging_speed
                if last_hour_energy > energy_needed:
                    last_hour_energy = energy_needed
                energy_consumption[end_hour] += last_hour_energy

# Average energy consumption per hour
average_energy_consumption = energy_consumption / num_iterations
print(f'Total Energy Consumption (Monte Carlo quick calculation) per hour (kWh):
{np.sum(average_energy_consumption)}')

# Calculate the total energy consumption
average_energy_monte_carlo = total_energy_monte_carlo / num_iterations
print(f'Total energy required to charge x cars (Monte Carlo Simulation):
{average_energy_monte_carlo:.2f} kWh')

# University energy consumption per hour
university_energy_per_hour = [4000, 4000, 5000, 4000, 5000, 4000, 4000, 4000, 6000, 6000, 6000,
6000, 6000, 6000, 6000, 6000, 7000, 6000, 5000, 6000, 4000, 6000, 4000, 5000]

# Plotting the results
plt.figure(figsize=(10, 6))
plt.bar(range(24), university_energy_per_hour, color='cornflowerblue', label='University Energy
Consumption')
plt.bar(range(24), average_energy_consumption, bottom=university_energy_per_hour, color='orange',
label='EV Charging Consumption')
plt.axhline(7500, color='red', linestyle='-', linewidth=1, label='7500 kWh Threshold')
plt.axhline(7000, color='red', linestyle='--', linewidth=1, label='500 kWh Margin')

plt.xlabel('Hour of the Day')
plt.ylabel('Average Energy Consumption (kWh)')
plt.title('Average Energy Consumption per Hour for EV Charging and University')
plt.xticks(range(24))
plt.legend()
plt.show()
```

4: Arduino Code

4.1 Code Arduino 1

```
#include <Servo.h>
#include <FastLED.h>

// Servo setup
Servo timeServo;
const int servoPin = 9;

// Potentiometer setup
const int potPin = A9;  // Potentiometer connected to analog pin A9

// Button setup
const int buttonPin = 2;
int buttonState = 0;
int lastButtonState = 0;

// Time management
int currentHour = 0;
unsigned long lastTime = 0;
const unsigned long interval = 2000;
bool timerActive = false;
bool scenarioLocked = false;  // Add scenarioLocked flag

// FastLED setup for first LED strip
#define NUM_LEDS_1 50
#define LED_PIN_1 7
CRGB leds1[NUM_LEDS_1];
CRGB currentLEDState1[NUM_LEDS_1];

// FastLED setup for second LED strip
#define NUM_LEDS_2 30
#define LED_PIN_2 6
CRGB leds2[NUM_LEDS_2];
CRGB targetLEDState2[NUM_LEDS_2];  // Target state for the charging bar animation

// Wire detection setup
const int wirePins[5] = { A0, A1, A2, A3, A4 };
const int analogPin8 = A8;
const int threshold = 1019;
const int sampleCount = 3;
int wireStates[5] = { 0, 0, 0, 0, 0 };

// Group 1 scenarios, UT energy consumption, worst case scenarios of every season
```

```
int group1Scenario1[24] = { 4000, 4000, 3000, 3000,   4000, 4000, 2000, 4000, 5000, 5000, 6000,
4000, 6000, 4000, 4000, 6000, 4000, 4000, 4000, 4000, 3000, 3000, 4000, 4000 }; //Spring
int  group1Scenario2[24]  =  {  4000,  3000,  4000,  4000,  3000,  4000,  4000,  5000,  5000,  6000,  6000,
6000, 6000, 5000, 6000, 7000, 6000, 6000, 6000, 5000, 5000, 6000, 5000, 5000 }; //Summer
int  group1Scenario3[24]  =  {  3000,  3000,  2000,  3000,  3000,  3000,  3000,  4000,  4000,  5000,  5000,
5000, 6000, 5000, 5000, 5000, 5000, 5000, 5000, 4000, 4000, 3000, 4000, 3000 }; //Winter
int  group1Scenario4[24]  =  {  3000,  5000,  3000,  3000,  4000,  4000,  4000,  4000,  6000,  5000,  6000,
6000, 6000, 6000, 6000, 7000, 6000, 6000, 6000, 5000, 5000, 5000, 4000, 5000 }; //Autumn
// Group 2 EV penetration rate scenarios 0-100%
int evScenario0[24] = { 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0 };
int evScenario20[24] = { 0, 0, 0, 0, 0, 0, 0, 0, 1000, 1500, 1000, 500, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0 };
int evScenario40[24] = { 0, 0, 0, 0, 0, 0, 0, 500, 2000, 3000, 2500, 1500, 1000, 500, 500, 0, 0,
0, 0, 0, 0, 0, 0, 0 };
int evScenario60[24] = { 0, 0, 0, 0, 0, 0, 0, 500, 3000, 4500, 3500, 2000, 1000, 500, 500, 0, 0,
0, 0, 0, 0, 0, 0, 0 };
int evScenario80[24] = { 0, 0, 0, 0, 0, 0, 0, 1000, 4000, 6000, 5000, 3000, 1500, 1000, 500, 0,
0, 0, 0, 0, 0, 0, 0, 0 };
int evScenario100[24] = { 0, 0, 0, 0, 0, 0, 0, 1000, 5000, 7500, 6000, 3500, 2000, 1000, 500, 0,
0, 0, 0, 0, 0, 0, 0, 0 };

int selectedScenario = 0;
int selectedScenarioGroup1 = 0;

void setup() {
  Serial.begin(9600);

  // Initialize Servo
  timeServo.attach(servoPin);

  // Initialize Button
  pinMode(buttonPin, INPUT_PULLUP);

  // Initialize LED strips
  FastLED.addLeds<WS2812B, LED_PIN_1, GRB>(leds1, NUM_LEDS_1);
  FastLED.addLeds<NEOPIXEL, LED_PIN_2>(leds2, NUM_LEDS_2);
  FastLED.clear();
  FastLED.show();

  // Initialize A8 as output
  pinMode(analogPin8, OUTPUT);
  digitalWrite(analogPin8, HIGH);

  // Initialize current LED state to off
  for (int i = 0; i < NUM_LEDS_1; i++) {
```

```
    currentLEDState1[i] = CRGB::Black;
  }
}

void setTime(int hour) {
  int angle = map(hour, 0, 23, 180, 0);
  timeServo.write(angle);
  Serial.println(hour);  // Send current hour to the second Arduino
}

void startLEDAnimation(int valueGroup1, int valueGroup2) {
  int numLEDsGroup1 = valueGroup1 / 250;
  int numLEDsGroup2 = valueGroup2 / 250;

  numLEDsGroup1 = min(numLEDsGroup1, NUM_LEDS_1);
  numLEDsGroup2 = min(numLEDsGroup2, NUM_LEDS_1 - numLEDsGroup1);

  int totalLEDsToAnimate = numLEDsGroup1 + numLEDsGroup2;

  for (int i = 0; i < NUM_LEDS_1; i++) {
    CRGB targetColor = CRGB::Black;
    if (i < numLEDsGroup1) {
      targetColor = (i < 30) ? CRGB::Blue : CRGB::Red;
    } else if (i < numLEDsGroup1 + numLEDsGroup2) {
      targetColor = (i < 30) ? CRGB::Yellow : CRGB::Red;
    }

    // Gradually change the color of the LED to the target color
      currentLEDState1[i] = blend(currentLEDState1[i], targetColor, 32);  // 32 defines the
blending factor
    leds1[i] = currentLEDState1[i];
  }

  FastLED.show();
}

void updateEVLEDs(int totalEVs, int scenario) {
   int numYellowLEDs = selectedScenario * 6;  // Determine number of yellow LEDs based on the
scenario

  int ledsToGreen = map(totalEVs, 0, 10000, 0, numYellowLEDs);
  ledsToGreen = min(ledsToGreen, numYellowLEDs);

  for (int i = 0; i < NUM_LEDS_2; i++) {
    if (i < ledsToGreen) {
```

```
      leds2[i] = blend(leds2[i], CRGB::Green, 3);  // Blend towards the target state
    } else if (i < numYellowLEDs) {
      leds2[i] = CRGB::Yellow;
    } else {
      leds2[i] = CRGB::Black;
    }
  }
  for (int i = 0; i < NUM_LEDS_2; i++) {
  }
  FastLED.show();
}

void loop() {
  unsigned long currentMillis = millis();
  buttonState = digitalRead(buttonPin);

  // Read potentiometer value before button press and select scenario from group 1
  if (!timerActive && !scenarioLocked) {
    int potValue = analogRead(potPin);
    selectedScenarioGroup1 = (potValue - 40) / 242 + 1;  // Calculate scenario directly (1-4)
    // Serial.print("Selected Scenario1: ");
    // Serial.println(selectedScenarioGroup1);
  }

  if (buttonState == LOW && lastButtonState == HIGH) {
    if (!timerActive) {
      timerActive = true;
      scenarioLocked = true;  // Lock the scenario
      lastTime = millis();
      // Serial.println("Timer started");
    } else {
      timerActive = false;
      scenarioLocked = false;  // Unlock the scenario
      // Serial.println("Timer stopped");
      currentHour = 0;

      for (int i = 0; i < NUM_LEDS_1; i++) {
        currentLEDState1[i] = CRGB::Black;
      }
      FastLED.clear();
      FastLED.show();
    }
  }

  lastButtonState = buttonState;
```

```
int highCount = 0;
for (int i = 0; i < 5; i++) {
  int totalValue = 0;
  for (int j = 0; j < sampleCount; j++) {
    totalValue += analogRead(wirePins[i]);
    delay(10);
  }
  int averageValue = totalValue / sampleCount;
  if (averageValue > threshold) {
    wireStates[i] = 1;
    highCount++;
  } else {
    wireStates[i] = 0;
  }
}

int *evScenario;
if (!scenarioLocked) {
  switch (highCount) {
    case 0: evScenario = evScenario0; break;
    case 1: evScenario = evScenario20; break;
    case 2: evScenario = evScenario40; break;
    case 3: evScenario = evScenario60; break;
    case 4: evScenario = evScenario80; break;
    case 5: evScenario = evScenario100; break;
    default: evScenario = evScenario0; break;
  }
}
// Serial.println(*evScenario);
int totalEVs = 0;
for (int i = 0; i <= currentHour; i++) {
  totalEVs += evScenario[i];
  // Serial.println(currentHour);
}

if (!scenarioLocked) {
  // Determine the scenario based on the number of wires in the high state
  selectedScenario = highCount;
  // Serial.print("Selected Scenario: ");
  Serial.println(selectedScenario * -1);
}

// Determine the interval to use based on the current hour
unsigned long currentInterval = (currentHour >= 7 && currentHour <= 14) ? 6000 : 2000;
```

```
  if (timerActive && (currentMillis - lastTime >= currentInterval)) {
    currentHour++;
    if (currentHour >= 24) {
      currentHour = 0;
      timerActive = false;
      scenarioLocked = false;  // Unlock the scenario
      // Serial.println("Timer stopped");
    } else {
      int valueGroup1;
      switch (selectedScenario) {
        case 1: valueGroup1 = group1Scenario1[currentHour]; break;
        case 2: valueGroup1 = group1Scenario2[currentHour]; break;
        case 3: valueGroup1 = group1Scenario3[currentHour]; break;
        case 4: valueGroup1 = group1Scenario4[currentHour]; break;
        default: valueGroup1 = group1Scenario1[currentHour]; break;
      }

      int valueGroup2 = evScenario[currentHour];
      startLEDAnimation(valueGroup1, valueGroup2);
      setTime(currentHour);
      lastTime = millis();
    }
  }

  // Call startLEDAnimation periodically to ensure smooth transitions
  static unsigned long lastAnimationTime = 0;
  const unsigned long animationInterval = 50;  // Adjust as needed for smoother animations

  if (currentMillis - lastAnimationTime >= animationInterval) {
    int valueGroup1;
    switch (selectedScenario) {
      case 1: valueGroup1 = group1Scenario1[currentHour]; break;
      case 2: valueGroup1 = group1Scenario2[currentHour]; break;
      case 3: valueGroup1 = group1Scenario3[currentHour]; break;
      case 4: valueGroup1 = group1Scenario4[currentHour]; break;
      default: valueGroup1 = group1Scenario1[currentHour]; break;
    }
    int valueGroup2 = evScenario[currentHour];
    startLEDAnimation(valueGroup1, valueGroup2);
    lastAnimationTime = currentMillis;
  }

  updateEVLEDs(totalEVs, highCount);
}
```

4.2 Code Arduino 2

```
#include <Servo.h>
#include <TM1637Display.h>

// Define connections pins
#define CLK 13
#define DIO 12
TM1637Display display(CLK, DIO);

// Servo setup
Servo timeServo;
const int servoPin = 7;
int chargers = 0;

void setup() {
  Serial.begin(9600);
  display.setBrightness(0x0f);  // Set brightness level (0x00 to 0x0f)
  timeServo.attach(servoPin);
  Serial.println("Receiver started");
}

void displayTime(int hour, int minute) {
  uint8_t data[] = { 0x00, 0x00, 0x00, 0x00 };  // Array to hold the segments data

  // Convert hour to 2 digits and store in data array
  data[0] = display.encodeDigit(hour / 10);  // Tens place of hour
  data[1] = display.encodeDigit(hour % 10);  // Ones place of hour

  // Convert minute to 2 digits and store in data array
  data[2] = display.encodeDigit(minute / 10);  // Tens place of minute
  data[3] = display.encodeDigit(minute % 10);  // Ones place of minute

  // Display the data array
  display.setSegments(data);

  // Show colon between hours and minutes
  display.showNumberDecEx(hour * 100 + minute, 0b01000000, true);
}


void loop() {
  if (Serial.available() > 0) {
    String input = Serial.readStringUntil('\n');  // Read the input until a newline character
```

```
    int currentHour = input.toInt();              // Convert the input to an integer
    Serial.print(currentHour);
    if (currentHour >= 0 && currentHour < 24) {  // Check if the received hour is valid
      displayTime(currentHour, 0);               // Display hour with minutes set to 00


      Serial.print("hi");
      Serial.print(currentHour);
    } else if (currentHour == -1) {
      chargers = 112;
      int Angle = map(chargers, 0, 600, 180, 0);

      timeServo.write(Angle);
    } else if (currentHour == -2) {
      chargers = 223;
      int Angle = map(chargers, 0, 600, 180, 0);
      timeServo.write(Angle);
    } else if (currentHour == -3) {
      chargers = 334;
      int Angle = map(chargers, 0, 600, 180, 0);
      timeServo.write(Angle);
    } else if (currentHour == -4) {
      chargers = 446;
      int Angle = map(chargers, 0, 600, 180, 0);
      timeServo.write(Angle);
    } else if (currentHour == -5) {
      chargers = 556;
      int Angle = map(chargers, 0, 600, 180, 0);
      timeServo.write(Angle);
    } if (currentHour == 0) {
      chargers = 0;
      int Angle = map(chargers, 0, 600, 180, 0);
      timeServo.write(Angle);
    }
    Serial.print(chargers);
    int Angle = map(chargers, 0, 600, 180, 0);
    Serial.print("Servo angle set to: ");
  }
}
```

5: User Evaluation

5.1 Questions User Evaluation

- Question 1: What category would you fall into?
    - Choose: **Student**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?
- Question 4: What are your general thoughts about the prototype?
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
- Question 6: Did you learn something from this prototype? If so what did you learn from this?

5.2 User Evaluation Interviews

Participant 1

- Question 1: What category would you fall into?
    - Choose: **Student**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
    - Has been to a project day of proto before, so saw many on that day.
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?
    - 3/10
- Question 4: What are your general thoughts about the prototype?
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
    - I think I would not have understood what would happen if you did not explain the prototype
    - I thought I could change the cars during the simulation
    - It’s annoying that servo twitches
    - I did not really look at the amount of chargers, my attention was going to the leds
    - I think everything looks nice, except the ledstrip that is not covered, I would not think about an electric wire.
    - It would be nice if the wires are covered at the side
    - Labels could be added to parts.
    - Was nice that you told me that blue included the electric cars
    - Maybe add a better explanation for if you are not there, maybe a nice poster with some information
    - Should change the green light, of the charging bar, it is not clear
- Question 6: Did you learn something from this prototype? If so what did you learn from this?
    - If there are more electrical cars, the university really needs to find a solution, maybe a solution for the peak hours. It’s nice that there is a line

Participant 2

Note: Did also not understand that you could only place cars down at the beginning

- Question 1: What category would you fall into?
  - Choose: **Student**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
  - Made some himself, tracked fitness data
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?
  - 4, knows a bit, but not specifics, knows about usage
- Question 4: What are your general thoughts about the prototype?
  - Looks really nice, usage of data and lights is clear and looks pretty
  - User friendly, easy to interact with, took a while to understand the goal, was understandable with the explanation
  - Data is really nice displayed, if you know a lot of about this, it would be nice to have such a visualization, and just really cool.
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
  - Improve clarity of why this product exists and its significance
  - If you know what to do, it is understandable
- Question 6: Did you learn something from this prototype? If so what did you learn from this?
  - Now he knows the limit of the electric cars with the current limit of the UT, and what the impact would be if hypothetically 300 of his friends would buy an electric car
  -

Participant 3

Note: Also had problems with placing down the cars, also thought he could place them down at the beginning, did also not notice the green charging bar.

- Question 1: What category would you fall into?
  - Choose: **Student**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
  - Made one himself
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?
  - 5
- Question 4: What are your general thoughts about the prototype?
  - Looks good, very pretty and thought it was cool that you could see the energy
  - Cool
  - Simple to take in the information
  - Satisfying to see the LEDS
  - Looks pleasing
  - Easy to understand to place what down
  - Looks well put together
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
  - Was not clear that you could first place the cars down

    - Lasercutting of the current hour is not printed that well
- Question 6: Did you learn something from this prototype? If so what did you learn from this?
    - Did not know that EVs need so much electricity to charge and that it had such a big impact on the electricity usage. Really needs to budget the cars their usage,

Participant 4

- Question 1: What category would you fall into?
    - Choose: **Student**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
    - Made one himself, in vr, tried out multiple ones
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?
    - 3
- Question 4: What are your general thoughts about the prototype?
    - Would be nice if you could cycle through the time, if you would have a slider instead of a simulation
    - Nice that you have cars, tactile
    - Does not think its logical that the input is continuos (potmeter), it's not clear which one you selected
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
    - Thinks its more logical if you have the leds with the corresponding cars
- Question 6: Did you learn something from this prototype? If so what did you learn from this?
    - That there is not a lot of room for electric cars, lot less headroom than he would have thought
    - Did not know the UT uses so much energy already

Participant 5

- Question 1: What category would you fall into?
    - Choose: **Student**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
    - Made one herself, seen multiple
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?
    - 6
- Question 4: What are your general thoughts about the prototype?
    - Thought it was really nice
    - The colors and bar shows it very clear
    - Clear
    - Thought you could see everything per hour, so you could see when something was the highest
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
    - Didn't understand at the beginning that the blue was from the university

    - Red yellow blue, maybe add an led as indication
- Question 6: Did you learn something from this prototype? If so what did you learn from this?
    - Did you learn something from this, if so what did you learn from this?
        - Did not know the UT uses so much electricity per hour
    - Even EVs are good for the environment, they really have an impact on the grid, they should be careful when choosing to charge them

Participant 6

- Question 1: What category would you fall into?
    - Choose: **Student**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
    - Made some himself
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?
    - 9
- Question 4: What are your general thoughts about the prototype?
    - Likes the light that comes from somewhere
    - Looks nice
    - Not too much information
    - Could have some nicer little things like other material than wood
    - Made good use off all the space, also not overloaded/overstimulated
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
    - Could tune down the green/yellow lights
    - Servo was annoying
    - Would make the maximum something like red on the sign itself, now it’s brown on the wood, it’s less clear in this way
- Question 6: Did you learn something from this prototype? If so what did you learn from this?
    - The UT uses a lot of energy in the night
    - Insightful that you see the impact of the EVs on one grid

Participant 7

- Question 1: What category would you fall into?
    - Choose: **Student Saxion**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
    - Seen data visualizatoins before, they were not physical models
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?
    - 8
- Question 4: What are your general thoughts about the prototype?
    - Nice
    - Needed some explanations to really understand it, would’ve been easier if it would display the total amount of chargers instead of added amount of chargers
    - Easy to understand

    - Thinks its creative how the ledstrip comes from somewhere
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
    - Could put the number 200 on the cars
    - Could also indicate stop
    - Instead of digital clock, also use a servo
    - Less bright LEDstrip
    - Maybe put the clock inside the plate (but not really necessary for the prototype)
- Question 6: Did you learn something from this prototype? If so what did you learn from this?
    - That EVs use a lot of consumption, the ratio is larger than he would expect

Participant 8

- Question 1: What category would you fall into?
    - Choose: **Student**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
    - Made one herself, seen multiple
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?
    - 3
- Question 4: What are your general thoughts about the prototype?
    - Clear what it is about, kotm door de de autotjes, laadpaaltjes, en elektriciteitsmast, decoratie helpt, heeft geen teksts om te weten dat het over elektrische auto's gaat
    - Likes how it works
    - Likes that you can see the charger amounts
    - LIkes the season
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
    - Not clear what the blue means
    - Servo is annoying
- Question 6: Did you learn something from this prototype? If so what did you learn from this?
    - That the University does not seem prepared for the future

Participant 9/10

- Question 1: What category would you fall into?
    - Choose: **Student**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
    - Both made one themselves
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?
    - 7+ 6
- Question 4: What are your general thoughts about the prototype?
    - Finds it nice
    - Has to gets used to the prototype

    - Could quickly make conclusions on how much the UT uses, in the future it would become worse, good easily see that in the physilization
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
    - Did not look at the amount of chargers, lights catches more attention.
    - Could be interesting to show the past, how much energy would be used by the ut f.e. 10 years ago
    - Could use average
- Question 6: Did you learn something from this prototype? If so what did you learn from this?
    - Would have expected that there would be room for the charging of EVs, even in spring there doesn't seem to be any room

Participant 11
- Question 1: What category would you fall into?
    - Choose: **Student**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
    - Made one himself
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?
    - 3/4
- Question 4: What are your general thoughts about the prototype?
    - Cool
    - Looks good
    - Pretty logical how to use it
    - The text is clear
    - The lights are nice to see, especially when it charges
    - Nice that the ledstrip shows the amount of cars
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
    - It would be handy to tell about what the things mean f.e. Blue = electricity consumption including current electric cars
    - Could be more clear that you could use the button to stop, now only says start
    - Instead of fade animation, maybe walking animation.
- Question 6: Did you learn something from this prototype? If so what did you learn from this?
    - EVs use a lot more electricity than he would initially thought, especially compared to the UT

Participant 12
- Question 1: What category would you fall into?
    - Choose: **Student**/UT employee/none of these
- Question 2: Do you have any prior experiences with using a data physicalisation?
    - Yes, made one himself
- Question 3: How would you rate your knowledge of electric vehicles on a scale of 1-10?

    - 6
- Question 4: What are your general thoughts about the prototype?
    - Very clear to interpertate
    - You know the function of everything on first eyesight
- Question 5: What would you improve about the prototype? Were there things that you did not like or bothered you?
    - You have to wait long to see everything, maybe a scroll function would be nice
    - Maybe that you show a number at the end that shows the peak consumption of the day
- Question 6: Did you learn something from this prototype? If so what did you learn from this?
    - The infrastructure of EVs cannot facilitate the amount that we want yet

6: Consent Form

Consent form user evaluation Jorick Schöndorff

I am a student at the University of Twente from the faculty of EEMCS. I'm currently working on my bachelor thesis project, which aims to asses the impact of future e-mobility scenarios; what will happen when the UT personnel will start driving electric cars. This session is used to evaluate the prototype.

The information you provide will remain **anonymous**, be stored for a few weeks, kept private and will be used to evaluate the prototype. You can **always resign** from this evaluation at any given moment. The evaluation might take around **3-10 minutes** to complete, during which you can test the prototype in the way you want. Before testing the prototype, you will be explained how it works, after testing, you are asked to fill in a questionnaire. You are also asked for your opinion on the prototype, your answers will be written down as notes. Please contact me if you have any questions by sending an email to: *j.j.schondorff@student.utwente.nl*

If you have any complaints, please contact the Ethics Committee Computer & Information Science (EC-CIS) by sending an email to: *ethicscommittee-cis@utwente.nl*

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Consent Form for User Evaluation Jorick Schöndorff

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information dated 01/07/2024, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves filling in a questionnaire and having a short interview in which the given answers are written down.	○	○
I understand that information I provide will be used for the user evaluation in the report of the bachelor thesis project of Jorick Schöndorff. The research will be published on the University of Twente website.	○	○
I understand that personal information collected about me that can identify me, will not be shared beyond the study team.	○	○

Signatures

____________________	____________________	________
Name of participant [printed]	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Jorick Schöndorff	____________________	________
Researcher name	Signature	Date

Study contact details for further information: Jorick Schöndorff
j.j.schondorff@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl

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7: System Usability Scale

System Usability Scale (SUS)

This is a standard questionnaire that measures the overall usability of a system. Please select the answer that best expresses how you feel about each statement after using the prototype

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
1. I think I would like to use this tool frequently.	☐	☐	☐	☐	☐
2. I found the tool unnecessarily complex.	☐	☐	☐	☐	☐
3. I thought the tool was easy to use.	☐	☐	☐	☐	☐
4. I think that I would need the support of a technical person to be able to use this system.	☐	☐	☐	☐	☐
5. I found the various functions in this tool were well integrated.	☐	☐	☐	☐	☐
6. I thought there was too much inconsistency in this tool.	☐	☐	☐	☐	☐
7. I would imagine that most people would learn to use this tool very quickly.	☐	☐	☐	☐	☐
8. I found the tool very cumbersome to use.	☐	☐	☐	☐	☐
9. I felt very confident using the tool.	☐	☐	☐	☐	☐
10. I needed to learn a lot of things before I could get going with this tool.	☐	☐	☐	☐	☐

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