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Blockchain Based Decentralized Electric Vehicle Charging through Smart Contracts

Table of contents

1 Introduction

Over the last decade, Bitcoin has been in the center of a hype establishing cryptocurrencies as a speculative investment. Invented by a still unknown person with the pseudonym Satoshi Nakamoto in 2008, it has become the first secure and mass adopted decentralized currency. Along with the success of Bitcoin came a lot of attention to blockchain, the technology behind most cryptocurrencies. While some only see it as gambling or a nice gimmick, others believe blockchain will bring disruptive changes to the way we consume goods and services and allow for a mass adoption of distributed systems into our economy. Further advanced blockchains like Ethereum do not just serve as a currency but also allow the implementation of programs and therefore lay the groundwork for developing whole decentralized apps. Implementations of such products in the real world are still rare. In this project, we will develop the idea of creating a decentralized sharing app for electric vehicles (EV) charging stations and demonstrate how it can be implemented on the Ethereum blockchain. During the course of the paper, we will differentiate between EV that contain any kind of electric engine including hybrid cars and battery-powered electric vehicles (BEV) that contain only an electric engine. To simplify things, we will focus our analysis on the German market and concentrate on developing the back-end code with the core functions to operate the app. After some context on why we think a sharing app for charging stations is a good idea we elaborate how the app would work and explain the technical implications behind it.

2 The project idea

2.1 Context of climate actions

Climate change has been one of the most dominant political issues over the last decades and will maintain this relevance for the foreseeable future. The necessity to reduce greenhouse gas emissions is widely acknowledged. In 2015, 175 parties signed the Paris Agreement and committed themselves to limit global warming to 2, preferably 1.5 degrees Celsius compared to pre-industrial levels (UNFCCC (2015)). Since then, governments worldwide have taken individual actions to meet this goal. Germany set the goal to reduce CO_2 emissions by 65% until 2030 and reaching climate neutrality by 2045 (Bundesregierung (2021)). Considering the status quo, those are ambitious goals. Whole industries have to be transformed with rapid speed and the economy as we know it today will be fundamentally changed. One of the sectors that will be affected by this development is transportation. Total emissions from transport had a share of 27% of global emissions in 2019 (IEA (2021)). With such a high impact on climate change, it is undeniable that this sector will face disruptive changes in the near future. Most of the cars used today generate power from burning fossil fuels and produce CO2. For our project, we want to focus on this individual road transport.

2.2 Development of electric vehicles market

Replacing fossil fuel cars with climate friendly alternatives plays a key role in many governmental strategies to meet climate goals. There are different approaches to decarbonize individual transport. Over the past few years, the industry seemed to view electrification as the most promising option. Tesla as a pure BEV company sees huge success and traditional car manufacturers like Volkswagen started to shift their strategy towards electric mobility (Volkswagen (2021)).

Although the overall impact on greenhouse emissions in the midterm might be questionable[1], political leaders do favor electric vehicles over other alternatives. Purchase of electric vehicles is encouraged with subsidies, taxes on CO_2 emissions which effects fossil fuels further accelerate their sale numbers. While BEV's currently only make up 0.6% of total cars on German roads (KBA (2021)), their total number is steadily rising with a growing pace (figure 1). Numbers of newly registered cars demonstrate the shift away from fossil fuels to electric mobility. Cars with an electric engine already make up more than 50% of

[1] For a more detailed analysis see Jochem et. al. (2015).

newly registered cars, with BEV's having a share of 21.3% (KBA (2022)). Former German Economy Minister Peter Altmaier projected a total number of 14 million cars with either full electric or hybrid engine by 2030 (Bloomberg (2021)), 10 times as much as 2021. All this demonstrates the potential of electric mobility for the future.

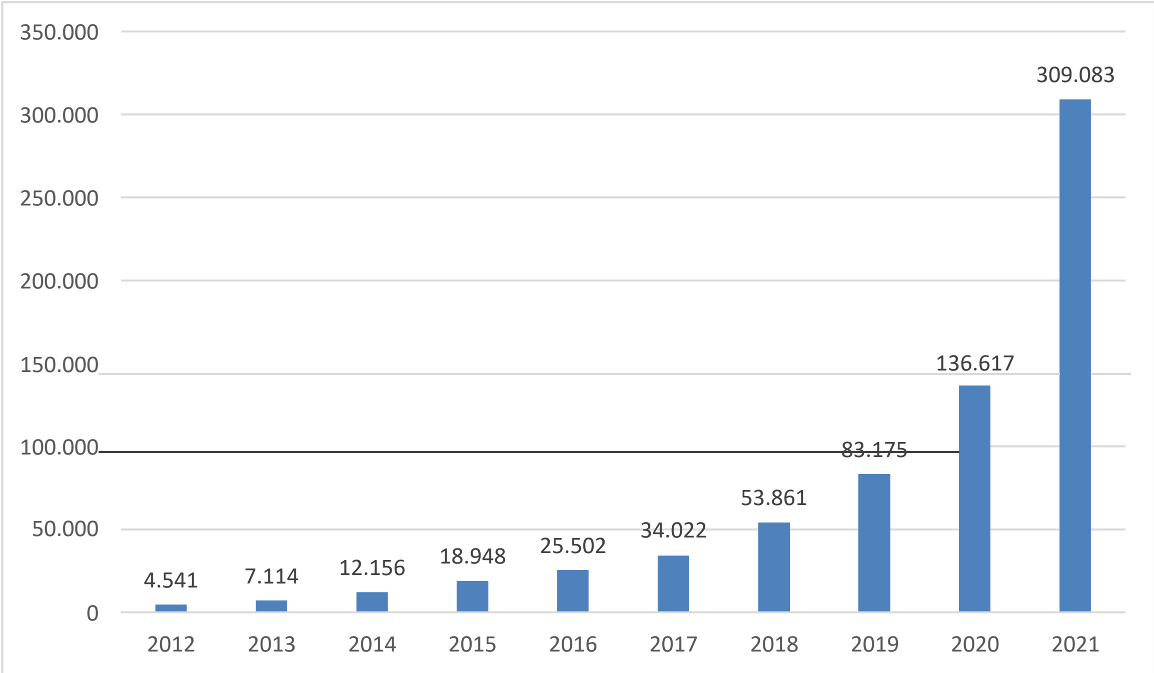

Figure 1: Total number of registered BEV's in Germany

Source: Statista (2021)

2.2.1 Deficits of public charging Infrastructure

Conventional cars can be refueled within minutes guaranteeing little time losses, especially over long distances. The infrastructure of gas stations is well established and adequate to provide a security of supply. The number of charging points for EV's on the other hand is barely enough to supply the existing number of EV's on the roads and needs to be greatly improved to meet the expected demand over the next years. There are approximately 50,000 public charging points in Germany (Bundesnetzagentur (2021)). The number of private charging points can only be estimated, a representative study from 2019 showed that 49% of all charging processes take place at home, 24% at work and 25% at public charging points (KfW (2019)).

Already today, 56% of German households see the limited number of public charging points as an argument against buying a BEV, making it the second important reason just after concerns about the range (57%) and more important than the higher price for BEV's (54%). For 27% the lack of possibility to charge at their workplace is another factor not to buy a

BEV (KfW (2021)). Improving the charging infrastructure for the growing number of electric vehicles is crucial for further development of electric mobility.

2.3 Creating a decentralized sharing app for EV charging stations

Our project idea is to provide owners of private charging stations with an easy opportunity to share their charging point with the public. The concept of sharing economy has become popular over the last decade and is expected to have growing importance and revenues in the future (Hamari et al. (2016)). One of the core features of sharing economy is collaborative consumption, the sharing of goods and services. Technological advancement is one of the main drivers of sharing economy and allows the development of products that enables the sharing (Hamari et al. (2016)). There are already companies that successfully deployed the idea of sharing economy to various industries, like Uber for taxi services or Airbnb for accommodation rental. We want to adapt this concept to sharing charging stations. That way, the public charging infrastructure can be significantly increased without building new stations. Additionally, this option would encourage more operators to build and provide public charging points. Out of the 3,500 existing operators, the vast majority of 3,200 are in charge of less than 10 charging points who are mainly provided locally (Bundesnetzagentur (2021)). Lowering the boundaries of offering public charging points can potentially improve the number of small operators and therefore expand the charging infrastructure. The product will be an app where owners of charging points can register their charger providing the location and the price they want to charge per kWh. All charging points are shown on a map, EV drivers can search for chargers in their area. If they agree to the price, they can start the charging process. The energy that is consumed is registered and after the process is finished the owner of the charging station receives the payment.

2.3.1 Benefits for app users

As the app does not operate charging stations itself and only works as an intermediary, it relies on the willingness of both owners of charging stations and EV drivers to use it. Hamari et al. (2016) identify four motivational motives to participate in sharing economy: Enjoyment, sustainability, economic benefits and reputation. Collaborative consumption is generally seen as ecologically sustainable as resources are shared and therefore more efficiently used. As electric mobility is itself seen as a sustainable way of transportation, we can expect EV drivers to have a higher affinity towards sustainability. Therefore, they might be open-minded to using a sharing app.

Private households can have economic benefits from sharing a charging point, especially when they generate their own electricity. An urban apartment building with own parking spaces and a solar panel on the roof can be considered as an example. During the day, it is likely that more electricity is produced than consumed. Right now, owners only have two options: Invest in a storage capacity to use the energy later which can be quite costly or sell it to the local energy provider. Providing a charging facility opens a third option: Sell it directly to customers at a potentially higher price than to the energy provider. For Germany, the feed-in tarrif that is guaranteed for 20 years depends on when the solar panels were built. Most solar panels on roofs have a capacity of under 10 kW. In the latest law from 2017 the tarrif for these systems is fixed to a maximum of 8.91 eurocents per kWh and is steadily decreasing (§§48, 49 EEG). The average cost of electricity for a German private household is 32.16 cents per kWh (Clean Energy Wire (2021)). That leaves a wide range of prices where a peer-to-peer contract for electricity is profitable for both the owner of the charging station and the EV driver.

The second group that can have a strong interest in sharing a charging point consists of small to medium sized businesses. Offering a charging facility can serve as an incentive to attract potential employees or customers. Many companies are struggling to find high qualified employees and try to offer incentives beyond the regular pay. As we have seen, not being able to charge at their workplace is a serious reason not to buy a BEV. With a steadily growing number of EV's, offering the ability to charge the car can become a relevant bonus. Similar logic can be applied to attract customers. With more people driving an EV and therefore demanding the ability to charge, offering that option can lead to additional customers. Especially where customers spend a relevant amount of time like restaurants, hotels, shopping malls etc., offering a public charging point can make the business stand out against competitors. In addition, companies can profit from a reputation gain when targeting sustainability affine customers. Right now, establishing a public charger can be a complicated process. Making it easier through a sharing app can convince more companies to offer that service.

2.3.2 Decentralization as a core feature of the project

In general, there are two different approaches on how to build a software infrastructure: Centralized or distributed. In a centralized system, individual components are only connected to one central component, but not with each other directly. In a distributed system, there is no such central component. Instead, individual components are all connected with each other forming a network (Drescher (2017)). Distributed systems offer some advantages. One of them is cost reduction. Creating, maintaining and operating a distributed system is cheaper than using one super computer. Distributed systems also offer a higher reliability since the network as a whole can still continue to operate when individual machines crash. The option to add individual machines to the network, when necessary, allows the system to grow naturally (Drescher (2017)). Sharing apps can specifically benefit from being decentralized by avoiding a complicated sign-up procedure and overbearing terms and conditions and additionally improving user privacy (Bogner et al. (2016)). No data regarding single users is stored in a central database. Providing an open-source program ensures transparency and allows all end users to have a critical look at the code used in the dapp.

However, distributed systems have challenges to overcome. Coordination and communication between components are more complex since there is no central institution, resulting in additional cost efforts, computing power and a standard communication protocol required to maintain the system. Other concerns are higher program complexity, security issues and dependencies on the network (Drescher (2017)).

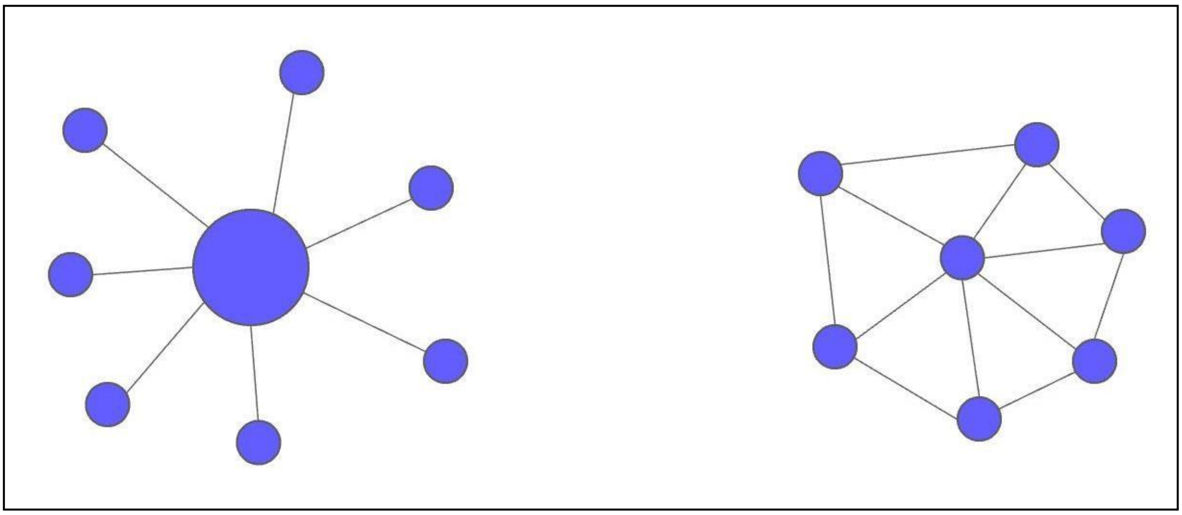

Figure 2: Centralized vs. distributed system

Based on Drescher (2017)

For this project, we want to demonstrate how a sharing app can be designed in a distributed system. That means that the owner of charging stations and EV drivers interact directly with each other throughout the whole process. There is no third party involved in providing access to the charging point or the payment, we create a pure peer-to-peer network. The app has the sole purpose of providing the overview on charging stations and offers a standardized interface for the users to interact with each other. Eliminating the third party creates a direct link between owner of charging points and EV drivers and therefore making it much easier and cheaper, especially for the owners to share their charging point. In addition, it helps to increase trust in the system and encourages private persons to share their chargers.

The main challenge in such a decentralized system is to make sure that only app users get access to the chargers and the owners will actually be compensated after the charging process for the electricity used. There is no central institution to solve possible disputes between users, so the whole software has to be secure. We will introduce blockchain as a solution to this problem in the next chapter.

2.3.3 Existing products on the market

There are a number of existing products already on the market that help EV drivers finding a nearby charging station. In Germany, the biggest app is the EnBW mobility+ app. From a user interface, it looks very similar to how we expect our app to appear in the end. There are two main differences to our idea: The operators of charging stations in the EnBW app are mainly commercial, while we want to allow private persons to share their existing or newly planned charger. Most sharing apps we know today like Uber and Airbnb are centralized. By combining both concepts of sharing and decentralization we hope to set the path for a broader adoption of sharing apps and combine the benefits of both worlds.

3 Technical part

3.1 Distributed systems

We already explained the basic difference between distributed and centralized systems in the previous chapter. To further discuss the technical parts of blockchain, it is necessary to have a closer look at distributed systems. Individual components in a distributed system are called nodes (Bashir (2017)). Nodes are capable to send and receive messages to one another and have their own memory and processor. They can be honest, fraudulent or malicious. In a distributed system, two or more nodes communicate with each other in a coordinated fashion to achieve a common outcome. A distributed system is modeled in such a way that the end user sees it as a single logical platform (Bashir (2017)).

3.2 Introduction to blockchain

While first concepts of distributed cash systems have been developed in the 1990's, the idea gained popularity when Bitcoin was created as a successfully working and secure decentralized currency using blockchain technology. Blockchain in general is a decentralized and distributed peer-to-peer system. It is cryptographically secure, immutable and updatable only via consensus or agreement among peers (Bashir (2017)). Important components of a blockchain that are worth explaining are addresses, transactions, blocks, nodes and consensus.

Addresses are unique identifiers and are used in blockchain to denote the sender and recipient of a transaction (Bashir (2017)). Every address has a private and a public key, where the address is a hashed version of the public key. Transactions build the fundamentals of blockchain. Transactions are transfers of values from one address to another (Bashir (2017)). Account balances are derived by reviewing the complete history of transactions, so verifying transaction data is key to a functioning blockchain. Specifically, the three aspects of verified transactions are formal and semantic correctness and authorization (Drescher (2017)). Various transactions are bundled together in a block. The block structure depends on the design of the blockchain, but it mostly consists of a block hash labeling the block and a reference to the previous block hash (Bashir (2017)). Thus, the entirety of blocks linked together build a chain, therefore the term blockchain. The first block of a new blockchain is called the genesis block. The blockchain contains the complete transaction history. Nodes perform various tasks in a blockchain. They can validate transactions to ensure there is consensus and the blockchain is secure. Nodes in a blockchain communicate with each other to form a peer-to-peer network (Bashir (2017)).

The main challenge of a distributed system is to provide a secure structure and make sure only transactions that are validated by the address owners get added to the blockchain. We will not explain in detail how verifying a transaction works for a private user, but one important concept of blockchain is consensus. A blockchain can be viewed as a distributed database that is shared with every node. The nodes have to reach an agreement on the current state of the blockchain and on the creation of new blocks. This agreement is called consensus and is reached when at least 51% of the nodes agree on the global stage of the network. Fixed consensus mechanisms allow distributed systems to stay secure and help preventing certain kinds of attacks against the blockchain (Ethereum.org (2022a)). An attacker trying to verify a false transaction would have to control at least 51% of the nodes. Common consensus mechanisms are proof of work used by Bitcoin blockchain and proof of stake, which is planned to implemented in Ethereum (Ethereum.org (2022a)).

3.2.1 Introduction to Ethereum

Bitcoin and Ethereum both use blockchain technology to create a secure distributed system. While Bitcoin has the sole purpose of being a digital and decentralized currency, Ethereum aims to provide additional functionalities.

> *Ethereum does this by building what is essentially the ultimate abstract foundational layer: a blockchain with a built-in Turing-complete programming language, allowing anyone to write smart contracts and decentralized applications where they can create their own arbitrary rules for ownership, transaction formats and state transition functions. (Buterin (2013)).*

In the Ethereum universe there is a single canonical computer that everyone agrees on, the Ethereum Virtual Machine (EVM) (Ethereum.org (2022b)). Every node of the network keeps a copy and can request a computation, which is then verified and carried out by other nodes and announced to the whole network. The Ethereum network allows to implement smart contracts, which are programs that run on the Ethereum blockchain (Ethereum.org (2022c)). They run as they are programmed and cannot be changed by the users; they can simply deploy them and interact via functions. Smart contracts have their own address and can send transactions as well as they can be funded by users. Ethereum has an own programming language called Solidity to write smart contracts. Ethereum enables the development of dapps, a backend code running on a decentralized peer-to-peer network combined with a frontend interface for users to interact with the program (Ethereum.org (2022d)).

The currency of the Ethereum blockchain is Ether (ETH) that can be divided into smaller fractions. The smallest unit of Ether is Wei, the denominations are fixed in the Ethereum whitepaper: 1 Ether equals 10^18 Wei (Buterin (2013)). As smart contracts often use Wei to calculate values, it is important to keep those conversions in mind. Another common unit is Gwei which equals 10^9 Wei or 10^-9 Ether (Ethereum.org (2022e)). Every transaction on the Ethereum blockchain requires a fee to compensate for the computational resources needed to process the transaction. This is the so-called Gas fee and is measured in Gwei (Ethereum.org (2022 f)).

3.3 Implementation in our project

To implement our idea of a decentralized sharing app on blockchain, we decided to use the Ethereum network to create a decentralized app. For this project, we focused on the back-end development of the smart contracts in Solidity, as this is the core of any dapp. We will describe how we wrote the program, how we tested it and what alternatives we considered on the way.

3.3.1 Writing the smart contracts

The purpose of the dapp is to give both the charging station owner and the EV driver the opportunity to interact with each other to agree on a rental contract without giving either side an opportunity to act against the other party's interest. The owner of the charging station, in the contracts called 'admin' wants to share the charger with potential customers. He can set an electricity price of his choice and make sure no one is able to charge without paying his price. The EV driver, in the contracts called 'user', should be able to access the charging station and charge the car to the predetermined conditions. For the interaction, both parties need an Ethereum wallet address with a unique public key and enough Ether currency to cover Gas fees when interacting with the programs. The smart contract code along with a description and the sources used for writing the codes are provided in the appendix of this report.

To provide a secure structure for our dapp we decided to create two separate smart contracts that interact with each other. The first is deployed by the admin when the charger is registered and is called 'ChargingStation.sol'. This program stores the basic information of the charging station: The public key of the owner, the electricity cost of charging per kWh and a required deposit. First of all, we define these three variables. The price and the deposit have fixed values that are chosen by the admin. We want the first person to deploy this contract, in Solidity code the 'msg.sender' to be the admin, so we define a constructor function to fix this variable once and for all. As mentioned in the previous chapter, Solidity calculates values in Wei. Since this is not intuitive, we want to give the admin and the user the chance to get the values in US dollars (USD). We will use the Chainlink data to get the current conversion rate. For this, we first have to import the interface and then define a function that gets the latest ETH price in USD. This is done by accessing the Chainlink data feeds that provide a unique address for every price in each network. After that, we can define another function that takes a USD amount as an input parameter and returns the equivalent ETH amount by calling the price of the previous function and dividing the USD amount with the ETH price. Lastly, we define three functions to call the parameters in the other contract. The admin is simply the admin of the contract defined in the constructor function. The electricity cost and the deposit are defined by calling the conversion rate function and inserting the USD amount. Since we have to further convert from ETH to Wei, the result has to be multiplied by 10^18. Because Solidity can only process whole numbers, we have to define the electricity costs in USD cents to get an accurate amount. To adjust for this, we have to divide the electricity costs by 100.

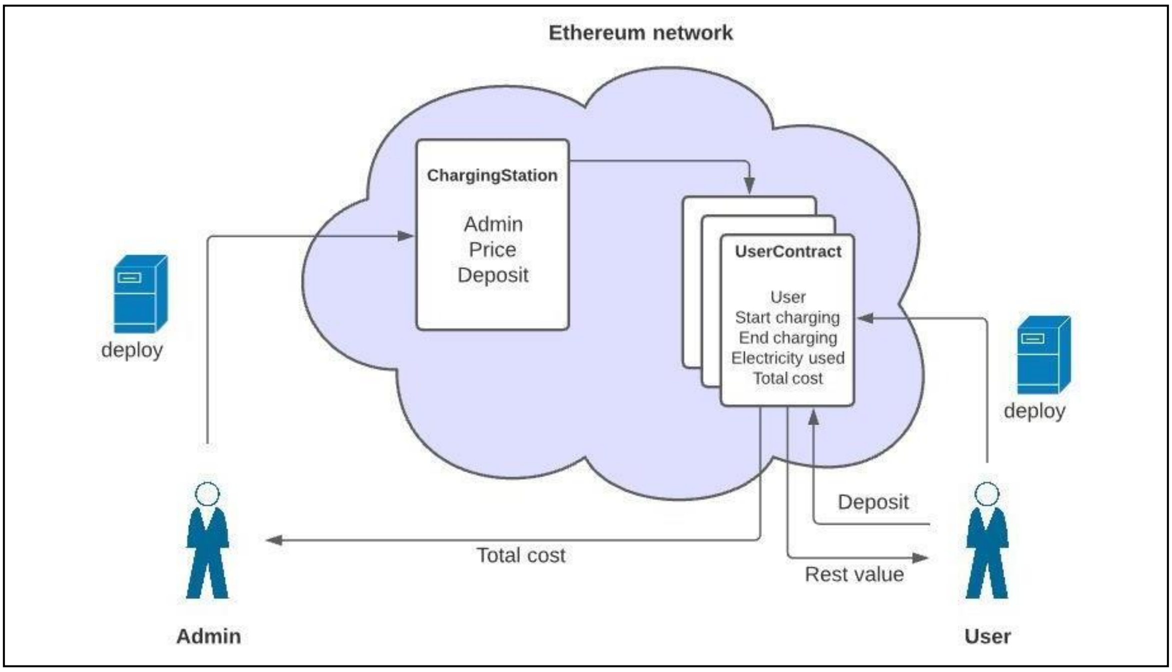

Figure 3: Simplified app architecture

Based on Bogner et al. (2016)

Once deployed, the charging station contract remains the same and serves as a template for future contracts of that specific charging point. The only reason to change the contract is if the admin decides to change his wallet address, the charging price or the minimum deposit.

Based on the charging station contract, users can deploy user contracts to start the charging. For each charging process a new user contract will be deployed. First of all, the user contract has to interact with the charging station contract to get the information stored there. This is done by creating an interface and importing the interface into the user contract. Required parameters for the contract are the addresses of the user and the admin as well as a start and end value to track the energy consumption later. To get an overview and control the charging process, we define five states the contract can have: Deployed, deposited, charging, awaiting payment and inactive. Initially we set the status to deployed. Once again, we create a constructor function fixing the user as the one who deploys this contract first, create the term 'stationContract' to interact with the charging station contract and fixing the admin address to the admin of the charging station contract by calling the 'getAdmin' function of that contract. Ethereum accounts do not work like a bank account where people can just allow others to withdraw money via debit node or can go into debt when they do not have enough money in their account to cover the expenses. We have to come up with an idea to ensure that the user has enough ETH in their wallet to pay after the charging is completed. This is why we defined a deposit in the charging station contract. As described, smart contracts have their own address and balance and can be funded by end users. We allow and insist that the user has to fund the contract to guarantee the payment. The required deposit can be set by the admin and should be high enough to exceed the maximum expected total charging cost with certainty. We define a payable function to make a funding of the contract possible. Sending ETH to the account should only be possible if the contract status is deployed and the ETH amount is higher than the required minimum deposit. Only the user should be able to fund the contract. If any of these conditions is not met, the funding request returns an error describing the reason. If the funding is successful, the contract status is set to deposited. The user can now start the charging process by calling that function. Once again, we require that only the user can exercise this function and the contract status should be deposited meaning that the charging process can only start after the deposit was made. The start amount of electricity is tracked and the contract status changed to charging. Finally, the user can end the charging and the program will complete the whole process automatically. First, the status is set to await payment and another function to complete the transaction is called. This function tracks the end amount of electricity and calculates the electricity used as well as the total cost of charging. If the deposit is high enough to cover the cost, the total cost of charging is paid to the admin and the user receives what is left from the deposit. If this function is successful, the status is set to inactive and the contract deleted from the blockchain once again making sure no ETH remains in the contract.

3.3.2 Testing the smart contracts

Besides the Ethereum main net there are several test nets that like the Ethereum main blockchain but do not require real funds to send transactions. To check whether the code is working properly we tested it using the Remix tool and MetaMask wallets on the Kovan test net. A detailed description how to do that is provided in the documentation. The addresses of the accounts and contracts used in the testing are provided in the table below and can be reviewed on Etherscan[2].

Table 1: Test addresses

Admin	0x4c071Cc9477EeA580869F53a7d60A6f0b0A55D72
User	0xe083c42c40525A897a884B1f53D793f3fE94beBc
ChargingStation	0x71460efE7a37E3Ed7AFdCcA092E60B0919232D75
UserContract address	0x7d12D46C4B60A7EfA0f87462C061E146345F5012

First, we use the Chainlink faucet[3] to fund admin and user wallets with 0.1 Kovan test Ether each. The charging station contract is compiled and deployed by the admin. For this example, we set a price of 0.3 USD/kWh and a minimum deposit of 50 USD. Using the address of this contract, we compile and deploy the user contract with the user address. Viewing the admin and user returns the addresses respectively. The current status can be called in the user contract. Trying to start the charging returns an error, as expected, because we have to make a deposit first. The deposit has to be made by the user and must be higher than the minimum deposit. In this example, we deposit 0.02 ETH to the contract and proceed to start charging. The end charging function terminates the contract. In a real dapp, there would have to be a connection to the charging point reading the amount of electricity used. For demonstration purposes we hard coded fictional values for now to get an energy usage of 60 kWh. Multiplied with the price we should have total costs of 18 USD. Reviewing Etherscan we can see that the contract sent appr. 0.006875 ETH to the admin address. At a current price as of March 04th 2022 of appr. 2,613 USD per ETH (Yahoo Finance (2022)) this actually equals appr. 18 USD. The user contract has been self-destructed; the charging station contract is ready to be used again as a template. The remaining deposit is refunded to the

[2] Kovan Etherscan: https://kovan.etherscan.io/
[3] Kovan faucet: https://faucets.chain.link/

user. The test is successful, the amount transferred from the user to the admin matches the expected value.

3.3.3 Discussion of alternatives

For demonstration purposes in this project, we showed how the implementation of the whole dapp on the Ethereum network could look like. Using Ethereum, building a fully decentralized app is possible. In reality, there are many other options how the idea could be implemented. Centralized and distributed systems are architectural antipodes, it is possible to create mixed systems like an architecture with a central component within a distributed system (Drescher (2017)). We will briefly discuss the main challenge of using the Ethereum network and possible strategies to overcome it.

Implementing the whole dapp on the Ethereum network has some advantages. It is transparent since the whole code would be open source increasing trust in the system. Ether is a well-known and established cryptocurrency and familiar to many end users. However, using Ether for the payment has some drawbacks. The EV driver always needs to have some Ether available to access the charging stations. The admin gets paid in Ether and therefore always has some of his value stored in this asset. Cryptocurrencies are notorious for being extremely volatile and Ether is no exception (figure 4). We analyzed the price data of the past year from March 01, 2021 to March 01, 2022 (Yahoo Finance (2022)) for Ethereum in Euro in a separated Python script. In this one-year period extreme price fluctuations occurred. The maximum weekly gain is 31.5%, the maximum weekly loss 41.3%. End users that want to hedge against this risk would have to constantly exchange their ETH in a FIAT currency resulting in additional fees. Prices can even change extremely within a day with a maximum recorded gain of 25% and a maximum loss of 26.9% between trading days. Even within a charging process of a few hours the USD value of the price in ETH that both parties agree on can significantly change. This uncertainty makes ETH absolutely inappropriate to serve as a currency for transactions.

One possible solution to this problem is to use a stablecoin, a cryptocurrency whose value is linked to a FIAT currency. The most popular stablecoin is Tether (USDT) that is always worth one US dollar. However, using stablecoins could impose another risk since some doubt their reliability (The Verge (2021)). Another option is to create an own token that is used only within the app and giving it a fixed value or execute the transactions in FIAT currency. Both would require a central institution to control which contradicts the idea of having a purely distributed system. This example demonstrates that sometimes a constant assessment is needed of how much centralization should be tolerated to provide a user-friendly app.

Figure 4: ETH price in EUR

Source: Yahoo Finance (2022)

4 Concluding remarks and outlook

In this project we developed a business idea that combines the three trends sustainable mobility, sharing economy and blockchain. By creating a decentralized sharing app, we approach one of the biggest challenges of electric vehicles: The lack of charging infrastructure. We wrote a program in Solidity that can serve as core for building a decentralized application. We successfully deployed and tested the smart contract and discussed possible alternatives to our approach. Due to limited time in the context of a seminar we focused our attention on the idea and the most basic parts of the code with the fundamental functions. Therefore, we see a lot of potential for follow-up projects.

One task would be further extension of the code to increase consumer satisfaction. For example, a function for the admin to reclaim the charging station and end a charging process if it takes too long would make sense in this context or an indicator showing in the app whether a charging station is currently occupied or free. Another assignment is a more detailed audit regarding safety and further testing of the code. In addition to further back-end coding, creating a front-end interface for end users to complete the app would be another useful addition. Once a beta version of the app is ready it would be possible to create a prototype or test it in a real charging station. Many more ideas would be conceivable, like building an AI mechanism for charging stations to communicate with each other and to EV's to adjusting charging prices according to other prices near the location, availability of chargers, battery levels of cars and so on.

For simplicity reasons, we also did not consider legal aspects like liability issues or taxation of revenues as well as a detailed analysis of Gas fees in a Ethereum dapp compared fees in a conventional app. For now, we are satisfied that we demonstrated how the general outline of the Solidity code could look like and were able to make it work in a secure way.

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Appendix

List of attached files:

Smart Contracts for back-end programming:

ChargingStation.sol

UserContract.sol

Documentation.sol

Python code for Ethereum price analysis:

EthereumData.ipynb

Ethereum_daily.csv

Ethereum_weekly.csv