A Crypto-Token Based Charging Incentivization Scheme for Sustainable Light Electric Vehicle Sharing

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***Abstract*— The ecological impact of shared light electric vehicles (LEV) such as kick scooters is still widely discussed. Especially the fact that the vehicles and batteries are collected using diesel vans in order to charge empty batteries with electricity of unclear origin is perceived as unsustainable. A better option could be to let the users charge the vehicles themselves whenever it is necessary. For this, a decentralized, flexible and easy to install network of off-grid solar charging stations could bring renewable electricity where it is needed without sacrificing the convenience of a free float sharing system. Since the charging stations are powered by solar energy the most efficient way to utilize them would be to charge the vehicles when the sun is shining. In order to make users charge the vehicle it is necessary to provide some form of benefit for them doing so. This could be either a discount or free rides. A particularly robust and well-established mechanism is controlling incentives via means of blockchain-based crypto-tokens. This paper demonstrates a crypto-token based scheme for incentivizing users to charge sharing vehicles during times of considerable solar irradiation in order to contribute to more sustainable mobility services.**

Keywords*— *sharing economy, micromobility, scooter, light electric vehicles, solar charging stations, blockchain, distributed ledger technology, cryptotokens, ethereum

1. Introduction

Free float *light electric vehicle sharing* (LEVS) has great potential to reduce greenhouse gas emissions and air pollutants, congestion, space demand, and noise in an urban environment [1]. However, the ecological impact of LEVS can still be improved, especially with regard to their energy supply. In many cases, vehicles or batteries are collected using diesel vans in order to charge empty batteries with electricity from unknown origin. This battery charging practice is one of the main contributors to life-cycle greenhouse gas emissions accounting for up to 50% of the total life cycle greenhouse gas emissions of LEVS [1]. At the same time, it constitutes a significant cost component [2]. A solution could be to let users charge the vehicle themselves whenever it is necessary. However, there is a lack of understanding of user behavior when it comes to charging the vehicles. If a user is tasked with charging the vehicle, it compromises the convenience of a free float LEVS since it costs time to identify a free charging station, approaching it and plugging the cable in. In case a charging station is not at the user's destination, the willingness to charge might be lower. Hence, an incentive in the form of free rides or discounts is an option to compensate for these inconveniences. A possible solution for charging points needed in such an incentive scheme could be a decentralized network of small off-grid solar charging stations, like suggested by Martinez-Navarro et al. [3], providing renewable electricity where it is needed, without requiring a grid connection, therefore increasing flexibility and reducing costs. In order to utilize solar off-grid charging stations effectively, the generated electricity must be used instantly instead of storing it in a battery for later use. Matching production and demand, so-called demand side management, in order to decrease costs and emissions, constitutes a well-known procedure in the solar energy sector [4]. However, for LEVS demand side management is a novel approach.

In this paper we propose an incentivization function and an exemplary software architecture for implementing a crypto-token based charging incentivization scheme for sustainable LEVS, with crypto-token being defined as a purpose bound cryptocurrency [5]. We therefore attempt to answer the research question: How can a token-based incentive concept for loading LEVs be conceptualized to enable ecological and economic improvements in a mobility service?

In addition, non-functional properties for the system design, such as cyber-security, data-security and privacy need to be considered. We therefore preliminary limit our solution space to *distributed ledger technology* (DLT) based solutions, since they are well suited for implementing systems that cater for those requirements, while at the same time providing additional technical and operational properties, such as decentralization, integrity, and overall resilience [6]. In order to assess potential patterns of light electric vehicle user behavior, currently available literature was taken into account [7, 8]. Accordingly, prior academic and community work about DLT and crypto-token based incentivization schemes was analyzed, with the goal of extracting potential blueprints and best practices [9-11]. A special attention was given to the

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work by Gogerty and Johnson, who conceptualized linking electricity to a cryptocurrency in the form of *SolarCoin* [12, 13]. Furthermore, the proposed system architecture is developed regarding technological feasibility in order to allow for future implementations, thereby limiting the solution space on already existing technologies. In this regard, this research intents to explore the possibilities and applicability of a DLT based system for the outlined use case.

In the following chapters we describe the assessment of the underlying incentive function that is implemented using a crypto-token based mechanism as well as a proposed system architecture.

II. Assessing the Incentive Function

Since the goal of the incentivization is to use solar energy as efficiently as possible, the charging should be incentivized during times of sufficient electricity availability. Hence, the produced electricity must not be stored in a buffer battery, thus reducing costs and greenhouse gas emissions. For the following calculations, a solar charging station of one kWp installed capacity and 2.4 kWh of lithium-ion battery storage is assumed. The charging station is facing south without shading and is located in Bochum. For assessing the sunshine and the electricity production respectively, we are using a typical week in mid-May as this season of the year is representing the most average sunshine conditions in Germany [14]. On the consumption side we assumed that the station itself continuously consumes 50W to provide for the microcontroller and other small loads. Furthermore, other scooters are already charged in order to simulate load variations. In this example one scooter charges with 80W load. For instance, at 13:00 two scooters are charging with 80W each, plus the base consumption of 50W, resulting in 210W of total load. For the solar off-grid system an efficiency of 86% is assumed [14].

In times of excess electricity production, the battery is charged accordingly. Fig. 1 depicts the resulting production and consumption curves in Watt on the primary x-axis as well as the State of Charge (SOC) of the battery on the secondary x-axis over the course of a day.

The most relevant parameter is the SOC of the scooter battery itself. With a fully charged battery there is no need for charging. On the contrary, if the battery is low the incentive to charge the scooter must be higher. Hence, Table 1 summarizes all relevant parameters for the scale of the incentivization considered in this paper.

It is worth noting that these parameters need to be computed in advance using weather data for each specific charging station near the destination because the charging process can take up to three hours depending on the SOCS.

Hence, the following incentivization function can be derived:

$$f(IC) = \frac{f\left(\frac{W}{W_{dmax}}\right) * f(SOCC)}{f(SOCS)} \qquad (1)$$

Due to a lack of data about the user behavior each function is an equally weighted linear function in this paper. For a practical implementation, the parameter weights of the incentive function and the impact on the user behavior need to be assessed in the field using e.g., an iterative approach. The resulting function is then normalized to show the fraction of the maximum possible incentivization for each period of time.

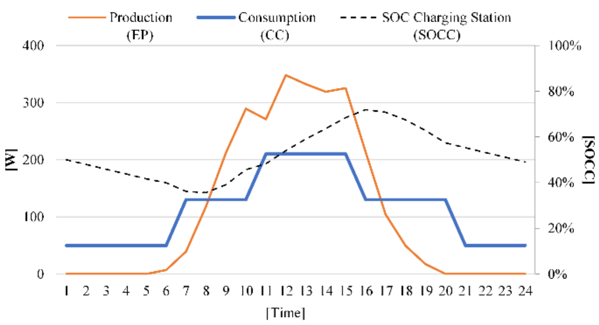

Fig. 1. Production, consumption and SOC of an off-grid solar charging station.

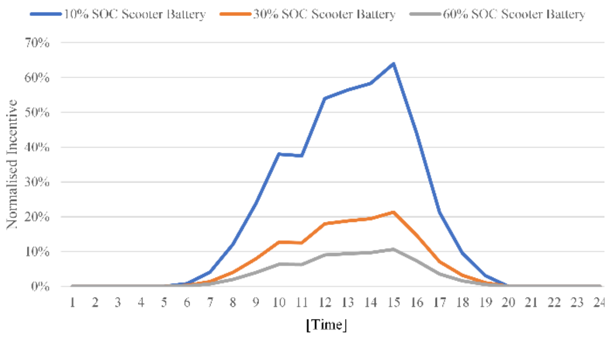

Fig. 2. Normalized incentive curves for a SOCS of 10%, 30% and 60% respectively.

E.g., if the incentive is a maximum of ten free ride minutes worth of token, a normalized incentive of 70% would mean an effective seven free ride minutes for charging the vehicle at the destination.

Fig. 2 shows the normalized incentive curves for a SOCS of 10%, 30% and 60% respectively. For a better user experience (UX) the scale should be less granular in order make sure the user understands the incentive provided. One option could be to split up the incentive scheme in four levels and indicate the size of the incentive by a more intense color as depicted in Fig. 3.

According to this incentivization function, we designed a blockchain-based crypto-token system, that uses a smart contract as an escrow for the scooter renting business transaction, similar to existing research designs for using blockchain-systems as an escrow component in business transactions [15 – 17], informed by an external weather station acting as an oracle [18].

III. Software Architecture and Incentive Design

The software architecture for the system design is depicted according to the C4 model [19, 20]. The system context diagram (see Fig. 4) provides a high-level overview with regard to interaction with other systems and the container diagram (see Fig. 5) acts as a more detailed breakdown of the logical deployment units involved in the design and operation of the system. Our system, hereby defined as *Solar Token System* (STS), interacts with several external systems (*Charging Station*, *Weather Station*, *Scooter*), all of which can

Normalised Incentive	Tier Level	Effective Incentive
<20%	0	0%
20% - 40%	1	25%
40% - 60%	2	50%
60% - 80%	3	75%
80% - 100%	4	100%

Fig. 3. Schematic representation of the proposed UX for incentivizing users to charge the vehicles.

be considered cyber physical systems [21]. In addition, the user, in the role of a mobile citizen, is the main driver of system interactions. The STS acts as a core business component, integrating the aforementioned cyber physical systems to allow for completely automatable business transactions for the use case of scooter renting and return, while at the same time adding a dynamically and automatically adapting incentivization layer based on weather data and remaining scooter and station charge.

As a technological basis for implementation, a combination of classical software components and blockchain technology is used. At the core of the system, an Ethereum smart contract implementing an ERC-20 token [22], *Solar Token Contract*, is responsible for handling all business transactions based on the configured incentivization scheme formular. The current solar radiation is continuously and transparently updated by an independent process (*Solar Oracle Proxy*), acting as an oracle for ingesting the current weather readings, as well as reasonable forecast, from the Weather Station into the Solar Token Contract, where the data can be used as input parameters for the incentivization scheme formula. On scooter return, the charging station reports the charging event, containing the remaining scooter and station charge, in the form of a Smart Contract transaction to the Solar Token Contract, which then finalizes the renting process. In this way, the Solar Token Contract acts as a Smart Contract in the most classical sense (as a machine controlling property by digital means, providing observation and verification) [23]. It thereby fulfills a role as the independent machine-controlled intermediary in the scooter renting transactions, where it acts as an escrow holder for the initial deposit of the user, which is dynamically redistributed to user and scooter on return, based on the current solar radiation and remaining scooter and station charge.

TABLE I. INCENTIVATION FACTORS

Parameter	Impact on Incentivization (II)	Indicator/ Unit	Time Reference
Electricity Production at the Charging Station (EP)	Higher EP, Higher II	W/W_{dmax} (W)	Prediction from weather station
Current Consumption at the Charging Station (CC)	Indirect, through EP and SOCC	N.a.	Current Status
SOC of the Charging Station (SOCC)	Higher SOCC, Higher II	(%)	Prediction from EP and CC
SOC of the Scooter in Use (SOCS)	Higher SOCS, Lower II	(%)	Current Status

IV. DISCUSSION AND FUTURE WORK

The scheme developed in this paper is the basis for a future technical implementation of a crypto token-based user incentivization-scheme within a research project case study, which would allow for the implementation of a decentralized system, that is decoupled from traditional drawbacks of payment provider integration, such as high transaction fees (especially high minimum fees, rendering micropayment practical infeasible) and vendor-lock-in effects. In addition,

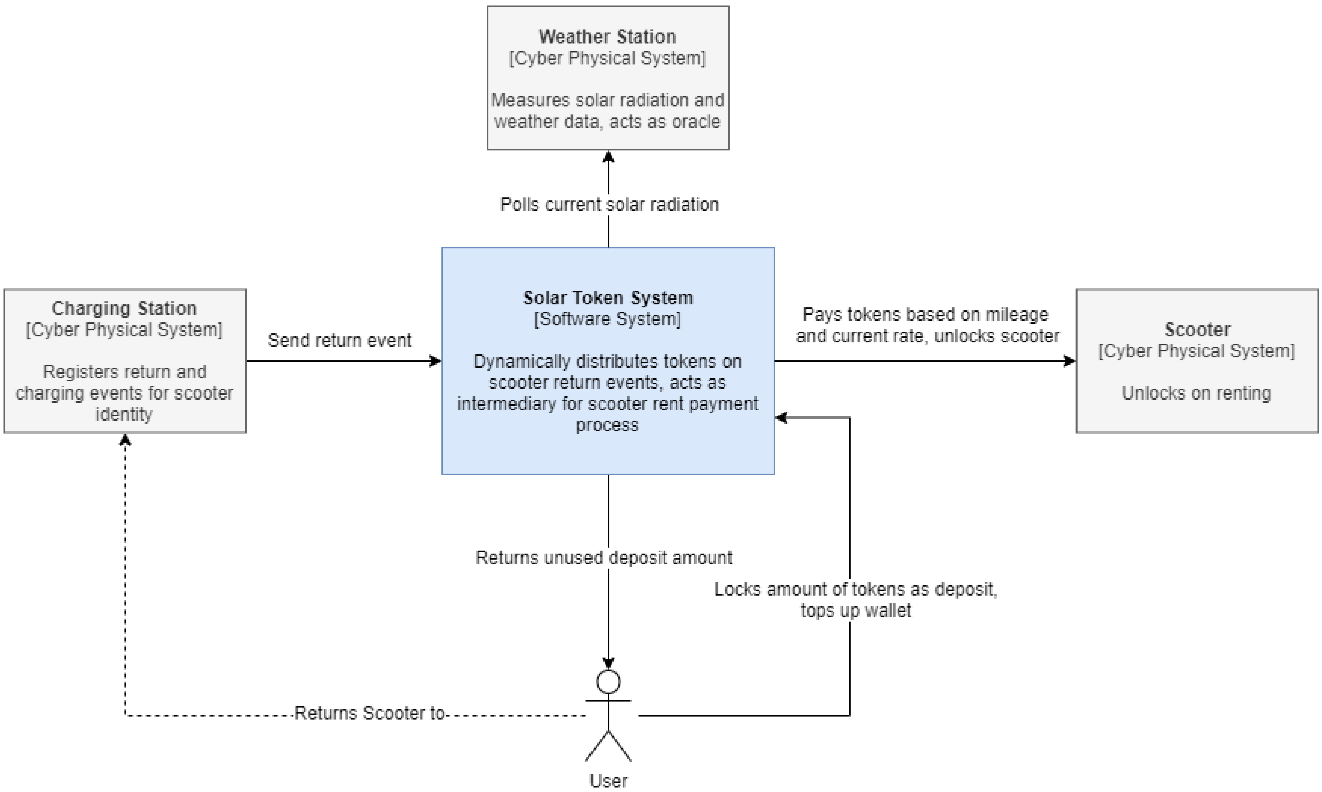

Fig. 4. STS system context diagram..

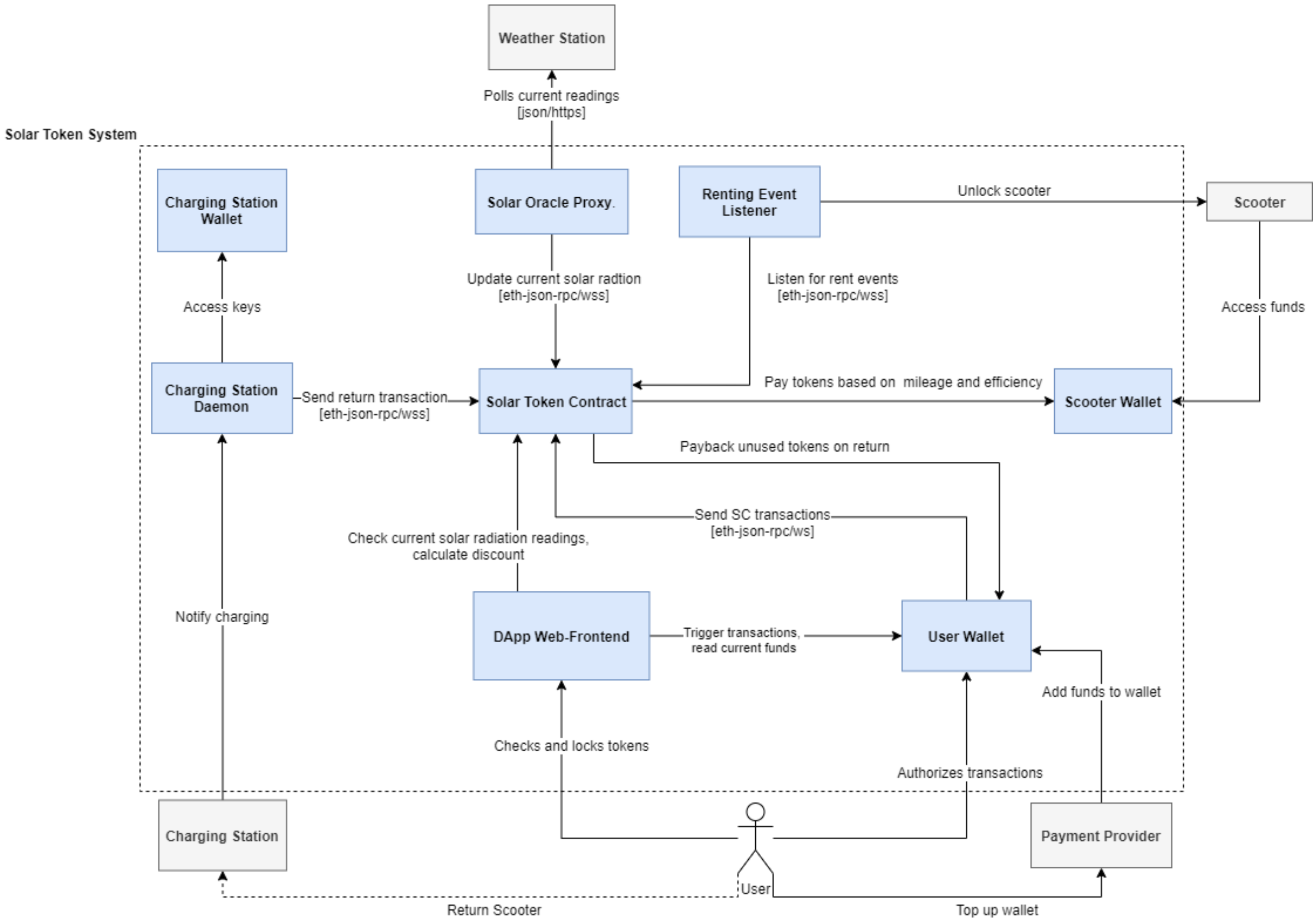

Fig. 5. STS container diagram (detailed descriptions and concrete technology selections omitted to improve readability in print).

such a system would be operated not by a central authority, but by a network (or decentralized organization), lending itself well for the context of urban networks spanning multiple cities, providing services to their citizens across their respective city limits.

During this project, the weighing factors and the function of each factor influencing the incentivization need to be assessed. This can be done using controlled experiments such as A/B testing [24]. Furthermore, the user acceptance for such an incentivization scheme as well as the parameters influencing the acceptance should be evaluated. The user needs to understand the benefit and the charging must be as convenient as possible. This could include measures like inductive charging, a clear and easy to understand UX as well as a dense network of charging stations in order to keep the benefits of a free-floating system. In addition to incentivizing users to charge scooters it is also possible to offer discounts incentivizing users to rent the scooters e.g., during traffic congestion periods using a dynamic price model for scooter usage. This can also be implemented via means of DLT based crypto-tokens. These tokens can be used to establish a closed-loop token economy, by allowing the payment of the scooter rent with aforementioned tokens. By freezing a certain amount of a user's tokens for future transfer to the scooter's account as a deposit, further securities against a shortfall in payments can be established within the system, allowing for a high degree of automated business transactions. Since the distribution of tokens back to the user and to the scooter on return is determined by formular (1), the encoded formular itself acts as a distinct control instrument for influencing user behavior.

In practice, the technical layout of the crypto-token based incentive scheme as well as the incentive function and the UI and UX of the proposed system need to be tested as part of the implementation. This requires a critical mass of users in order to allow for statistically significant results. Also, it must be evaluated in what scale there are ecological and economic benefits associated with the implementation of such a scheme.

Besides an empirical evaluation of an actual implementation and the analysis of resulting human interaction using behavior-science paradigms, the proposed design artifact of the underlying information system should be assessed using a scientific methodology such as design science [25]. The proposed system can, therefore, act as an initial starting point for an iterative generate/test cycle, which would ideally generate machine-readable artifact models. As part of this research methodology, special care should be giving to comparing and contrasting a DLT based design with more classical architectures for information technology systems. Note that this research process itself could benefit from an increase in transparency, integrity, observability, and reproducibility, by incorporating and integrating against DLT [26, 27].

Furthermore, this system might be extended by additional use cases and services, that can benefit from such a "green" token-economy blueprint, thereby creating new digital markets and ecosystems. While those token economies can be easily envisioned, the usage patterns and potential ways of exploitation by users are sometimes counter intuitive [28, 29].

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