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Connected E-Mobility, IoT and its Emerging Requirements for Planning and Infrastructures

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1 ABSTRACT

The worldwide expansion of electric vehicle usage comes with the challenge of adapting the respective traffic and charging station infrastructure in cities, resulting in profound changes not only to traffic itself but also to the way energy is being distributed. An ongoing all-embracing real-time IoT-network will provide a vast amount of new possible data for planners, for example in order to get useful insights into the relationship between traffic flow patterns and loading patterns of e-vehicles. For this, the use of e-mobility data is essential. This paper will present potential ways of gathering data for infrastructure planning and user-oriented recommendations, such as movement patterns and charging status of vehicles, since this information is already available but not being shared by car companies. The given perspective will take into consideration individual vehicles and vehicle fleets as well as the traffic network as a whole. Efficient access to current and predicted load for charging stations in the electric vehicle transition would be a beneficial factor for the promotion of electricity-powered vehicles. In this paper, we lay out different approaches. Besides manufacturer related data-acquissition, this includes as well to provide this information via user-generated content (UGC), and to derive charging recommendations from a user-oriented, intelligent recommendation system. Furthermore, the challenges regarding the effects towards the electricity network and the necessity of physical charging infrastructure will be discussed. In a future situation of more heterogenous and dispersed energy supply, being able to predict the energy consumption of e-vehicles individually and instantaneously based on collected data will be a necessity for energy supplying companies. This will intentionally lead to more grid stability, by distributing electricity inside the network based on predicted loads, as well as work as an incentive for drivers to make the transition to e-mobility, because finding e-charging stations will eventually not be an issue. This paper will take the respective questions and potential control mechanisms for traffic patterns into consideration.

Keywords: Smart Grid, e-Mobility, User-generated-content, Traffic planning, Smart mobility

2 INTRODUCTION

A major factor holding back the expansion of renewable energy are the shortcomings of today's power grids that are unable to effectively handle decentralized and periodically fluctuating power production. One of the most far-reaching political topics in Germany is fostering the development of a smart energy grid, an integral part of the transition to green, renewable energy, the so-called "Energiewende". Offering great ecological, economic, and social opportunities- the growing share of renewable energies in energy production also poses enormous challenges for energy supply in general. But these problems do not only concern the production, but also the consumption side of the electricity infrastructure, especially considering the advent of e-mobility. A secure and sustainable energy grid of the future must take e-mobility into consideration and meet its fundamental prerequisites. The ongoing proliferation of charging stations for electronic vehicles puts an ever-growing strain on the electricity grid, not only because of the additional load but also because of the fluctuation in load during peak times. An adapted build-up of the electric vehicle (EV) charging infrastructure, including the need for embracing loading patterns in all parts of the mobility network, is needed to further facilitate sustainable e-mobility.

The approach to solving the problem laid out in this paper involves gathering relevant data, such as movement patterns of vehicles and information provided by charging stations like location, time and load to predict and thus manage electricity distribution in the grid. By intelligently distributing electricity to places with high demand at peak hours, the risk of energy oversaturation as well as shortage are minimized, and the groundwork is laid for further expansion of the charging infrastructure, thus creating incentives and lowering the cost of opportunity to charge electric vehicles. First, this paper will establish a theoretical framework incorporating viewpoints from different perspectives, such as urban planning, energy infrastructure and smart mobility, in order to emphasize the need for a systemic perspective on the issue. After that, a methodological approach to gathering relevant data will be introduced. This data can also be used in other contexts, for example by adding an intelligent pricing system at EV charging stations based on expected load, that could be used as an implicit way of traffic control akin to conventional city toll systems. Therefore, the last step is to consider potential further use cases for the collected data.

3 THEORETICAL FRAMEWORK

Other than conventionally fueled vehicles, which can rely on established infrastructures such as petrol stations, the expansion of e-mobility is highly dependent on infrastructures that are not sufficiently available yet. The buildup of those infrastructures needs to take into consideration the comparatively small energy storage of e-vehicles and long charging times as well as constraints of today's power grid and employ a systemic perspective. The low energy efficiency of e-vehicles necessitates the availability of charging stations practically everywhere, which means that a sufficient supply of electricity has to be available even in rural areas. Therefore, the proliferation of e-mobility must be one of the driving forces behind the overhaul and expansion of the existing power grid, and vice versa.

From a systemic perspective, this opens other areas, where the relationship between e-mobility and infrastructure must be considered. In urban planning for example, the expansion of e-charging stations needs to be extensive, but at the same time additional traffic congestion caused by short loading cycles and long loading times must be prevented. Transmission system operators and electricity distribution operators, on the other hand, need to build a secure and sustainable power grid equipped to incorporate highly fluctuating energy production and consumption. Developers and system engineers must craft an ICT environment around those systems in order to enable them in the first place, by gathering, transmitting and processing data that power intelligent machine learning processes, able to predict changes in energy consumption or traffic routing instantaneously and operating the elements autonomously. Additionally, and often overlooked, politics have to shape adequate laws and regulations as well as offer incentives in order to facilitate this overall transition process. The development of e-mobility and energy infrastructures will be strongly connected in the future and enable new methods for data gathering.

4 ASSESSMENT OF METHODOLOGICAL APPROACHES

The methodological approaches differ between their nature of data gathering regarding the location information and in addition the respective charging patterns.

4.1 Manufacturer-related data acquisition

Today's cars are utilizing sensor technology to gather a wide variety of user and vehicle data. McKinsey estimates that modern cars collect up to 25 gigabytes of data per hour, much of which is then transferred to the manufacturer by Wi-Fi or mobile data connection to be analysed for performance control and maintenance. The most notable data collected by a car is illustrated in a study conducted by German automobile club ADAC (2020). According to them, a new Mercedes B-Class for instance collects data such as GPS position, mileage, consumption, tank filling, tire pressure and various liquid levels like coolant, brake fluid and screen wash, which is sent to the Mercedes backend every two minutes. Sensors also record the style of driving by measuring how often the seatbelt is tightened up by breaking too hard or how often the engine running speed and engine temperature are too high. Additionally, the car collects data allowing the manufacturer to create a detailed user profile by tracking the last one hundred charging cycles with GPS coordinates, date, time and mileage. While this approach by Mercedes is basically a standard procedure for modern cars, other manufacturers like Renault employ much more curious practices. Not only can they read the data provided by the different sensors, they can also send commands to the car via mobile connection, for example to prohibit drivers from charging their car, if they failed to pay a bill for example, activate remote diagnosis, which is deactivated by default, or remotely extend the kind of data being transmitted. Practices like these open up a lot of questions regarding data privacy, one of which is: What happens with all the collected data? A good example of how to profit from this data is GM. They offer a service called GM Marketplace that brings personalised advertisements into your car, thus for example guiding you to a specific gas station or local restaurant by offering discounts. But vehicle data isn't just valuable because of suchlike business models. Car manufacturers want to improve their product and increase lifetime value, insurance companies want to provide more accurate, individual estimates for usage-based insurance, urban planners want to know more about people's movements and developers want to build new products and services utilizing this data. Therefore, McKinsey predicts as much as $750 billion of value in vehicle data by 2030 (Peters 2019).

This paper aims to present potential ways of gathering some of the same data, also independent from the car manufacturers, in order to better inform infrastructural planners as well as potentially drivers. The underlying technical approach to this will be presented in the following paragraphs. Furthermore, corresponding use cases for the approach shown are presented. E-fleet-Management is such a use case, because E-fleets are an essential component of future e-mobility, and they will generate large, local energy fluctuations in the power grid if they are not charged in a coordinated manner. This problem is prevented with the following, data-driven methodology.Sensor and telematics-based data gathering. One approach could be to collect data by a telemetry module, which reads the energy status of the car. One use case is to minimize the energy costs of a fleet with the help of a recommendation assistant for intelligent charging management. The first component of the solution is a recommendation wizard for the load operation strategy. This recommendation wizard creates a charge plan for all vehicles in the fleet under a fixed timetable, depending on network charge estimates, for example, or flexible electricity tariffs and solar yield forecasts using optimization methods and artificial intelligence methods. This plan contains which vehicle is charged when and with which power source and thus attempts to minimize the maintenance costs of the eFleet and indirectly brings stability to the energy grid. This can be further improved by adjusting the schedules. This adjustment depends strongly on the energy consumption of the vehicles during a journey. Based on this, the second component for this use case is the forecast of the energy consumption of a vehicle for one journey. This can be predicted using artificial intelligence methods on the basis of destination, starting time and the route to be taken - for the destination as well as for each part of the route. Among other things, neural networks, especially recurrent networks, can be used for this forecast.

The next component is the adaptation of the timetables to further improve the results from the first component. For instance, ferry schedules include which vehicle is assigned for which trip at which time. For this purpose, the forecasts from the second component and other data such as vehicle specifications, in particular the loading capacity and performance of the vehicle and the requirements of the trip (number of people/goods transport) are used. This can be solved with methods of combinatorial optimization such as Evolutionary Algorithms.

Another use case of this data is the optimal positioning of charging infrastructure. This depends above all on the level of demand for charging at a particular position. Such data is very difficult to obtain at the moment. But with this approach it can be also calculated by user generated content, because the demand of charging depends mainly on the traffic flow of electric vehicles and the charging status of these vehicles. Whereas some of these mentioned solutions were used in the fleet-management context for a dedicated set of vehicles, the principles could be transferred also the mobility network as a whole.

4.2 Data gathering by UGC

A potential way to collect location and charging data is with user-generated-content (UGC). In this way, a platform based on UGC could be the foundation for an improvement in the efficiency of future charging infrastructures, targeting electric vehicle owners, with the intent of making the charging process effective for both the users and the mobility network in general. The focus on UGC from other approaches, is the scheme to collect user-generated content, that has been created with a collaborative effort of individuals, contrary to using data from third parties, because it is not certain if this data will be provided by car companies. We consider a platform where users exchange information with each other, including several important parameters such as how long they plan to charge, flexibilities that state whether they can, for example, make a 30-minute charging break for a user who needs an urgent charge. This data is transmitted to all users of this network, and they can plan their route in advance or real-time accordingly. This platform would be ideal for an EV owner, as they would be able to have an expectation time for how long they would need to charge their vehicle at a station, with respect to the demand at charging stations nearby, by using an intelligent system that learns user preferences and peak load times on local or regional charging stations. The motivation is to save their time and make the EV charging experience more efficient and comfortable. Besides this approach, there are also potential other ways of gathering, like for instance with a camera based solution or if that's not possible, by a camera, which takes pictures of the charge display. This data can be collected until the drive ends and uploaded to the cloud. An artificial intelligence service such as a convolutional neural network can classify these pictures into an energy status.

Once UGC is available from other users, the model capable of predicting peak loads on a charging station and estimating the typical waiting time for a user at a specific station, will be used to build a user-oriented recommendation system. The system is capable to handle each user individually and create their own route recommendation based on estimated charging times and preferences. The vision for this application is, however, broader than just information exchanging in a narrow network connecting the EV owners.

We plan to use this user-generated content to train an Artificial Intelligence model to make predictions of the electricity and traffic load on the charging station during various times of the day or week or year as well as getting insights to the mobility traffic patterns at the charging stations. This would aid in monitoring and limiting traffic congestions in cities. Crowdsourcing in real time can provide great input data to current applications for computing optimized routes to current and forthcoming users. One of the reasons for such an approach is to be independent of collecting data from the third-party EV companies or EV charging stations, which can become quite a difficult task due to information sensitivity, competition, and data ownership. This data retrieval method is known as user generated content mining which is formatted into a knowledge representation entity, used for downstream tasks. One of the main advantages of user generated content mining for data in a recommender system is the initial setup time period. The duration is relatively short, some data is ready instantly, and the system can start using its algorithms to make recommendations for the users. Another feature is the ability to adapt to changes quickly. This can be an advantage in comparison to other methods, when the environment (in our case the amount of charging stations, chargers, and electrical vehicles) changes rapidly. Since the Artificial Intelligence model needs data to learn a function to make a load forecast, using newly collected data would increase the accuracy of the model and prevent data from going out of date. When using data collected over time, the AI responsible for decision making would only learn the trends of EV usage at certain charging stations for the given time period. However, as soon as the number of electrical vehicles would change, new data would be needed for the training of the AI, whereas with the user generated content approach, no changes would be needed. One disadvantage of this mining method is that data can contain false information, as it is no requirement of proving the validity. Another challenge that we would face is to motivate the users to submit data. However, if the product is rewarding, as it would make it easier for users to get used to the EV charging and avoid conflicts at charging stations, there would be a positive dynamic of people using the platform and submitting their data. Crucial aspects in this approach is the user acceptance and willingness to contribute UGC for the named purpose, since this data would allow very detailed personal movement patterns to be analyzed, so there should be necessary mechanisms to protect the privacy of users.

Data mining with sensors and by user generated content do have their own strengths and weaknesses. Sensors for example can be quite intrusive by not being transparent on what kind of data is collected precisely. This raises issues of data privacy and leads to negative public reception. They are also intrusive in the way that they are either part of the road network or your car, as a driver you don't have a lot of control over them. On the positive side, they're quite cheap and easily employed and they can reliably collect vast amounts of very different kinds of data. While this sounds good, it also comes with the challenge of transferring and analyzing huge amounts of data effectively. User-generated content on the other hand will most likely not raise any questions regarding data privacy as the user has full control over what kind of data he wants to send to whom. The data generated here is also processed already by the user who puts it into some kind of website or application, thus the chance of collecting irrelevant data is much lower and it is presumably easier to process the data. But the kinds of data that can be gathered is limited to something that can easily be perceived by the users and it likely suffers from subjectivity, either in the way it is perceived or whether it is recognized as relevant in the first place.

5 POTENTIAL APPLICATIONSFOR URBAN AND TRAFFIC PLANNING

Theoretically, urban and traffic planners can apply the data in two different ways, on the one hand there is the location data enabling the informed improvement of traffic routing and on the other hand the information on charging patterns are helpful for upgrading and expanding the energy infrastructure. Generally, digitization will have a drastic and lasting impact not only on mobility, individual transport as well as public transport, but also on infrastructure planning overall, especially the relationship between traffic control and energy distribution. Thus, the future development of urban areas and districts will require a new and innovative approach to energy supply, particularly involving solutions for renewable energy, storage possibilities and adequate e-mobility infrastructure.

The following chapter will introduce a potential additional use case for the data generated by the proposed methods, aiming to further demonstrate the intricate relationship between e-mobility and energy infrastructure, at the same time taking political control mechanisms into consideration.

5.1 Potential further data use traffic planning

The data collected by the presented approach can be used for infrastructural planning purposes in primarily two ways, firstly for monitoring purposes in general and secondly for traffic management, for example by providing incentives and restrictions.

5.1.1 Real time traffic Monitoring

A smart e-mobility charging infrastructure, as outlined in this article, would be an integral part of a holistic mobility concept for future smart cities and the potential synergies between such a system and other key elements of smart urban mobility promise to offer an interesting outlook into the future. As a conclusion to this article, the following chapter investigates the potential interaction between a smart charging infrastructure and a real time traffic management system. Smart traffic management is often perceived as synonymous with smart mobility in an urban context even though it is only one component of it. An integrated real time traffic management system could possibly circumvent issues such as traffic congestion, insufficient parking space capacities, high emissions and low quality of life for residents, e.g. because of noise pollution. While the goals and presumed benefits of such a system are clear, the implementation is still severely lacking. This is because it is heavily reliant on several preconditions, some of which are technological ones, that have not yet been realized. In order to illustrate this, it is helpful to envision the implementation of a smart traffic system as a multi-stage process (Citron 2019):

- Developing (Vehicle Detection & Data Collection): Camera, sensor, GPS data Focus on traffic planning
- Managed (Traffic Analytics & Evaluation): Traffic routing is possible Travel time analysis Optimization of traffic lights
- Mature (Advanced Traffic Management): Real time control of systems Integrated in vehicles AI & cloud-based platforms Data exchange with other places

In order to realize a fully manageable real time traffic control system, several enabler technologies need to be widely available and controlled via a shared platform, e.g. IoT, Cloud Computing, Machine Learning / AI. A smart way of energy distribution, that can supply energy needs when und where they occur, will be an integral part of such a system. One example for an integrated system like that could be a connected grid of charging stations for e-vehicles that is supplied depending on traffic flow. Thinking even further, a smart charging infrastructure that is integrated into a smart traffic control system could be used as a way of controlling traffic flow itself, by providing a system of incentive-based pricing. One of the reasons why data is often referred to as the 'oil' of the digital age, is because of its 'raw' nature and its ability to be refined into a plethora of useful states. This means the same data can be used for different means, depending on how it's processed. The data produced by the means presented in this paper for example can also provide the basis for smart traffic management.

5.1.2 Incentive based pricing for e-mobility as a way of traffic management

Theoretical incentives could be distinguished into "positive" and "negative" approaches. Be it positive ones, such as tax exemptions, money grants or other benefits like free parking, being able to drive on bus lanes or being exempt from paying city tolls, or negative ones, like city tolls, auto free zones or combustion engine bans, incentives already are a main driver behind the proliferation of e-mobility (Wang et al. 2015). Other approaches for toll systems based on location data (Nagothu 2016) as well as potential applications in highway networks (Lee, Tseng, and Wang 2008; Tan et al. 2017) are discussed in relevant literature (Sanal et al. 2019). While suchlike measures are mostly explicit and therefore obvious, possibly leading to negative repercussions, additional implicit measures promise a way of more subtle control. A possible way of

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'nudging' residents to use specific routes could be to employ smart pricing at e-charging stations. For example, an app in your car or on your phone, like electrific (electrific 2020), that aims to optimize your routing through everyday traffic based on anticipated congestion and other factors, may be able to guide you to charging stations that have lower prices, therefore disincentivizing you from using 'more expensive' routes. The prices at such stations would of course be variable and based on the current traffic flow or on city policies, e.g. to make districts car free, etc. A system like that could even work better than city tolls, that are generally not very appreciated by most residents. An implicit system, that guides you based on prices on charging stations, could eventually replace city tolls altogether.

City tolls have been established in many cities around the world (e.g. Civitas 2013), while implementation practices differ widely. Whether there is a ring of toll stations around cities or there are electronic means of tolling residents (Sanal et al. 2019), while effective, these measures tend to be unpopular with local inhabitants. The challenge with a system like that is that it needs a highly integrated, interoperable ICT and energy infrastructure. While IoT-sensors or cameras need to measure traffic flow and/or other environmental data, this information needs to be bundled, analysed and interpreted by AI in a cloud computing environment, and the derived optimizations need to be communicated, e.g. by changing traffic light circuits, adjusting energy prizes at charging stations or directly messaging drivers (Popoola et al. 2018; Abari et al. 2015; Soylemezgiller, Kuscu, and Kilinc 2013). This in turn requires drivers to be able to receive such information, either by phone or directly in the car and acting on it. All in all, a system like that is only imaginable in a holistic integrated smart city environment.

Research in this field is scarce. Most projects are limited in scope to specific use cases, for example lokSmart (LokSMART 2020), which is focussed on local flexibilities for e-mobility, 3connect (Smartlab 2020), mainly concerned with commercial e-mobility in smart grids or electrific (electrific 2020), a consumer side platform for smart routing. Only very few research projects, such as iMove (Hubject GmbH 2019), are trying to bring data from different sources together and craft an integrated ICT infrastructure. But even those are mostly limited to a technological perspective and don't account for political viewpoints. Incentive based routing options could also be used ultimately for virtual city tolls. They can be designed theoretically with "soft barriers". Tolling by making charging costs related to geographical location (expensive charging prices in the city center) as well as with a stricter concept, like a geofencing for vehicles. This means that toll barriers could theoretically be installed everywhere in the urban area, flexible in location and also time. This enables new possibilities for real-time-traffic management for planners, such as influencing the rush-hour traffic as well as reactions to natural disasters like flooding for instance. In addition, this potentially enables new business models. Though, this far reaching possibilities have to be critically considered reagarding legal, privacy and ethical aspects. There are first concepts regarding privacy-preserving toll systems (Jardí-Cedó, Castellà-Roca, and Viejo 2016), but the embracing view regarding the mentioned aspects have to be taken into consideration.

5.2 Requirements for energy infrastructures

It will be important to demonstrate how intelligent grids with a majority of renewable energy ensure a secure and efficient energy supply and which concepts and technologies can be used for this purpose to achieve efficient and safe energy networks, especially in the traffic context. The core functionality of Smart Grids itself is connectivity. With this, it is possible to connect plants, systems and devices via the Internet, regardless of location. If the systems and components involved can communicate quickly and securely, they can, for example, be combined into virtual power plants and controlled as required for instance. These aspects will be especially crucial regarding the development towards a more e-vehicle based transport model. The resulting effects of a higher rate of e-vehicles for the grid will be enormous. Besides, for instance the potential location finding process and approval of combined heat and power plants, district-based energy storage, geothermal powerplants the impacts of the mobility sector will seriously induce some effects. General question concerning the general model of transport (more public transport, more individualized, more car-sharing) have their own demands for the design of the urban space and the corresponding connection to the electricity network. In this way, the design of a mobility concept is inseparably connected to the design of a Smart Grid in the light of a Smart City (Exner et al. 2019). Especially with question of using approaches such as vehicle to grid, the planning and use of grids has to be linked to real time – as well as strategic - traffic management.

6 CONCLUSION

From a systemic point of view, fundamentally new requirements for vehicle-related charging will develop, as well as an increasing demand on the power grid. It will be crucial, how the amount of investments in the low, medium and high voltage grid by 2050, in case of a strong electrification of transport (more than 50% of all vehicles), will be held at a level comparable to the historical investment level by the use intelligent management of charging all vehicles. This new digitized world of electrified transport provides multiple new options for planning purposes based on location data and charging status. Society will face a post-fossil fuels – future, but in this world, data will be the new oil. The transport and mobility network and stable electricity network won't work together efficiently, if there aren't any real time information available regarding location and charging of vehicles within the traffic network. We presented different methods to collect a coherent dataset, with all respective advantages and disadvantages. From one perspective, this database enables totally new possibilities for monitoring the traffic network as a whole, but also for an embracing traffic management, even towards the use of virtual city tolls, which are flexible in time and location. Though, this raises issues of security and data privacy, especially when new technologies have to be applied (blockchain for instance) in order to address these problems. Also, ethical questions will arise in this context, if restrictions could be applied, regarding who can drive where and if these issues will also be incentive-based. All of these aspects have to be considered from a multidimensional and interdisciplinary perspective which will strengthen the need for cooperation of urban planners, traffic planners, data scientists and respective other partners.

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