Assessment of Electromobility in Non-Urban Environments

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Abstract—**Electric vehicles have specific requirements regarding their range capacity and their needed charging infrastructure. In a non-urban environment the usage of electric vehicles appears to be challenging as these requirements differ from an urban setting with a high density network of charging stations. In a field study with 20 families, the mobility behavior of the participants and the attitude towards electric vehicles usage was recorded. A circular range analysis and a cumulated distance behavior analysis was performed to analyze the mobility behavior. The results of the analysis are presented as a prediction about the effectiveness of electromobility in non-urban environments under private usage conditions.**

Keywords — mobility tracking, electromobility, non-urban mobility analysis

I. INTRODUCTION

Electromobility seems to be a valid solution for traffic problems in large cities and urban areas, where the streets are often congested and the air is critically polluted due to heavy traffic density. In order to introduce more electric vehicles (EV) into the cities there are various ideas of giving EVs a considerable advantage over conventional cars. London for example collects fees for driving a vehicle within the charging zone during working hours, thus trying to reduce the number of vehicles on the streets [1]. As an incentive for using an EV, they grant complimentary travel within the city and free parking at several spots [2]. Since EVs travel without direct driving related CO_2 emissions and with minimal noise, EVs embody an obvious improvement for traffic conditions [3].

The driving dynamics at low speed and potential recuperation of brake energy in frequent stop-and-go traffic are indicative that EVs are ideal means of transportation for a city environment, since the EVs' electric engines can work constantly in high efficiency and thus minimize the propulsion energy [4]. Considering the demanded trip lengths in urban mobility which are in general shorter than 50 km and in mean about 10 km per trip [5], it is obvious that those ranges lie well within the current bounds of the technical feasibility of the EVs' battery capacity.

Nevertheless, the usage of EVs in urban environments faces problems too. The usually dire parking situation leads to the issue, where to park and simultaneously charge the vehicle in comfortable distance to home or the general current whereabouts [6]. For this case the implementation of EVs in non-urban environments, where most people own a garage or at least a defined parking lot, seems promising. Especially since the overall energy demand dependent on driving characteristics does not vary significantly between urban and non-urban conditions [4]. For that reason, the usage of EVs in non-urban areas necessitates an essential analysis of the general mobility demand at hand. This becomes more important since the non-urban mobility behavior differs significantly from that of urban areas, where public transport, social infrastructure (schools, medical supply, and the like) as well as shopping facilities are easily accessible.

In this approach, the feasibility of electromobility in non-urban environments is analyzed. Thereby not only the actual mobility demand is considered but also the relation between range demand and range anxiety as a key driver for electromobile usage is surveyed. In the conducted associated casefile study the attention is directed towards the private usage of vehicles in the context of everyday domestic mobility.

II. TRACKING DATA FOR MOBILITY ANALYSES

The key method that needs to be applied to assess the private usage of vehicles in a non-urban setting is movement tracking. For tracking purposes, various hardware and tools are available that make use of sensor data and passive location identifiers like GPS. Based on what kind of information is desired and where the data is recorded, its needs to be decided which system should be used for data recording. The main challenges for tracking the movement of vehicles is continuity of the recorded data, the data quality, the accessibility of the data and the implementation of supportive tools.

Scientific studies carried out with GPS loggers focus on the task of collecting GPS data from GPS-equipped vehicles for static offline processing. In [7] the authors equipped a car with GPS receiver to record a preset number of vehicle trips. After the recording phase, the data is matched with GIS maps (global information system) to estimate the travel time data more accurately. This is extended by applying a dynamic mode and monitoring the vehicle speed in an aggregated approach to monitor traffic conditions.

The authors of [8] used a Garmin model 35-LVS wearable GPS receiver and a GPS data logger, both from GeoStats to collect GPS data in a field trial. They present a system that automatically clusters GPS data taken over an extended period of time into meaningful locations at multiple scales. This is performed in a static approach by transferring the GPS data in to a Markov model, which can be access by third-party applications.

Studies that make use of smart phones in a tracking context served various dynamic goals like mobility prediction, mode of mobility identification and assessing the CO2 emissions [9].

Mok et al. [10] tested the usefulness of GPS and sensor data of modern smart phones for vehicle tracking in dense high-rise environments. The authors point out that the low quality of collected positioning data can be enhanced by magnetic to grid north correction. Combining values from the magnetic sensor with GPS is seen as a useful approach to generate data sets that are more accurate by correcting or smoothing the data. However, the accuracy of the magnetic sensor is also affected by environmental conditions and magnetic fields in urban areas can be affected in the same way like the GPS data. Further, the positioning of the smartphone in the vehicle needs to be well defined as GPS works best with a clear view of the sky and the magnetic field reception needs to be continuous, which is often not the case. It is assumed that the mentioned lowered quality of collected GPS positioning data in an urban environment is enhanced in a non-urban environment due to reduce noise sources.

A real-time traffic data collection and dissemination that make use of the Android operating system is presented in [11]. The authors applied proportional computation and freesim to simulate and analyze a transportation scenario and do not used any additional infrastructure. The use of smart phones together with backend post-processing reduces the cost for tracking hardware compared to integrated state of the art tracking system solutions. This setting is ideal for the purpose of data analysis, as it allows for the analysis of real time data that is post-processed on a server.

Regarding the continuity of the data, GPS logger based recordings often do not store any information, when the GPS position cannot be determined over a certain time span. In contrast, positioning data recorded by smart phones are already optimized by taking the user location in relation to cell tower and Wi-Fi signals into account (e.g. Android Network Location Provider). This offer a continuous recording in road scenarios with tunnels and during bad environmental conditions. The data quality of the recorded positioning data with GPS loggers is considerably good, while smart phones need to be positioned in a static place in the car, to secure an optimal position for GPS reception. This is also the case for the GPS loggers, but this step needs to be performed only once, as the smartphone might be removed and the logger stays in the car.

The data can be access easily if they are stored on a smartphone. Integrating a serveruplink for a database connection and storing the data on an external SD card gives the possibility to access the data remotely or directly. The recordings stored in the data logger needs to be transferred manually to analyze them. In most cases, remote data access is not possible or requires a specific setup that do not leave room for further improvements.

Adding features and tools to the tracker is particularly of interested to improve the tracking method in terms of accuracy and data aggregation. Applying a limited and closed environment like represented by the GPS logger, reduces the usefulness for the targeted mobility tracking approach especially in a scientific and exploratory setting.

III. METHODOLOGY

A. *Field Study*

The field study took place in Garmisch-Partenkirchen, a middle sized town in Southern Bavaria, with a subject group of 20 families consisting of 58 participants. The project town itself is characterized by a strongly developed social infrastructure, where all daily needs can be provided for in close proximity, but with an overall low population density, constituting the non-urban environment.

All participating families owned a private residential building with a garage. The subject group consisted of 47 participants older than 18 years with an average age of 44.25 years. All those participants owned a driving license. Additionally there were 11 participants younger than 18 years.

The participant group covers a wide range of social characteristics, varying from pupils, part-time workers, workers to retirees. This mixed group is a viable basis for a detailed realistic sample of non-urban mobility demand. Furthermore, since the field study time span covered a whole year, even seasonal particularities can be included.

B. *Mobility Tracking*

As introduced in [9] 52 participants out of the total subject group were given smart phones to track their mobility behavior. For this objective the smart phones were equipped with an application with whom the individual users were able to actively track their everyday routes and gather information about the emerging mobility behavior. During the project period of 12 months all participants combined tracked approximately 200.000 km, not only driven by vehicles but also through trips by public transport, cycling or walking. The tracked mobility data together with the participant's structure provided an overall insight in the daily mobility behavior in a non-urban environment with a detailed understanding of mobility routine and mobility demand.

In addition to this, the participants were surveyed at several points during the field study in order to gather more detailed information about their everyday mobility behavior as well as their acceptance towards technical aspects of the field study.

IV. RANGE ANXIETY AS MOTIVATION FOR THE ASSESSMENT OF ELECTROMOBILITY

Urban areas are characterized by a high population and a strongly developed infrastructure. In consequence of the recent and persistent promotion of urban electromobility even the charging infrastructure for EVs is clearly advanced and further increasing [12]. Consequently, range anxiety in the context of electromobility is not significant in the urban context, since the risk of having a breakdown is reduced by the given public infrastructure. Different from that, people in non-urban environments are dependent on their own efficiently functioning vehicle in order to get safely back and forth between their starting point and their destination.

Among other questions concerning economic status, attitudes to electromobility and technical affinity, the participants were asked about their safety requirements regarding the overall safety (assistance systems, security systems) and the guarantee of the vehicles' range. Having a safety level of a conventional car ranked lower in importance than the absolute distance and the guarantee of the vehicles range ("Range over 100 km", "Display of range information"), as can be seen in Fig 2. Lower ranking of the aspects of driver security like security assistance systems and safety assistance systems points to the special needs in a non-urban environment.

Cars are necessary to master the normal life and they must be reliable, even under non-plannable conditions. Asked about them being uncomfortable with a half discharged battery 45.5% had a positive to rather positive attitude. The question concerning their feeling towards the added range safety via the range extender showed, that this aspect positively influences up to 79% of the opinion about range safety [Fig. 1].

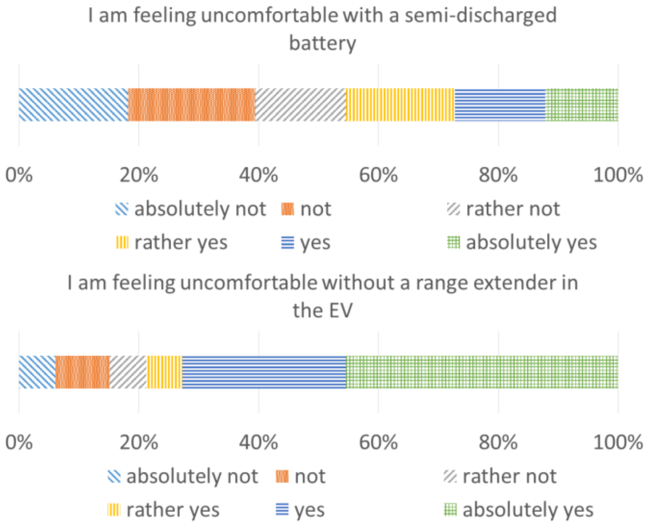

Fig. 1: Survey results concerning evaluation of range capability (n=33)

The users were further asked about their rating appertaining to crucial qualities of EVs. This inquiry is to ask for the important aspects that are connected with electromobility. As one of the most important features [Fig. 2], the aspect of range safety is integrated by different approaches:

- State of charge
- Absolute range
- Charging specifics
- Range information

These results combined show that the range anxiety plays a major role in the everyday application of electromobility. It is not that important that the vehicles' battery is always fully charged and thus the maximum technical range is available over the whole time. It is rather the illusion over an additional available range and therefore a reliable range that are the critical key factors determining the feasibility of electromobility.

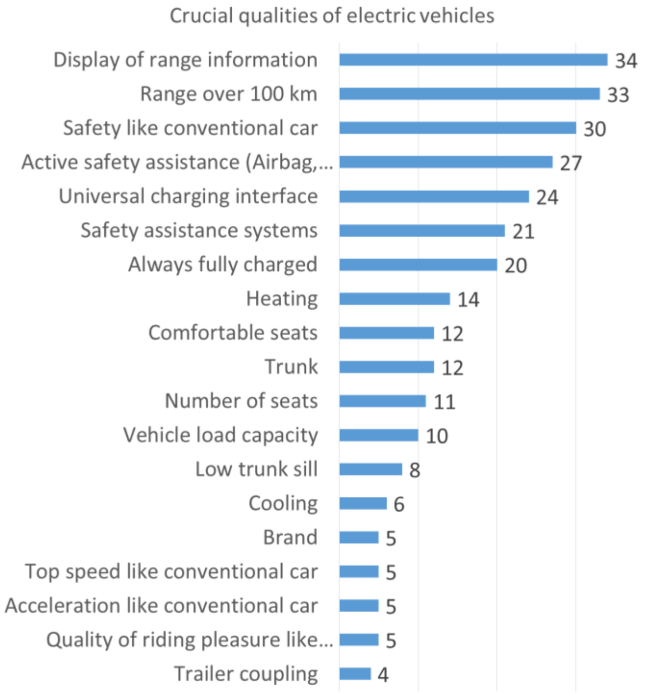

Fig. 2: Survey results concerning crucial features of an EV (n=34)

V. NON-URBAN MOBILITY ANALYSIS

The raw data from the mobility tracking is comprised of the GPS locations tagged with the corresponding timestamps. With this information a general analysis concerning the range behavior is conducted. Thereby, it is not distinguished between the mode of travel, but rather between the whole mobility demand. Two aspects are taken into consideration to give an assessment of the technical practicality of electromobility under non-urban constraints:

1. The circular range analysis of the mobility demand, describing the (percentile) mobility range spread over the cardinal direction.
2. The cumulated distance behavior, which considers trip lengths under the aspect of interim charging possibilities.

A. Circular Range Analysis

The first aspect in the analysis is concerned with the circular range of the distance radiant from the hometown city center. The radiant displays the actual mobility area, which has to be theoretically realized by a vehicle in the specified non-urban environment. For that purpose, all locations tracked during the field study are taken for a radiant analysis and are further spread over the cardinal directions. After matching all points to their corresponding directions and smoothing aberrations, the circular ranges for 75-, 95- as well as 99-percentiles of the mobility dissemination are calculated. Radiating from the home base Garmisch-Partenkirchen the detailed direction-dependent median, mean and maximum distance are depicted in Table I. In the context of analyzing the circular range, it has to be emphasized that the actual mobility trips never spread straight in cardinal directions. Thus, the circular range does not represent the actual driven mobility distance, but rather the main area, in which everyday mobility happens. A more detailed analysis based on reachability models as well as the driving patterns has to be appended, if the main mobility area proves feasible for electromobility.

TABLE I. RADIUS PERCENTILES OF THE SIMPLE CIRCULAR RANGE ANALYSIS

	75-percentile	**95-percentile**	**99-percentile**
median [km]	14	63	113
mean [km]	34	90	158
max [km]	375	709	777

Evaluating those percentile ranges in the context of realizing all of non-urban mobility by electromobility, the maximum ranges over 300 km are in contrast to this aim. Nevertheless, the median and even mean value of below 160 km represent a feasible range limit for nowadays EVs. Even the 99-percentile mean and median mobility demand lies in realistic range scales in the short-term future.

Analyzed with an empirical cumulative distribution function (ECDF), the range results demonstrating the cumulated percentage of the mobility distribution are shown in Fig. 3. The result indicates the high feasibility of electromobility, because of the very likely demand below 160 km.

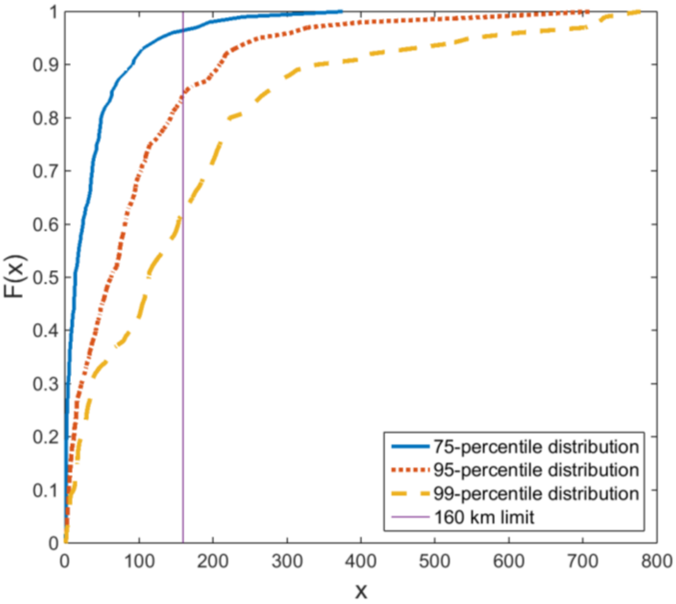

Fig. 3: ECDF of range (=x, km) distribution of total mobility behavior during the field study.

Focusing on the aspect of everyday domestic electromobility, a more critical approach for the circular range analysis is necessary. Tracked points of trips outside of a crucial area around the examined hometown are considered unimportant for the electromobility assessment. Since the EVs used in the field study have a purely electric range of 50 km, the crucial radius is set to this value. The dataset is filtered in a way that only trips, whose start or end point lies within the crucial area, are analyzed. This elimination process leads to a more realistic everyday mobility range.

Taking this filtered data into analysis and calculating the corresponding percentiles of mobility the results display a realistic 99-percentile at a mean radius of about 28 km and a maximum radius of less than 80 km around the hometown [Table II].

TABLE II. RADIUS PERCENTILES OF THE FILTERED CIRCULAR RANGE ANALYSIS

	75-percentile	**95-percentile**	**99-percentile**
median [km]	56	16	29
mean [km]	10	19	28
max [km]	42	55	77

The results reveal that the actual day-to-day mobility is a highly qualified area of application for electromobility, since even the maximum distance of the 99-percentile range demand lies well within the boundaries of state of the art EVs battery ranges. Graphically depicting the analysis concerning the crucial radius of 50 km only one significant transgression can be detected [Fig. 4].

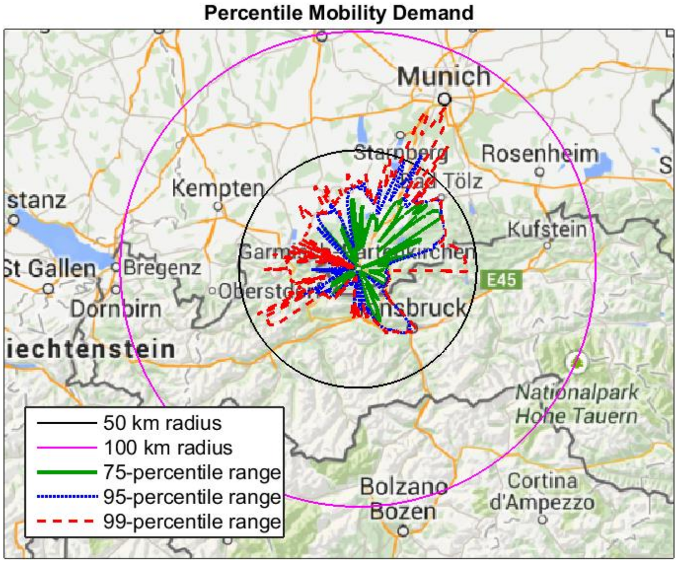

Fig. 4: Circular mobility range with filtered tracking data. Only slight transgressions of crucial 50 km radius in direction of large cities can be determined (in this case Munich).

In this instance the transgression is in the direction of traffic connections, e.g. highways, to larger cities, here Munich. These mobility demands can theoretically reach the limits of electric range. Considering the highly developed electromobile infrastructure in urban areas, there existing charging stations can guarantee a recharging of the battery before driving home again.

The ECDF of the filtered mobility demand depicted in Fig. 5 shows that the significant mobility takes place inside the crucial range of 50 km.

Inquiring into everyday mobility, it becomes obvious, that not all mobility demand is equivalent in its significance. Some trips are random and spontaneous and some trips have a high repetition rate, thus signaling a more pronounced importance for mobility demand analysis. For this reason, the third and last step for assessing the circular range demand considers not only the tracked points but their weight indicated by replicates. For this purpose the user-individual mobility is divided into timeslots of 3 hours each. All trips in those respective timeslots are matched geographically. If trips have a high consistency rate they can be clustered and marked as more important and thus the weight is determined. Applying the Matlab function WPRCTILE [13] the percentile weighted by their importance in everyday mobility can be calculated.

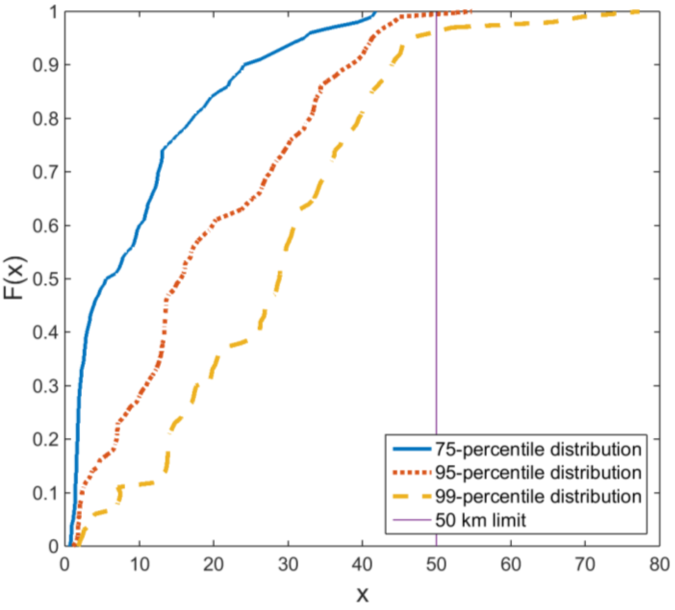

Fig. 5: ECDF of range (=x, km) distribution of filtered mobility behavior

With this data processing the assessed range radius percentiles for individually weighted mobility are established [Table III].

TABLE III. RADIUS PERCENTILES OF THE WEIGHTED CIRCULAR RANGE ANALYSIS

	75-percentile	**95-percentile**	**99-percentile**
median [km]	4	13	20
mean [km]	9	17	25
max [km]	52	64	130

All median and mean values decrease in comparison to the corresponding percentiles of filtered circular range analysis. In case of the 99-percentile the median range demand drops by 30.7% to 20 km, the mean range by 9.8% to 25 km. In contrast, the maximum range increases by 68.5% to a value of 130 km.

The resulting actual circular range is depicted in Fig. 6. Comparing that mobility spread to the filtered expanse it can be seen that the large portion of mobility shrinks towards the hometown center itself. Simultaneously the absolute number of transgressions across the crucial range limit of 50 km increases. In this case even the 100 km limit is breached once.

Conducting the corresponding ECDF analysis and comparing those results directly with the filtered mobility effects [Fig. 7], it is specifically clarified that intensifying the effect of repetitive mobility by their respective weight, the cumulated mobility demand tends to shorter trips.

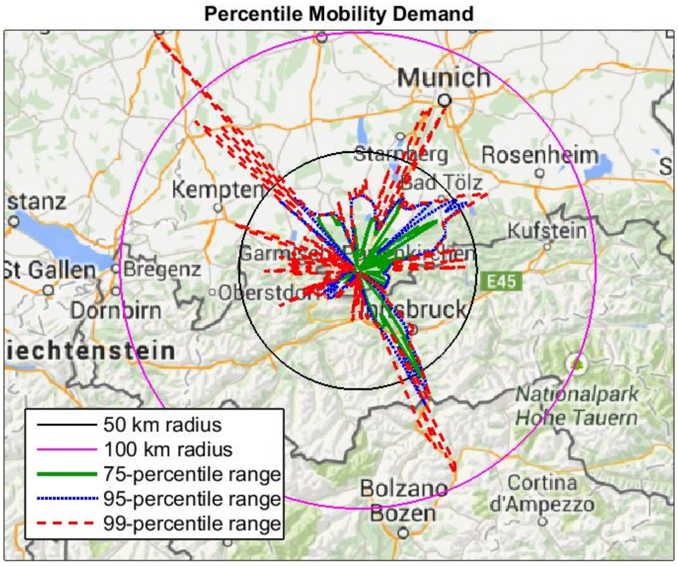

Fig. 6: Circular mobility range with weighted tracking data. Frequently occurring trips with larger distance demand lead to transgressions over a radius of 100 km.

The maximum ranges in the weighted analysis exhibit larger absolute values than in the filtered analysis. This can be ascribed to the description by percentiles. Since even the 99-percentile analysis omits certain extreme values, the shift induced by the weighing effects leads to a likewise shift in percentile limits. This behavior is expressed in the breakeven point of the filtered and weighted analysis depicted in Fig. 7.

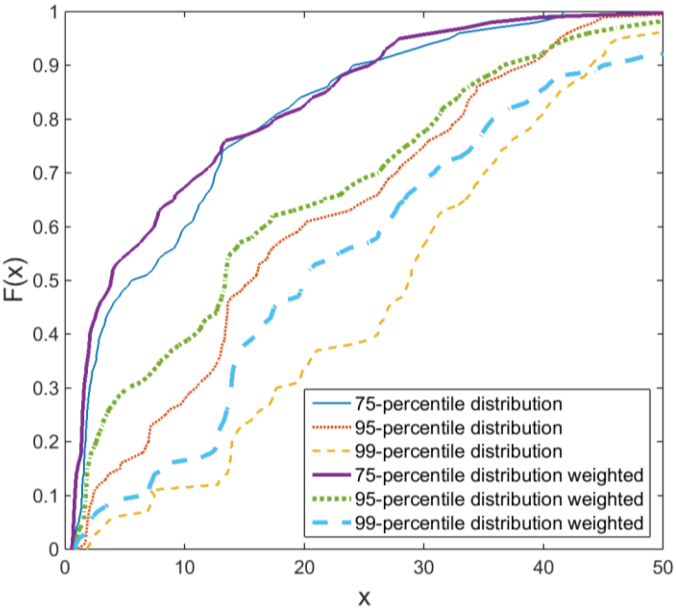

Fig. 7: ECDF of range (=x, km) distribution of weighted mobility behavior compared to ECDF of filtered mobility behavior in the crucial range interval 0 to 50 km

This highlights the large impact of short trips in weighted mobility model. It also represents a more realistic range demand than the filtered analysis, since with this approach also the longer trips are taken into account and represented by the results.

The circular range analysis does not take the actual topographical opportunities and conditions for mobility into account. Since the field study region of Garmisch-Partenkirchen is located north of the Tyrolean Alps, a natural mobility border is given. This can be concluded by the lesser markedness of the circular range to the south, separate from the urban area of Innsbruck, and the highway route to the south.

B. Cumulated Distance Behavior

The second aspect in the analysis addresses the distance behavior of the specified trips. Not only the driven distance of one stand-alone trip has to be evaluated but also a more complex driving-charging-model is needed. This model has to take into account the potentially required time for recharging an EV, in order to accomplish several trips in a limited time.

All trips with either start or end point within the crucial radius of 50 km around the home town Garmisch-Partenkirchen are analyzed. Since the mobility of a total household is considered in this context, there is no distinction between actual separate users, as all members of the same household are taken together and treated the same in the following clustering process. In order to understand the influence of charging times, the trips are clustered in families as well as day-wise. Trips without a defined time space of one hour in between are regarded as cumulated trips, adding up the distance demands.

The resulting findings are presented in Fig. 8, differentiated by either weekdays or weekends and sectioned by the hour of the day the cumulated trip is initiated. The logarithmic representation of the distance demand in kilometers is chosen due to the circumstance that the absolute demands range from a few meters up to over one hundred kilometers. Without the logarithmic transformation, the most interesting interval up to 50 km cannot be interpreted sufficiently.

Specifying the cumulated distances in detail by means of an ECDF analysis [Fig. 9], a slight difference to the range analysis is visible. Due to the summation of trip distances, the cumulated distribution is shifted slightly towards higher absolute distances.

Despite the maximum total cumulated distance demand adds up to 200 km, which lies just outside of most currently technically feasible EV range, the 90% mobility demand coverage is reached at the 50 km range. Considering the distribution shown in Fig. 8, a clear tendency to shorter ranges can be detected, since all outliers are caused by large distance values.

The cumulated distances in the context of everyday mobility around the home town mainly ranges lower than 50 km, which is still manageable by EVs. It is also observable that the distance demand is at a constant level during the waking hours of the day, and even slightly more constant on the weekends.

Overall, it can be said that there is a stable cumulated distance demand of 2 to 30 km throughout the day. Taking into account an average number of trips of 10 per day and household based on the field study data, as well as an exponentially decreasing mean distance demand with an increasing number of trips per day and household [Fig. 10], the time potential for recharging the EV can be further determined.

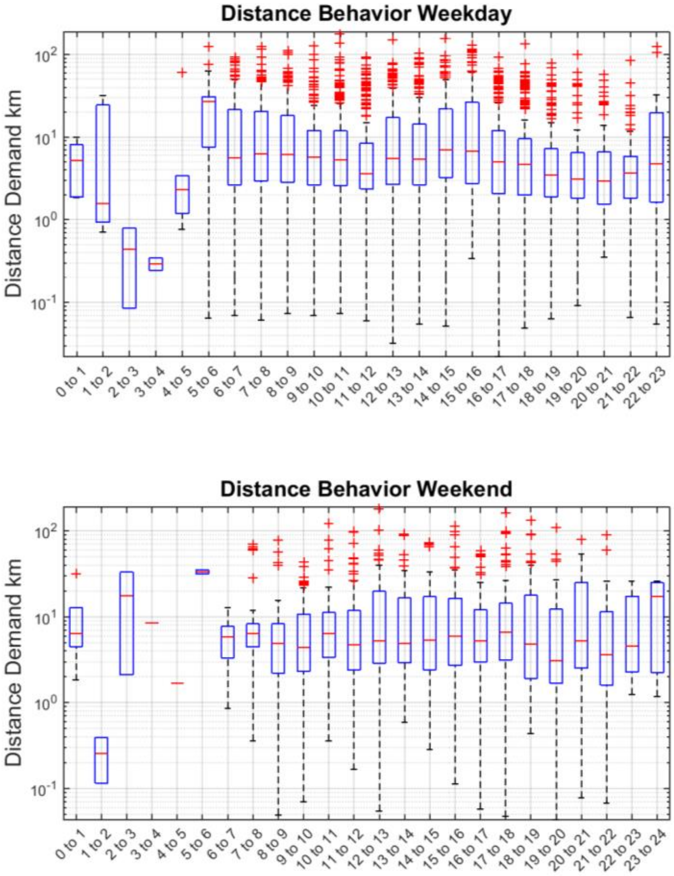

Fig. 8: Cumulated mobility demand of filtered tracking data during weekdays (top) and weekends (bottom) during the field study. Even cumulated distance mainly ranges between distances of 5 to 100 km.

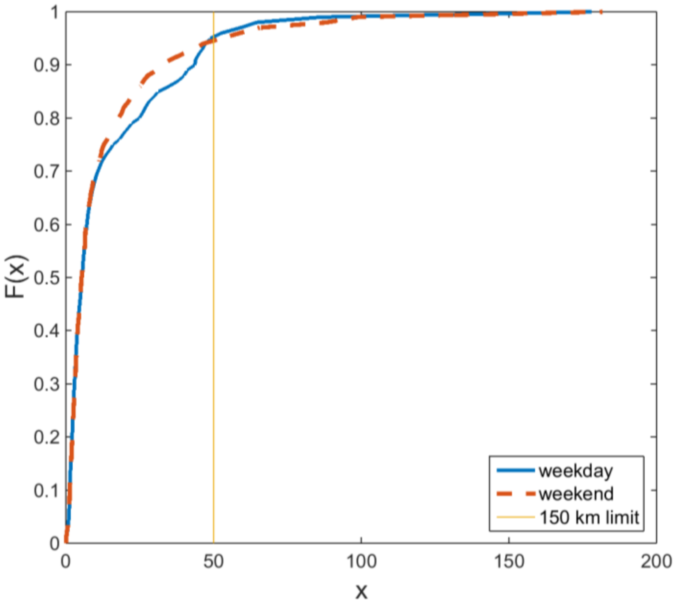

Fig. 9: ECDF of cumulated distance (=x, km) distribution

With a 30 percent rate of starting or ending a trip in a range of below 130 m around the respective household location, signifying a returning home rate with every third trip, the recharging potential in between trips or alternatively overnight, where there is fewer mobility demand, is given.

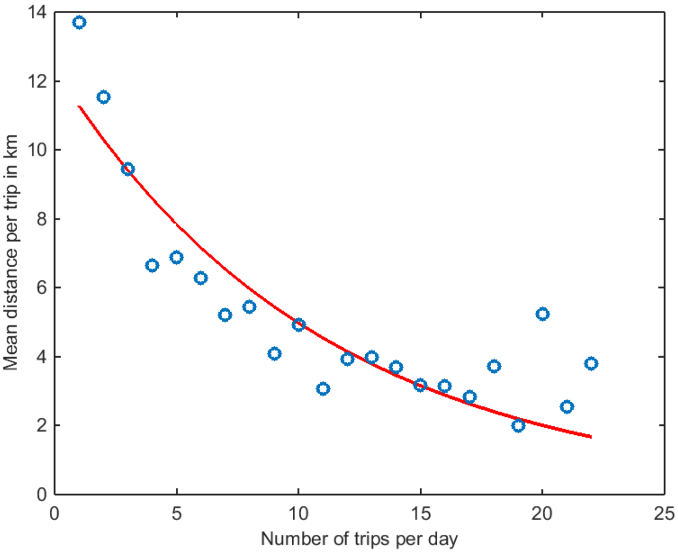

Fig. 10: Exponentially decreasing correlation between number of trips per day and household and the mean cumulated distance demand of each trip based on the data gathered during the field study

VI. Assessment and Conclusion

The analysis of the range behavior of the daily mobility demand is concluded by an assessment for the application of electromobility in non-urban areas. Since the practical implementation of electromobility in such a fundamental everyday aspect as mobility, the consumer acceptance is highly important besides the mere technical feasibility. For this reason the attitude towards and therewith the acceptance of electromobility was questioned at the end of our field study. We focused on two aspects:

- the overall skepticism towards electromobility, and how it changed during the field study
- the realistic rating of electromobility for fulfilling their own demands in an overall consideration (range, charging, handling, comfort, etc.)

The results of those survey questions are graphically depicted in Fig. 11. As can be seen, the overall skepticism regarding electromobility did not change during the field study. In combination with the underlying high technology affinity throughout the participants and a high rate of enthusiasm towards EVs of 80% an overall positive attitude concerning electromobility is stated. Analyzing the results of the realistic rating of electromobility, about 80% of the participants assessed electromobility as viable for their everyday life, under the assumption that their positive skepticism was not impaired by the practical test.

Additionally to the participants' general attitude towards electromobility, their expectations of and experience with the EV was queried before and after the field study. The focus lay especially on the practical and successful integration of electromobility in their everyday life. As can be seen in the results listed in Table IV, the experience slightly improved from 0.44 before the practical test to a more positive assessment of 0.56 after driving and using the EV.

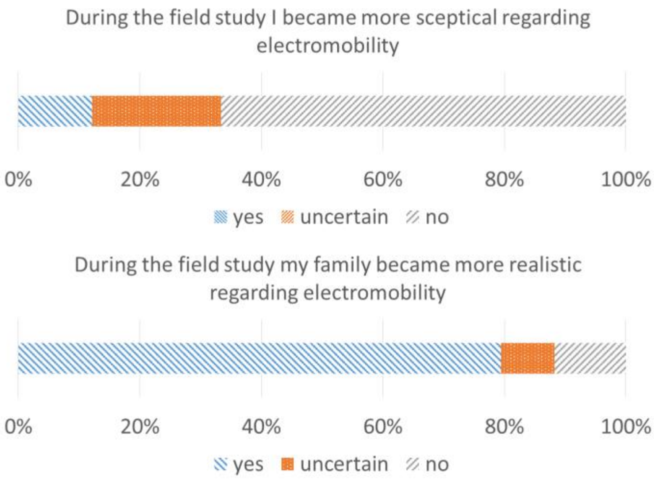

Fig. 11: Survey results concerning skeptical attitude towards electromobility (top, n=33) over the field study period and realistic assessment of electromobility (bottom, n=34)

TABLE IV: SURVEY RESULTS CONCERNING THE PARTICIPANTS EVALUATION OF THE SUCCESS OF ELECTROMOBILITY IN PRACTICE, BEFORE AND AFTER THE FIELD STUDY

	n	**mean (1 = yes; 0 = no)**
Will the EV prove itself successful in in everyday practice?	18	0.44
Did the EV prove itself successful in in everyday practice?	18	0.56

As the soft, user-oriented facts of integrating electromobility are ascertained, the theoretic technical assessment is justified.

The results of the circular range analysis indicate that the main share of everyday non-urban mobility happens in relatively close proximity of around 50 km to the hometown. Weighing factors describing the mobility demand further reinforce the effect of short trips in everyday life, but also emphasize the further necessity of long trips in order to depict all of the non-urban mobility demand. These long trips are out of the technical range of the EVs. In order to still integrate electromobility in non-urban mobility, the users would be compelled to fall back to intermodal mobility or make higher planning efforts for longer trips. Those options tend to be not acceptable by users, what can be assumed based on the high importance of guaranteed range, as seen in Fig. 2.

With detailing the rate of mobilization in non-urban environments, another feasible option is provided. Analyzing the survey data from “Mobility in Germany 2008”, where approximately 25 000 German households where questioned about all aspects of their mobility behavior, an upwards tendency concerning number of vehicles in non-urban regions can be derived [14]. Herein lies a high potential for the realization of electromobility, since short everyday trips are predestined for being executed by second cars, since the primary car is often used for trips to work or longer distances. Those short trips around the hometown and between the household and nearby destinations can be completely covered by EVs. The constant mobility demand over the day [Fig. 8] indicates that those frequently repeating trips can be easily realized by a second, electric car, since the users can plan their daily schedule straightforward and with less planning and charging effort.

The result of assessing electromobility in non-urban areas emphasizes a feasible applicability in private usage. Nonetheless, seldom trips appear outside the range of current EVs, the evaluation shows that there are feasible fallback levels for those events. In our estimation, this can be resolved by introducing electromobility via second cars to non-urban environments, since the environmental conditions consent to this development.

This use case of electromobility leads to a detailed understanding about the dimensioning of vehicles for a usage in non-urban environments. All day-to-day trips, signifying the mobility demand implemented through the electric second car, range in dimensions up to 50 km and are conducted mostly under city traffic conditions. As a result the comparison and evaluation by reference to the New European Driving Cycle (NEDC) is valid with a distance of approximately 11 km. Since most second cars are from smaller car classifications, those reference cars are taken as a reference for comparing the energy demands. Thus, the mean energy demands of 11 to 15 kWh per 100 km of current available EVs are at the basis of the evaluation for the optimal second car EV dimensions. Those numbers are considered, together with the results of the cumulated distance analysis depicting distances mostly below 10 km. Thus, a battery capacity of 5.5 to 7.5 kWh can be estimated as satisfying under NEDC conditions and for the usage as second car. Including more range safety and reducing the dependence on in-between-charging, a battery capacity of 10 kWh is assessed for minimal requirement in order to fulfill the second car mobility demand. Aiming to realize all of the mobility demand through EVs also the longer trips need to lie within the capable battery range. This dimensioning is based on the maximum 130 km range and results in a required battery capacity of 14 to 20 kWh under NEDC conditions. Those capacity ranges cover the 99-percentile of the filtered mobility dataset. The NEDC conditions feature approximately up to 25% uncertainty compared to real driving conditions [15]. Therefore the battery capacity has to be adapted and scaled according to those requirements as well as another 20% surcharge for auxiliary consumers, as heating and cooling.

Concluding the results, a high possible effectiveness of electromobility under private usage as well as non-urban conditions is attested. The high distribution rate of private carports in non-urban environments, where the EVs can be charged, promise a successful implementation of electromobility. This is promoted by the mobility demand in non-urban environments that accommodates the range limitations of EVs.

ACKNOWLEDGMENT

This work was conducted within the eGAP Modellkommune Elektromobilität Garmisch-Partenkirchen project, funded by the Bavarian State Ministry of Economics and Media, Energy and Technology.

REFERENCES

[1] Transport for London, "Congestion Charge," [Online]. Available: https://www.tfl.gov.uk/modes/driving/congestion-charge. [Accessed 16 February 2015].

[2] Transport for London, "Electric Vehicles," [Online]. Available: https://www.tfl.gov.uk/modes/driving/electric-vehicles. [Accessed 16 February 2015].

[3] E. Verheijen and J. Jabben, "Effect of electric cars on traffic noise and safety," *Bilthoven: RIVM,* 2010.

[4] H. Helms, M. Pehnt, U. Lambrecht and A. Liebich, "Electric vehicle and plug-in hybrid energy efficiency and life cycle emissions," in *18th International Symposium Transport and Air Pollution*, 2010.

[5] G. Wilkerson, R. Khalili and S. Schmid, "Urban Mobility Scaling: Lessons from `Little Data'," *IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS),* 2014.

[6] H. Hanabusa and R. Horiguchi, "A Study of the Analytical Method for the Location Planning of Charging Stations for Electric Vehicles," *Lecture Notes in Computer Science,* pp. 596-605, 2011.

[7] Y.-J. Byon, A. Shalaby and B. Abdulhai, "Travel time collection and traffic monitoring via GPS technologies.," *Intelligent Transportation Systems Conference,* 2006.

[8] D. Ashbrook and T. Starner, "Using GPS to learn significant locations and predict movement across multiple users," *Personal and Ubiquitous Computing 7.5,* pp. 275-286, 2003.

[9] M. Kugler, S. Osswald, C. Frank and M. Lienkamp, "Mobility Tracking System for CO2 Footprint Determination," *Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '14,* 2014.

[10] E. Mok, G. Retscher and C. Wen, "Initial test on the use of GPS and sensor data of modern smartphones for vehicle tracking in dense high rise environments," *Ubiquitous Positioning, Indoor Navigation, and Location Based Service,* pp. 1-7, 2012.

[11] J. Magtoto and A. Roque, "Real-time traffic data collection and dissemination from an Android Smartphone using proportional computation and freesim as a practical transportation system in Metro Manila," *TENCON 2012 - 2012 IEEE Region 10 Conference,* pp. 1-5, 2012.

[12] ChargeMap, "Statistiken über Ladestationen," [Online]. Available: http://de.chargemap.com/stats. [Accessed 17 February 2015].

[13] D. L. Shrestha, "Returns weighted percentiles of a sample," MATLAB Central File Exchange, 16 October 2007. [Online]. Available: http://www.mathworks.com/matlabcentral/fileexchange/16920. [Accessed 20 January 2015].

[14] Institut für angewandte Sozialwissenschaft (infas) and Institut für Verkehrsforschung (DLR), "Mobilität in Deutschland 2008," Bundesministeriums für Verkehr, Bau und Stadtentwicklung (BMVBS), 2008.

[15] P. Mock, J. German, A. Bandivadekar and i. Riemersma, "Discrepancies between type-approval and "real-world" fuel-consumption and CO2 values," The International Council on Clean Transportation, 2012.