Impact of home- and destination charging on the geographical and temporal distribution of electric vehicle charging load
*

Aurora Flataker[a*], Olav Kåre Malmin[c], Odd A. Hjelkrem[b], Rubi Rana[b], Magnus Korpås[a], Bendik N. Torsæter[b]
[a] *Dept. of Electric Power Engineering, Norwegian University of Science and Technology - Trondheim, Norway*
[b] *Dept. of Energy Systems, SINTEF Energy Research - Trondheim, Norway*
[c] *Dept. of Mobility, SINTEF Community - Trondheim, Norway*
*Corresponding author - Email: aurora.flataker@ntnu.no

Abstract

In this paper, we analyse how a shift from home charging to destination charging impacts the charging demand, based on data from a regional transport model and results from an EV survey. The impact and flexibility potential from EV charging depends on where chargers are located and how they are used. Since home charging and destination charging have different characteristics, it is necessary to analyse how the combination of home- and destination charging impact the total charging demand. To address this, we perform a case study for Western Norway, which is divided geographically into 2570 zones. The charging demand is distributed to the zones in two charging scenarios. The results show that more destination charging will reduce the load in many residential areas, while the demand increases in zones that contain large workplaces, malls, universities and hospitals. Moreover, it is found that 40% of the EV charging demand is from work-related travels. Thus, there is a potential for more workplace charging than what is the current situation according to the EV survey results.

1 Introduction

The transport sector contributes to 24% of the global direct CO_2 emissions, of which the road transport is responsible for almost 75% [1]. To reduce emissions, many countries have stated political ambitions and introduced various incentives for phasing out sales of internal combustion engine vehicles (ICEVs) and increasing the share of zero-emission alternatives [2]. In Norway, the share of battery-electric vehicles (BEVs) in new passenger car sales reached 64.5% in 2021. At the end of 2021, BEVs made up nearly 17% of the vehicle fleet [3].

The needs for charging- and grid infrastructure depend on the composition of residential, commercial and industrial activity. Experience and surveys [4] from Norway, which is a front-runner in EV adoption, show that home charging is the most used charging type. Destination charging, for instance at workplaces, supermarkets, restaurants, and other destinations are, at least so far, less widespread. However, as the EV share increases, there may be higher shares of EV owners without access to home charging. Moreover, different types of charging gives different grid impacts and availability of flexibility services from EVs. Therefore, it is important to understand how combinations of home- and destination charging affect *where* and *when* vehicles are connected to, and use, charging infrastructure.

A number of studies have been carried out to evaluate the impacts of home charging on the power system [5–8]. In these studies, the authors simulated the EV driving patterns based on data from national driving patterns, demographics, and probability density functions. The authors in [9] presented an approach used for forecasting the spatially and temporally resolved ramp-up of BEV ownership within a region of interest. In this study, the spatial distribution of EVs is forcasted based on socio-economic factors and modelling of the future EV market penetration. A study from 2020 [10] presented a framework for calculating

*The authors would like to thank the Research Council of Norway and industry partners for the support in writing this paper under project 295133/E20 **FuChar - Grid and charging infrastructure of the future**

energy consumption of BEVs based on models from traffic flow theory, vehicle dynamics such as vehicle speed, acceleration as well as available Information and Communications Technology (ICT) devices.

The authors of [11], who reviewed modelling techniques for EV ownership, use and charging applied to transport and power system analysis, pointed out that there is a need for more detailed representation of EV use and charging behaviour in time and space. They also emphasized the need of validation of assumptions and choice of parameters in the models, as they often are theoretically based and lack comparison to real-world adoption. To address this, we use results from a large EV survey that provides information about EV owners' charging habits in an advanced EV market. Moreover, the transport model that our charging model builds on, has a detailed representation of the transport system as well as the travel demand for different travel purposes.

To analyse the impacts of charging type on the geographical and temporal distribution of EV charging, we perform a case study for a region in Norway. The travel demand and energy consumption from trips performed with BEVs are modelled using an existing transport model called the Regional Transport Model (RTM) [12]. We use the output from RTM to generate two charging scenarios with different distributions of home- and destination charging. Further, we discuss the assumptions and the results of the case study in context of information about current charging habits and preferences from an EV survey [4] performed by the Norwegian EV association.

The main contributions are:

- A structured presentation of results from a survey on EV ownership and charging habits from Norway, which is a leading country for EV adoption.
- A methodology for analysing the zonal distribution of charging demand based on information about transport and energy demand for EVs.
- Insight on today's charging habits and how changes in charging habits and availability of charging infrastructure may impact how the charging demand from electric vehicles are distributed. The methodology and case study results can be used as basis for further analysis on charging infrastructure and grid capacity needs, as well as analysis of how different combinations of charging can contribute to minimizing the grid impact and maximizing the flexibility potential from EV charging.

The paper is organized as follows: In 2, the transport model, RTM, is presented. Further, the EV survey and relevant results from the survey are included in section 3. The method for generating charging scenarios, as well as information about the case study, are explained in 4. The results from the case study are presented and discussed in 5. Finally, section 6 concludes the paper and proposes future research directions.

2 Travel demand: regional transport model for short travels

The average daily travel demand for passenger transport is modelled using the Norwegian Regional passenger Transport Model (RTM) described in [12], which is implemented in the Bentley CUBE software [13]. RTM is a four step model with a hierarchic logit choice demand model developed by TØI, Møreforsking, Numerika and SINTEF [14]. It is widely used for transport analyses and assessment of new infrastructure projects in Norway. The demand model is estimated on the national household travel survey (NHTS) [15] using data from Statistics Norway, including demographics, households, and location of schools and work places.

RTM uses a road network description including horizontal and vertical curvature. The road curvature is used to calculate fuel and electric energy use on each road link and on the total trip between all origins and destinations for trips in the model.

The travel demand for personal travels is modelled per travel purpose and travel mode. The travel purposes included in the model are work related, shopping, recreational trips as well as freight transport. The travel modes are car driver, car passenger, public transport, walking and cycling. Car driver trips are split into trips using BEVs or ICEVs based on prognoses for car ownership share between BEVs and ICEVs, and difference in toll road costs between origins and destinations. The EV trips are modelled for only Battery Electric Vehicles (BEVs), not including Plug-in Hybrid Electric Vehicles (PHEVs).

3 Charging habits: Results from an EV survey

In this section, we present results from a survey performed by the Norwegian EV association. These results are used for establishing the charging scenarios in our case study. Moreover, they are used as input to the discussion on how changes in charging habits can impact the distribution of load from BEV charging.

The survey is performed annually to gather information about EV owners' preferences, choices and charging habits. In our analysis we use data from the EV survey from 2021. A general explanation about the survey can be found in ref. [4]. The survey include questions regarding EV ownership and satisfaction, travel habits and charging habits. The 2021 survey was responded by 15 467 EV owners.

3.0.1 Dwelling type and access to parking

Since it impacts the availability of home charging, we present the distribution of dwelling type and access to own parking from the survey. The respondents were asked about their dwelling type and whether they have their own parking place. Of the respondents who answered the particular question, 97% reported to have access to their own parking place. There are no specific questions in the survey about access to a charger at the parking place. However, another question is on how people charge at home, where 77% report to have a home charger available/installed while 18% are charging from a ordinary socket (Table 1).

Table 1: Data from EV survey: Charger type

How do you charge your EV at home?	**Share of responses [%]**
Ordinary socket	18
Industrial socket	3
Home charger	77
Other	2

The survey also contained a question about type of dwelling. In Table 2, the distribution of dwelling types of the EV respondents is presented together with corresponding data for the general Norwegian housing stock. The largest difference is on the share of single family houses, where 58% of the respondents report to live, in contrast to only 49% of the general housing stock.

Table 2: Dwelling types: the Norwegian housing stock vs. the EV survey respondents

Dwelling type	**Norwegian housing stock [%] [16]**	**Respondents of the EV survey [%]**
Single family house	49	58
Double family house	9	8
Row house	12	8
Apartment	25	24
Other	5	2

3.0.2 Choice of type of charging

In the survey, the respondents were asked how often they use different types of charging. Table 3 summarize the survey results for these questions. The majority (90%) of the respondents report that they charge at home one or several times per week. Most respondents only use public charging stations (up to 22 kW) and fast charging stations monthly or less frequently. When it comes to charging at the workplace, 68% report that they never do, while 16% charge at work once a week or more.

In table 4, survey results regarding use of fast charging is presented. It shows that the majority of those responding to this question use fast charging for longer trips outside their county or for trips within the county outside their own municipality.

3.0.3 Charging times for home charging

The respondents have also been asked to estimate in which time windows their EVs were normally being charged on an average working day. In the formulation of the question it is stated that they should try to answer in which time window the vehicle was actively being charged, not the time window where the vehicle

Table 3: Data from EV survey: Charging habits

	How often do you charge..			
	..at public charging stations? (3.7 - 22 kW)	***..at home?***	***..at your workplace?***	***..at fast-charging stations?***
	[%]	[%]	[%]	[%]
Daily	1	29	5	0
Every 2nd-3rd day	2	32	5	1
Weekly	7	29	6	6
Monthly	13	3	4	28
Less frequently	47	1	12	51
Never	30	5	68	13

Table 4: Data from EV survey: Use of Fast charging

Where do you mostly use fast charging?	**Share of responses** [%]
In my own municipality	13
Outside my municipality, within my county	34
On longer trips outside my own county	53

is connected to the charger. The respondents could choose from five different time windows, shown with different colors in Fig. 1. The figure shows the share of the respondents reporting that they normally charge in the respective time windows. As the question was a multiple choice question, each respondent could choose several alternatives. It can be seen that the majority of home charging is reported to occur in the evening from 8 to 12 pm and during the night from midnight to 7 am. Only 7% report charging at daytime between 9 am and 4 pm. 58% of the respondents are controlling the EV charging either through the car, the home charger or other app/provider, see Table 5.

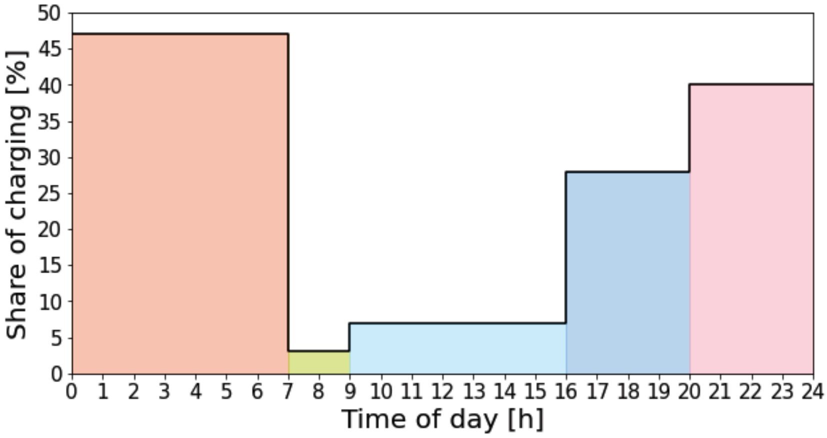

Figure 1: EV survey results: Charging times for home charging.

.

Table 5: Data from EV survey: Controlling EV charging

Do you control the charging of your EV?	Share of responses [%]
No	40
Yes, through the car/the car's app	35
Yes, through the home charger/app for the home charger	16
Yes, through other app/provider	7
Don't know	1

4 Case study: assessing the impact of home- vs. destination charging

To assess the impact of home- vs. destination charging, we perform a case study for a region in Norway. The geographical distribution of charging demand is modelled for different shares of home- and destination charging in two charging scenarios.

The case chosen for the study is a region in the western part of Norway, consisting of the two counties Vestland and Rogaland, hereafter referred to as Western Norway. The region is illustrated in Fig. 2. It is divided into 2570 zones, where the zone with highest population has 6354 inhabitants. In the case, the BEV share is 11%.

Figure 2: The figure shows the transport links (black) and the zones (green) that are included in the RTM model for the region of study

From the EV survey results presented in section 3, it can be seen that the majority of respondents are using home charging at a weekly basis, whereas charging at workplace or at public- or fast charging stations is used at a less regular basis. The survey results also show that EV owners typically use fast charging for longer trips. Since the RTM model is used for modelling of short trips at a typical working day, we assume that fast charging is not relevant for our case study. Therefore we focus on home charging and destination charging, where potential destinations include every destination that the RTM is modelling the BEV users to reach. This includes workplaces, stores, restaurants, hospitals, and other ending points of modelled trips. The two charging scenarios are as follows:

- **Scenario 1 - Home charging:** The energy demand from BEV trips for the region is distributed to the zones according to the population in each zone. Hence, it is assumed that all of the energy demand for BEVs in Western Norway is covered by home charging.
- **Scenario 2 - Combination of home- and destination charging:** The charging demand is distributed to each zone depending on the traffic going into the zone. All energy used by BEVs traveling in to zone n, will be recharged in zone n. The RTM model is symmetric, i.e. assuming people always end up at the same place as they started. Therefore, in scenario 2, BEV owners charge at least twice a day: when they reach the destination of their travel, and when they come back to the starting position.

5 Results and discussion

5.1 Energy demand from BEV charging per travel purpose

The total energy demand for BEV travels for an average workday, as modelled by the RTM for Western Norway, is presented in Table 6.

Table 6: RTM results: Total EV energy consumption per travel purpose in the region

Travel purpose	**Electricity demand [MWh/workday]**	**Share of electricity demand [%]**
Work-related	158	40
Non-work-related	240	60

It can be seen that the energy demand for short BEV trips is split 40- to 60% between work-related and non-work-related travels. However, according to the EV survey, most EV owners mainly charge at home and only a minority charge at the workplace regularly. Hence, the RTM results indicates that there is a possibility for more workplace charging if such charging become more available and can compete with home charging in convenience and cost for the BEV owners. Some of the energy demand could also be covered by other destination charging, e.g. at schools, supermarkets and restaurants.

5.2 Geographical distribution of charging in the two charging scenarios

Fig. 3 shows the change in charging demand from scenario 1 to 2. In the figure, zones with red color represent an increase in charging demand, and zones with blue represent a decreased charging demand. In 739 of the zones, the charging demand increases from scenario 1 to 2, while in 1831 zones, the charging demand decreases. The variation between zones when it comes to the change in charging demand between the scenarios is illustrated in the boxplot in Fig. 4. It can be seen that there are more outliers in the boxplot on the positive than the negative side. Hence, the maximum increase in demand is larger than the maximum decrease. When studying the zones in more detail, we find that the zones that have a large increase in demand from scenario 1 to 2, are zones with very small population, but where large workplaces or other destinations generates visits to the zone. The zones with a decrease from scenario 1 to 2, on the other hand, are zones where the population caused a higher charging demand in scenario 1 when all charging demand was assumes to be charged at home, than in scenario 2, when trips into the zone is driving the charging demand.

In Fig. 5 and the map at the right side of Fig. 3, we zoom in to the area of the city of Bergen, Norway´s second largest city. These figures shows the change in charging demand from charging scenario 1 to 2. The zones showing a large increase in demand, are zones where big workplaces, shopping malls, the business school and the city's hospital, are located. Many other zones have a decrease in charging demand. However, the reductions in charging demand in those zones are less extreme than the growth in some of the zones with a demand increase. These are therefore less visible in the map. However, from a the perspective of grid planning in residential areas it can be relevant to assess different scenarios of home charging. For such purposes, an interactive map, as the one illustrated in 5, can be helpful.

Fig. 6 illustrates how the charging maps also can be used to gain insight on how transport demand for different travel purposes can be distributed. In the figure, one heatmap shows the charging demand for work-related travels and the other heatmap show non-work-related travels. Both maps shows the charging demand for scenario 2, where a combination of home- and destination charging is assumed.

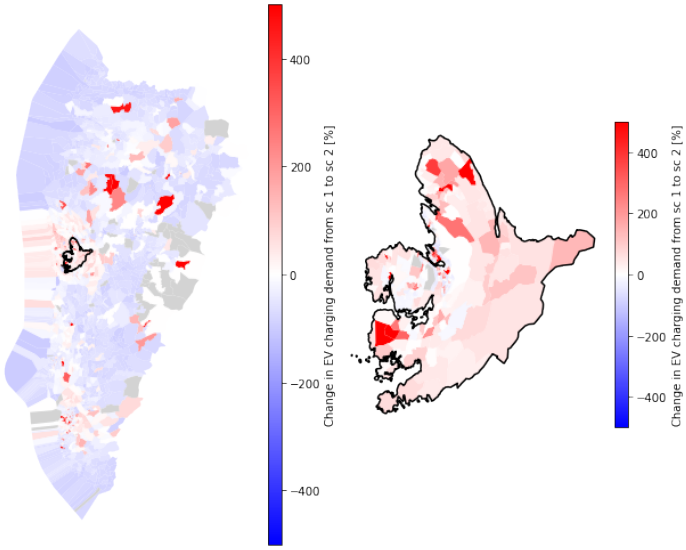

Figure 3: Change in charging demand from scenario 1 to 2 (in percent), for Western Norway (left) and Bergen municipality (right).

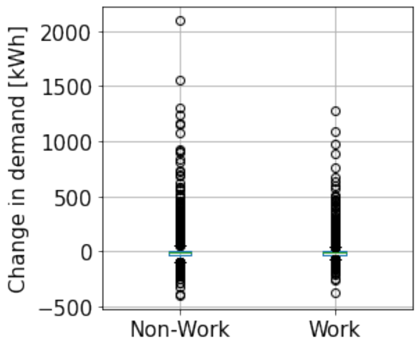

Figure 4: Boxplot showing the variation between zones in how the charging demand changes from scenario 1 to scenario 2, for non-work-related and work-related trips respectively.

5.3 Temporal distribution of charging in the two charging scenarios

The time of day where the BEVs are connected to the charger, vary depending on whether BEVs are charged at home, at the workplace, or at other destinations. Hence, the times of day where BEVs charge or are available for providing flexibility to the system through smart charging or vehicle-to-grid- schemes will depend on which types of charging that are available and chosen by the BEV owners. From the EV survey, it can be seen that the majority of respondents report that their EVs charge in the evening or during the night when home charging is used (ref. Fig. 1). For workplace charging, there is no similar question in the survey. However, for workplaces with typical daytime jobs, BEVs are parked during the day.

Assuming that the home charging follows the pattern from Table 1, charging will mainly happen during the evening and night for charging scenario 1. Since work-related travels contribute to a high share of the total travel demand (40 % in the case study, see tab. 6), workplace charging has potential to be one important type of destination charging. Hence, in scenario 2, some of the charging demand will be shifted to daytime and the afternoon.

6 Conclusions and further work

This paper has presented a method and case study for geographically distributing the charging load from BEVs based on output from the regional transport model RTM. It has also presented relevant results from an EV survey providing insights to the current charging habits of Norwegian EV owners. The EV survey shows that home charging is the most widely used charging method, whereas workplace charging is less frequently used. However, results from RTM show that the transport- and energy demand from short BEV trips are split 40-to-60% between work-related and non-work-related travels. This indicates that there is a potential

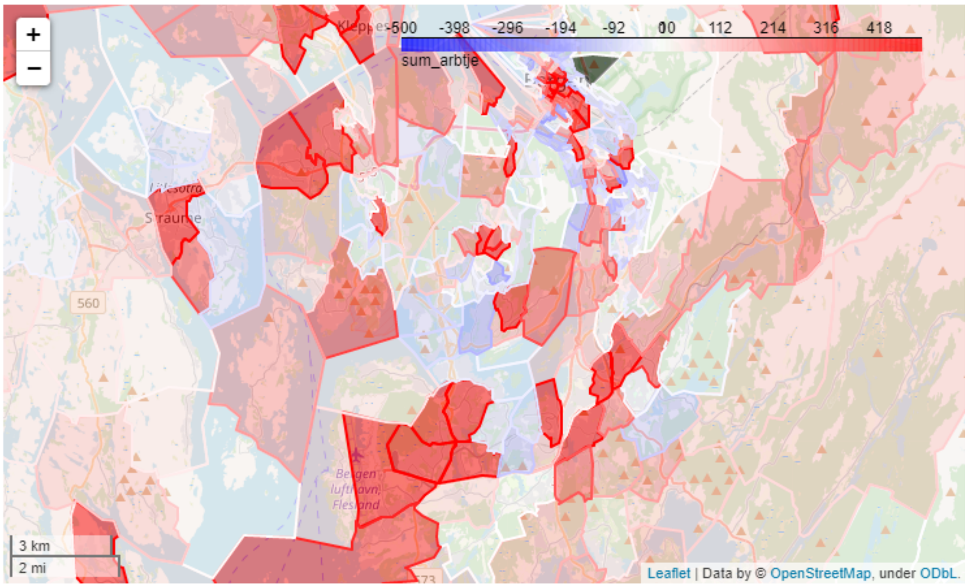

Figure 5: Screenshot showing parts of Bergen city in an interactive version of the charging map. The map is generated using the Python package GeoPandas which uses data by OpenStreetMap under ODbL.

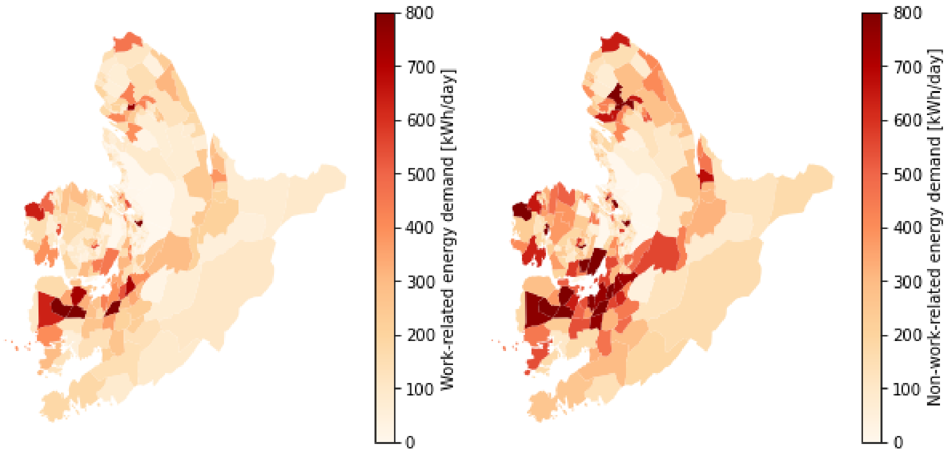

Figure 6: The charging demand [kWh/workday] in scenario 2 for zones within Bergen municipality for work-related travels (left) and non-work-related travels (right)

for more workplace charging if this become more available. In the case study performed in the paper, it has been studied how a transition to more charging at workplaces and other destinations will impact how the charging demand is distributed in time and space. The results shows that more destination charging will reduce the load in many residential areas, and that some zones containing large workplaces, malls, universities and hospitals will have a large increase in charging demand for a scenario where BEV owners recharge at their destination. The framework presented in this paper will be further developed to a model for generating aggregated load profiles for different types of charging by combining the transport model and the EV survey results. It is also planned to couple the geographical location of the charging demand with a power system model. This will make it possible to analyse the grid impact of BEV charging, as well as the availability of BEVs as flexible resources that can provide both temporal and spatial flexibility. The transport and EV data presented will also be used as input to a model for optimizing the use of different types of charging for future scenarios with higher BEV shares.

Acknowledgment

The authors would like to thank the Research Council of Norway and industry partners for the support in writing this scientific paper under project 295133/E20 FuChar. Also, we would like to thank the Norwegian Electric Vehicle Association for access to data from the annual EV survey.

References

[1] IEA. (2020) Tracking Transport 2020. [Online]. Available: https://www.iea.org/reports/tracking-transport-2020

[2] IEA, "Global EV Outlook 2021 - Accelerating ambitions despite the pandemic," 2021.

[3] The Norwegian Electric Vehicle Association. (2021) Elbilsalg [Electric Vehicles sales]. [Online]. Available: https://elbil.no/om-elbil/elbilstatistikk/elbilsalg/

[4] ——. (2021) Elbilisten - Norges største underøkelse av elbileiere i Norge [The EV Owner - Norway's largest survey on EV owners in Norway]. [Online]. Available: https://elbil.no/elbilisten/

[5] K. Clement-Nyns, E. Haesen, and J. Driesen, "The impact of charging plug-in hybrid electric vehicles on a residential distribution grid," *IEEE Transactions on power systems*, vol. 25, no. 1, pp. 371–380, 2009.

[6] Q. Gong, S. Midlam-Mohler, V. Marano, and G. Rizzoni, "Study of PEV charging on residential distribution transformer life," *IEEE Transactions on Smart Grid*, vol. 3, no. 1, pp. 404–412, 2011.

[7] A. Ramanujam, P. Sankaranarayanan, A. Vasan, R. Jayaprakash, V. Sarangan, and A. Sivasubramaniam, "Qantifying the impact of electric vehicles on the electric grid: A simulation based case-study," in *Proceedings of the Eighth International Conference on Future Energy Systems*, 2017, pp. 228–233.

[8] R. Rana, S. Prakash, and S. Mishra, "Energy management of electric vehicle integrated home in a time-of-day regime," *IEEE Transactions on Transportation Electrification*, vol. 4, no. 3, pp. 804–816, 2018.

[9] J. Hiry, J. Peper, S. Peter, C. Kittl, and C. Rehtanz, "Regional spatial distribution of electric vehicles–a data-driven approach for distribution grid impact case studies," in *ETG Congress 2021*. VDE, 2021, pp. 1–6.

[10] A. I. Croce, G. Musolino, C. Rindone, and A. Vitetta, "Energy consumption of electric vehicles: Models' estimation using big data (fcd)," *Transportation Research Procedia*, vol. 47, pp. 211–218, 2020.

[11] N. Daina, A. Sivakumar, and J. W. Polak, "Modelling electric vehicles use: a survey on the methods," *Renewable and Sustainable Energy Reviews*, vol. 68, pp. 447–460, 2017.

[12] T. Tørset, O. K. Malmin, E. H. Flaata, and O. A. Hjelkrem, "Cube – regional persontransportmodell versjon 4.3 [Cube - Regional passenger transport model, version 4.3]," Tech. Rep., 2022.

[13] Bentley CUBE Voyager. [Online]. Available: https://www.bentley.com/en/products/product-line/mobility-simulation-and-analytics/cube-voyager

[14] J. Rekdal, O. I. Larsen, O. K. Malmin, N. Hulleberg, S. Flügel, and A. Madslien, "Etablering av etterspørselsmodell for korte personreiser," Transportøkonomisk institutt, Oslo, TØI-rapport 1814/2021, 2021.

[15] R. Hjorthol, Engebretsen, and T. P. Uteng, "Den nasjonale reisevaneundersøkelsen 2013/14 - nøkkelrapport," Transportøkonomisk institutt, Oslo, TØI-rapport 1383/2014, Dec. 2014.

[16] Statistics Norway (SSB). (2021) Dwellings, by type of building (m) 2006 - 2022, table 06265. [Online]. Available: https://www.ssb.no/en/statbank/table/06265/tableViewLayout1/