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A contribution to the Edison project

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A contribution to the Edison project

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Background

The Danish government has decided that 25 % of the electric energy consumption in 2025 should be CO_2 free. And the Danish Climate Commission has shown that Denmark with a very low economic effort could base all national energy consumption in 2050 on renewable energy if we start to prepare now. The use of renewable energy as wind and wave power, solar cells etc. is more complicated than conventional energy production because production is fluctuating over the hour, day, week and month. It is therefore necessary to be able to store the energy from high peak periods to low peak periods and to smoothen out the daily fluctuation. For this purpose batteries of electric vehicles (EVs) might be one of the good solutions. At the same time as transport is getting electrified and based on renewable energy it will also be more energy efficient than conventional cars because.

Electric vehicles are therefore expected to get a main role in the reduction of CO_2 from the transport sector. Several demonstration projects on Electric Vehicles (EVs) will in the near future be started in both Denmark and at the European level. And a handful of car manufacturers have started production of EVs which are not only rebuilt conventional cars. If they will be successful price will slowly start to fall on both cars and batteries and it would be possible that mass production will start after some years.

One of the most important preconditions for the EV to be a success is that it is able to fulfil the travel behaviour needs of the costumers. This question is analysed in the Danish Edison project. A conventional car is fuelled at a filling station after 500-600 km. And drivers are used to do that. This is not the case with EVs. Their driving range is much shorter than conventional cars, typical 80-160 km officially but in practise normally only 50-120 km. People therefore need to charge much more often than they need to fuel. On the other hand for many people it is easy to establish charging facilities at home so that the driver only needs to plug in to a normal electric pole in the carport. Or charging poles can be established at the parking lots of stock houses.

But is it enough to have charging facilities at home when the practical driving range is only 50-120 km? And if not, how many charging facilities are needed and where should they be placed. This is what this paper is about.

Methodology

The paper includes three main questions which will be analysed separately

- Travel behaviour and the need for charging
- Demand for charging infrastructure at different kind of activities
- Demand for a fast charging network and its national localisation.

Travel behaviour and the need for charging

To be able to evaluate the possibilities of using EVs to cover the transport needs, it is necessary to analyse the data regarding the use of conventional cars, as there is not enough EVs on the market, and thereby not sufficient data, to analyse the use of EVs.

The problem of using data for conventional cars is partly that people may very well change their transportation pattern when they get used to an electric car, and partly that it will not be a random selection of the population that will buy an electric car, but rather those people with a transportation pattern that is suitable for using EVs.

In Denmark we have two datasets relevant to use for analysing travel patterns of passenger cars, the Danish National Travel Survey (NTS) and the AKTA data. None of these are ideal for the purpose, but together they can illustrate the travel pattern to a certain degree. For goods transportation only exists a dataset with odometer reading.

The advantages and disadvantages of the two datasets for passenger cars are:

- The NTS data are interview data about travel behaviour of the population, collected daily for over 15 years. The number of interviews is large (much more than 100,000 interviews) and they contain a huge amount of information on travel behaviour. The problem is that the information follows the respondent's behaviour and not the travel pattern of the car, because the Danish NTS opposite to some other countries is collected based on individuals and not on households. This means that it is impossible to know how much the car is driven by others than the respondent. The greatest problem related to this is households with one car and two or more driving licenses. In addition, the interviews only report the respondent's behaviour on one particular day. In this way you do not know how much the behaviour varies from one day to another, from one week to another and from one month to another. And this is very important for the driver when he has to decide whether he will choose an EV.

- The AKTA data is GPS-based data following the cars. They were collected in 2001-2003 as part of a road pricing trial. A total of 360 cars were followed by GPS from 14 to 100 as a base period for comparing with the trial. These data obtain knowledge about travel pattern of the cars and the variation during a week and partly also during a month. The dataset, however, includes significantly fewer cars and the detailed information about the trips is, apart from the exact geographical positioning, very modest. The most important disadvantage is, however, that it only regards cars belonging to families with only one car, families living in Greater Copenhagen, and only families attached to the labour marked. It means that data is not representative.

To cope with the problem with the NTS data for the car in a one car family with two drivers a new dataset for the car is constructed based on the dataset of the respondent. It is assumed that the respondent has a spouse who is behaving as another person in the dataset who share personal and familiar characteristic with the driver and his/her family. This person is not allowed to travel as car driver in those periods where the respondent is away from home by car as driver. The characteristic of the driver and the person he/she is combined with is:

- Number of cars of the household
- Number of driving licenses of the household
- Weekday (working day, Saturday, Sunday)
- Size of the urban area (the actual geography is not included for the calculations for this paper it will be analysed later)
- Type of family (single/couple, with/without children)
- Age class and gender is correct for the spouse (unfortunately is the main occupancy not known for the spouse)

For this paper only families with one car and two drivers are included. Between 98.0 and 98.8 % of the respondents in the dataset finds a partner in the dataset. 90 % a partner with all criteria are found for the rest the age group is broader or age/gender and family size is not correct.

For lorries and vans a database with odometer reading is used (MD cars we call the copy of the database DTU Transport has bought). For this kind of cars only the yearly mean kilometres is known so the individual differences over the day and week is unknown. To get a realistic picture of the daily travel distance it is assumed that the cars are only driving 5 working days a week and only 45 weeks a year because vacations and holydays are not included. If more than one driver use the car it will be used more and the mean kilometres per day is over estimated. On the other hand sickness is not taken into account.

Technology of EVs and charging facilities

Whether an EV can fulfil the need for transport depends on the range of the battery. The elderly EVs only have capacity for driving of 60-80 kilometres before they need to be charged. The new generation of EVs with Li-Ion batteries has an increased driving range which according to the car manufacturers is 120-180 km. However these driving ranges are only obtained if the cars are driving at a maximum of 80 km/hour. As soon as the speed is increased to 100 km/hour or more it will run out of electricity after a much shorter distance. A car with a formal capacity of 160 km will in practise only run 120 km. It is therefore decided to elucidate the possibilities of different battery capacities with driving ranges from 80 km to 200 km.

Even though the cars have these capacities, the drivers will not discharge the battery completely, as they will of course not risk running out of power. The Citroen is even lowering the velocity when the left battery capacity is about to run out. In the calculations it is therefore assumed that the driver will insist on charging the battery when 20 km of the travel range is left. When using NTS data it is furthermore assumed that all cars can start the day with a fully charged battery, i.e. they are charged during the night.

For the charging facilities four types of technology can be considered.

- Normal plugs and lines with 230 Volt. In Denmark these will facilitate 10 Ampere as maximum.
- New charging poles with a stick for 400 Volt. In Denmark these will facilitate 16 Ampere as maximum in other countries it might charge be up to 20 Amp. Standardisation for such plugs is at the moment being developed including possibilities to facilitate billing infrastructure.
- Fast charging stations with higher voltage and more current to be able to charge the cars in a short period. These stations have to be developed and will in all circumstances be under a more effective control for security than charging poles which can be used by the EV costumers themselves.
- Battery swapping stations at which the battery pack is removed and replaced by a fully charged battery pack

The normal plugs and the 10 Amp will typical be used for night charging at home whereas the 2 fase plugs with 16 amp might be used in the future for charging poles for cars parked in town for some hours.

The fast charging and the battery swapping facilities will only be used when the driver is at a longer trip at which the car will not stop until the driving range is close to be exceeded. Which of the two will be used depends on the type of the EV. Therefore fast charging in this paper is used synonymous with battery swapping and only means that charging can be overcome fast. It is expected that fast charging will be much more expensive for the costumer than normal charging because the investment in the infrastructure is high. Furthermore fast charging a battery will shorten its life time and make the provision for the battery investment higher. Battery swapping will not be as burdening for the battery as the battery can be charged with for instance 400V/16 amperes. The charging price will therefore depend on the investment and access to swapping stations.

Table 1 Assumption of the needed charging time dependent on the driving range of the battery

Capacity range: Maximum need for charging for:	**80 km** 60 km	**100 km** 80 km	**120 km** 100 km	**160 km** 140 km	**200 km** 180 km
Time use at one phase 10 Amp (hour:min):	2:30	3:20	4:10	5:50	7:30
Time use at two phase 16 Amp (hour:min):	0:47	1:03	1:18	1:50	2:20

In table 1 is shown how long time it takes to charge a battery if only a travel distance of 20 km is left at the battery dependent on the type of the charging facility. With the actual available one phase charging facility it takes a little less than 6 hours to charge a car with a travel range of 160 km. This will normally be enough for the night and even for parking at the job for full-time workers. If the charging pole is improved to a two phased stick the car will be fully charged after less than 2 hours. The analyses in this paper are based on the existing charging facilities with one phased sticks with 10 Amp.

Need for charging poles

The NTS data is used to calculate if a car has a travelling distance at the response day so that it can do with night charging. If this is not possible it is analysed if it can do with charging at home in the running of the day. If this is neither possible the calculation is going on for a charging possibility at a working place. If this is neither possible no more restrictions are put into the calculations and the driver is expected to charge the rest every time a pause of 10 minutes is available.

With this set up for the calculations it is analysed how often a driver need to charge compared to how often the different activities are visited.

Location of fast charging facilities

As part of the Edison project a methodology to optimise localisation of fast charging stations is developed. The analyses are based on origins and destinations of all trips along the day of cars that need to fast charge one or more times along the interview day. It is presupposed that the charging stations are located at some of the existing manned gas stations of which exists around 1200 today. The method is parted into three stages.

Stage 1 reads the NTS Data and a digital map of Denmark which includes the entire road network and builds the digital search Graph. Origin and destination pairs of the NTS Data are used to find the extended routes for all trips. Then trip kilometers for all cars are used in the simulation part to calculate the fast charge potential points in the road network, i.e. the point where the most optimal fast charging station for the actual travel should be located. The extended trips and fast charge potential points are stored as output of stage 1.

Stage 2 reads the data for the existing manned gas stations in Denmark and includes the fast charge potential points from stage 1 to find the optimal placement of fast charging stations. Then the location model uses simulated annealing to find which gas stations that should be upgraded to serve EVs. The list of upgraded gas stations and the matching between gas stations and fast charge potentials are stored as output from stage 2.

Stage 3 reads NTS data, fast charge points, gas stations and extended trips. These data are used in a simulation where the number of customers which can be served by an upgraded gas station is calculated for all extended trips. The list of the customers which cannot be served is stored as output from stage 3.

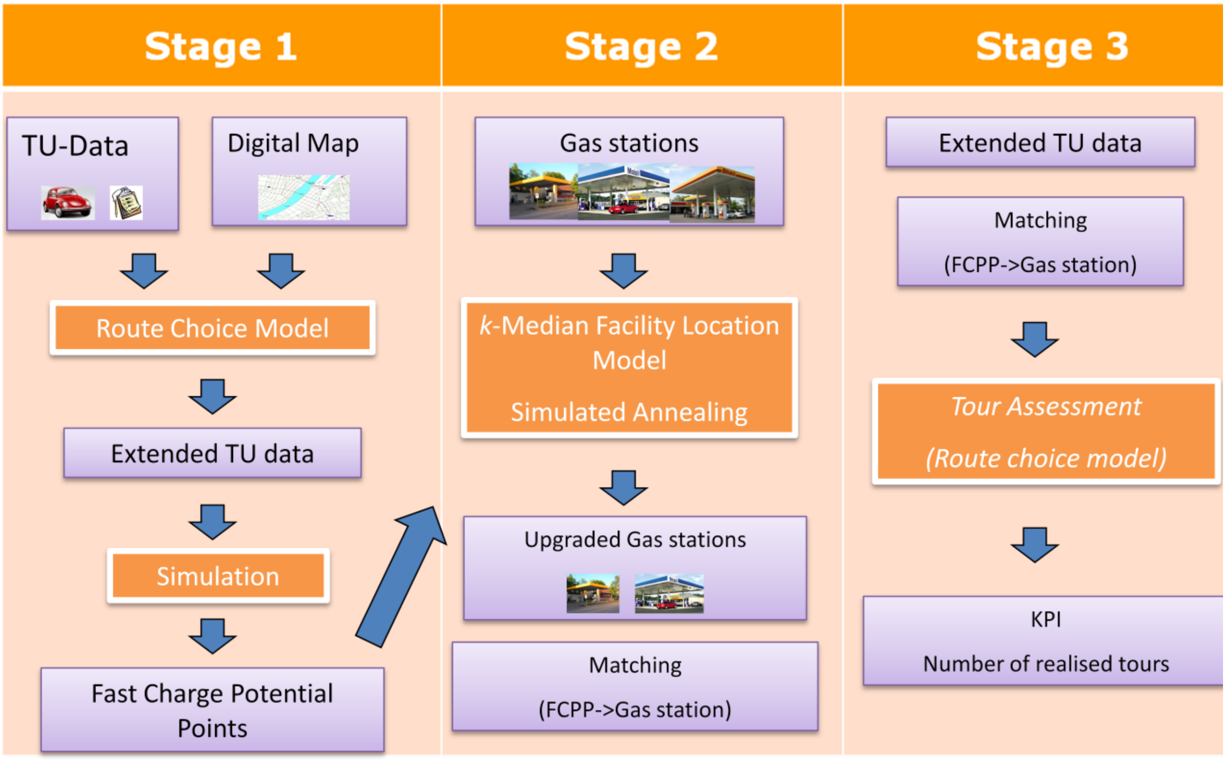

Figure 1 Illustration of the principles of the calculation of the optimizing of the localisation of the fast charging stations (TU data is the Danish name for the NTS data)

Results

Charging away from home

In the first years until the charging infrastructure is established outside the user's own home, it will be relevant for potential owners of EVs to consider whether they can avoid charging during the day. As the charging infrastructure becomes available at workplaces, in city centres etc., the need to charge the car away from home will only be a source of irritation and only on rare occasions considered a barrier as such.

Table 2 Share of cars not driving the actual day. Share of driving cars which need to charge during the day dependent of the travel range of the car

Number of cars and number of people with driving license in the household	1 car 1 driver	1 car 2 drivers	2 cars 2 drivers	All Cars except 3+ drivers and less cars
Share of cars not driving	38%	12%	27%	22 %
Share that drive but and need to charge during the day as function of battery range:				
80 km	22%	30%	33%	30%
120 km	10%	15%	16%	15%
160 km	5%	8%	9%	8%

In table 2 the driving performed by the car is elucidated. In families and singles with 1 car and only one driving licence, the car kilometres is considered to be more or less equivalent to the car driving performed by the respondent. This group makes up 16 % of the cars (c.f. table 3). 22 % of these cars drives more than 60 km on the particular day (given they are driving) and will therefore need to charge during the day if the driving range is 80 km. If the driving range of the car is 160 km, only 5 % of the cars need to be charged during the day on a given day.

For cars belonging to families with more than one driver the share, which need to charge is about 50 % higher than for singles. There is not much difference in need for charging between cars in families with one and two cars, given that the car is driving at the actual day. The most important difference is the share of the cars, which are not driving. Only 12 % of cars in families with one car and two licenses is at home the whole day. 27 % is at home in families with 2 cars.

According to the NTS data and based on the above prerequisites, 70 % of the cars are not travelling so far on a given day that they have to charge during the day, if the car has a travel range of 80 Km. If the battery holds a travel range of 200 km, only 6 % of the cars will travel distances during the day that are longer than allowed by the battery capacity (cf. Table 2).These results are based on cars owned by families who have the same number of cars as drivers in the family or who have 1 car and two drivers. Families with 3 or more drivers and with less cars than drivers are not included. Those left out makes up 11 % of the cars and 15 % of the drivers (cf. Table 3). If a family has more cars than drivers it is calculated as if they only have the same number of cars as drivers.

Table 3 Share of cars / share of license holders in families with different number of cars and number of driving licenses. Families with more cars than licenses are pooled in one group.

Number of cars	**1 license**	**2 licenses**	**3 or more licenses**	**All**
1 car	16% / 10%	41% / 54%	4% / 9%	61% / 73 %
2 cars		28% / 18%	5% / 5%	34% / 24%
3 or more cars	5% / 2%		2% / 1%	5% / 3%
All	20% /11%	70% / 74%	11% / 15%	

However, based on these numbers it is not possible to assess how much the cars drive when studied over a longer period. To assess this variation in more details, the AKTA data is analysed. They cannot be directly compared with the above-mentioned average numbers for the entire population, because they only comprise one car families in the working age population and only cars in the Copenhagen area.

Part of the cars comprised by the AKTA data was followed during 13 days and nights, whereas others have been followed for a longer period. In figure 2 and 3 it is therefore shown how many days the car could not avoid charging during the day during a 13 days period dependent on the number of people who has to share it (one or several).

It appears that very few cars can avoid charging during the day one or several times during the 2 weeks (13 days). If the car only has a driving range of 80 km, only 3 % of the owners in families with 2 or more drivers can avoid charging and 11 % of singles (cf. Figure 2 and 3). With this low capacity a smaller share of the potential car owners will have to charge away from home at least every second day.

Even with a capacity of 160 km, it is only one third of the families with 2 or more drivers and a little less than half of the singles that can avoid charging along the day during a 2 weeks' period. So it is of no use that 12 % of the families attached to the labour market and holding 2 driving licences and 7 % of the singles can manage without charging on a given day with this capacity. Over a period only few will manage without charging during the day.

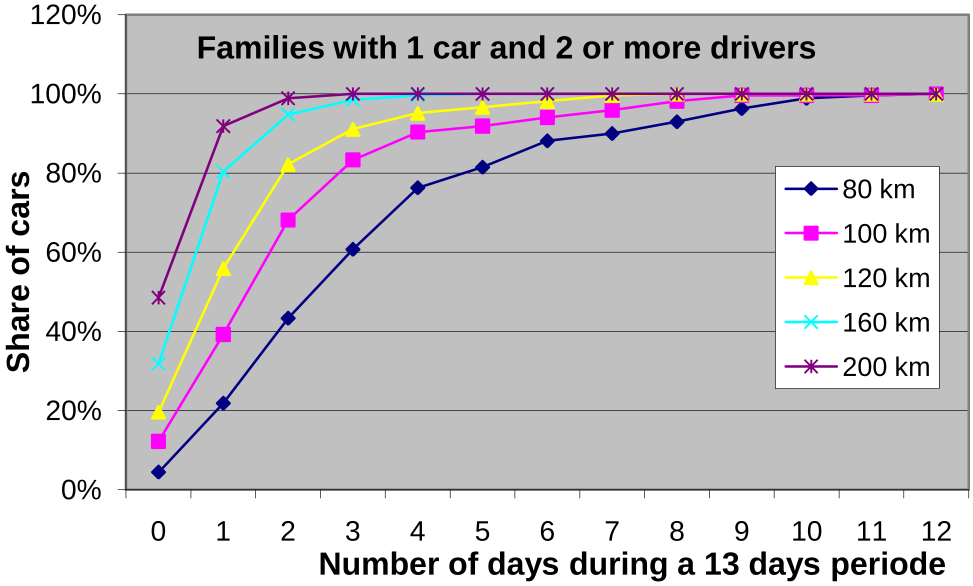

Figure 2 Share of cars needing to be charged away from home 0, 1, 2 etc. days during a 13 days period. Represents a family with one car and 2 or more driving licences in Greater Copenhagen. Akta data

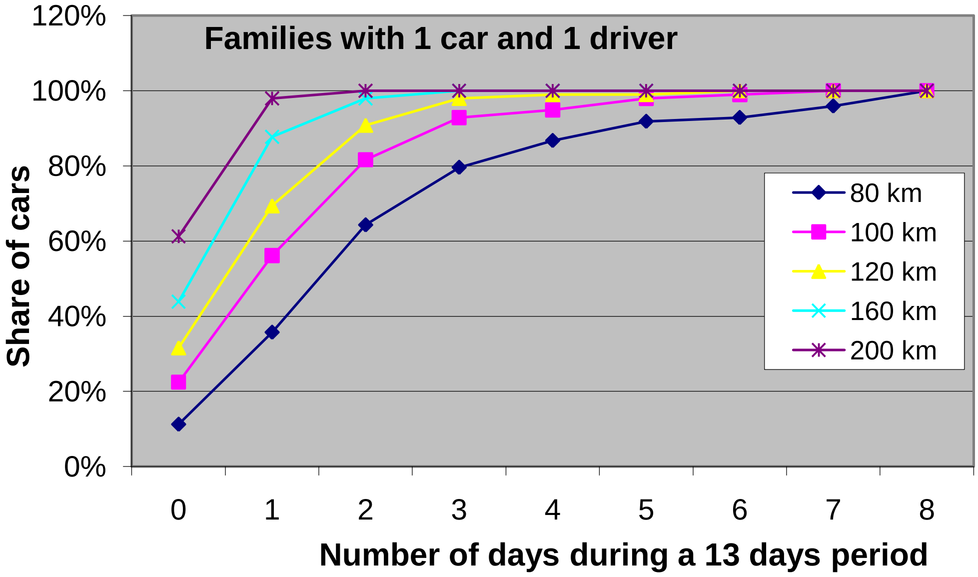

Figure 3 Share of cars needing to be charged away from home 0, 1, 2 etc. days during a 13 days period. Represents singles in Greater Copenhagen. Akta data

Charing needs for electric vans and lorries

It might also be relevant to have electric goods transport vehicles. Figure 4 is illustrating the cumulated daily mean distance of the vans and lorries. Vans with a weight under 3.5 ton total weight can be driven by people with a license to passenger cars. Close to 90 % of these are driving less than 150 km per day in mean taken over a year with 225 working days. About 70 % are driving less than 100 km. If the travel distance is not varying much from day to day these 75 % of the vans might be potential electric vehicles.

For the small lorries under 8 ton and between 8 and 12 ton total weight less are driving upto 120 km per day in mean. But still 60 respectively 55 % drive less than 100 km in mean 80 /

70 % drive less than 150 km which means that more than half of the small lorries could be potential electric vehicles.

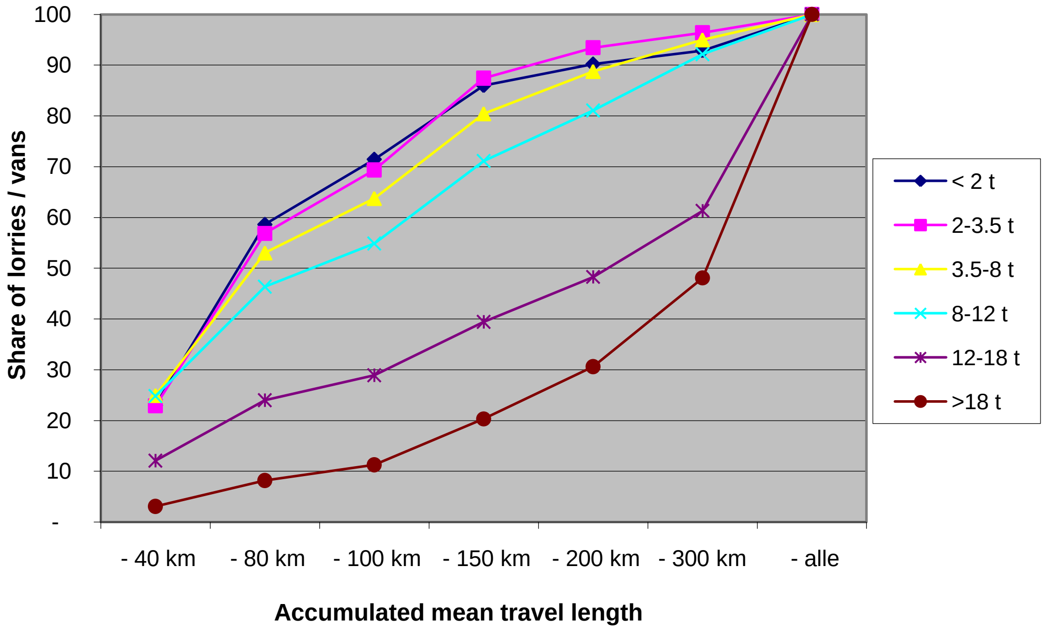

Figure 4 Accumulated distribution of the mean travel length of vans and lorries when it is assumed that they drive 225 working days per year. Source: MD database

Of the big lorries over 12 respectively 18 ton only 30 respectively 10 % drive less than 100 km. They are therefore not obvious candidates for being electric vehicles. The need for power is another reason for that.

Charging infrastructure

The important question is where the daytime charging facilities need to be. Figure 5 shows the main needs for charging. As described above around 85% of the charging will take place at home. Some - 5 % of those who only have a driving range of 80 and 3 % of those with 120 km - can do with charging at periods when they are at home.

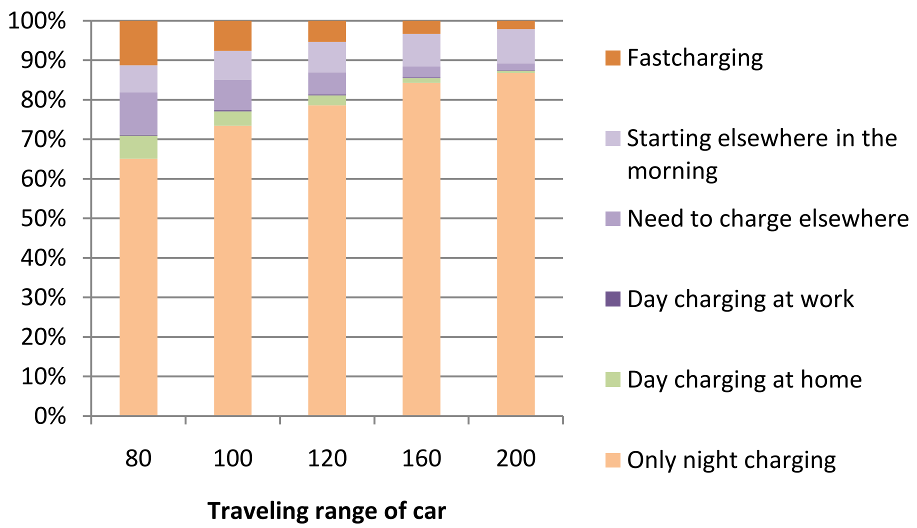

Figure 5 The share of driving cars that will do with night charging at home and the share that need to charge during the day in different ways. Source: Akta data

7-10 % are not at home at 3 o'clock in the morning when the starting time for the travels of the interviews are fixed. Some of these are at work or out for night life and will drive home later in the morning and stay at home for so long that the car will be charged fully later in the day. Others are staying out in the night, for instance in summer houses or visiting friends and relatives. In general this group is not of special interest for charging poles because they stay in private homes or eventually at work. But some might prefer to charge in the city centres when they are there for night life.

12 to 3 percent needs fast charging during the day and will only to a small extent need charging poles. The rest is another 12 to 3 percent of the cars driving that need to charge somewhere else. For those with a driving range of 120 km it is 5 % who need charging at poles and similar facilities outside home.

Figure 6 is elucidating which kinds of activities are used when charging is needed. The distribution is compared to the share these trips make up for all trips. If the share is the same in the two columns about 5 % of the parking spaces need to have charging facilities. The figure shows that commuting and education is very close to the general share. Figure 5 shows that only very small shares of the cars need to charge at work.

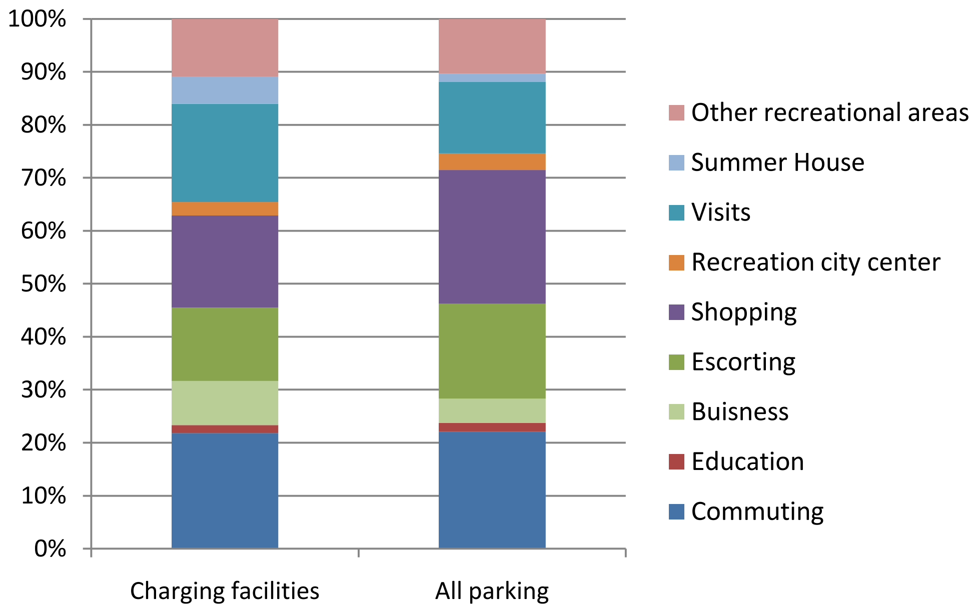

Figure 6 The share of trips that need charging at different activities compared with the share of trips to the different facilities. Source: NTS data

Over represented in the need for charging is private visits (one third higher than the share of the tips) and especially parking at summer houses (5 times higher than the share of the trips). As these places are private owned the charging has to be established at the host or at the owner as an alternative to home charging.

Business trips are also over represented in the need for charging (25 % higher).

The need for charging at shopping is smaller than the general number of trips (only two third). The general need for parking at recreational city centre facilities like restaurants, cinemas and night life is the same as the number of trips. The same is the case with recreational trips as trips into the nature and sports activities. Escorting trips are under-represented.

Need for fast charging
Sometimes the car owner will travel longer distances and therefore need fast charging on the trip. According to the analyses of the AKTA data, it is less than half of the drivers that can almost avoid fast charging during a month, if their cars have a driving range of 80 km, cf. figure 7. If the range however is 150 km it is almost one third that can avoid fast charging during a month. Approximately 15 % of the cars must perform fast charging at a couple of days and approximately 20 % once a week if they only have a range of 80 km. In case of a driving range of 150 km or more, a maximum of 8 % will have to perform fast charging approximately once a week.

Furthermore it will often be necessary to charge several times during the day, once the need for fast charging has been established, (cf table 4) If the capacity is 80 km, it is less than half of the cars that can do with charging only once, and 20 % must charge more than 3 times. And even in case of a capacity of 150 km, half of the cars must charge more than once the actual day. One of the reasons for this is of course that many of the daily tours consist of a outbound and a return trip which are both to long for driving them in one charging..

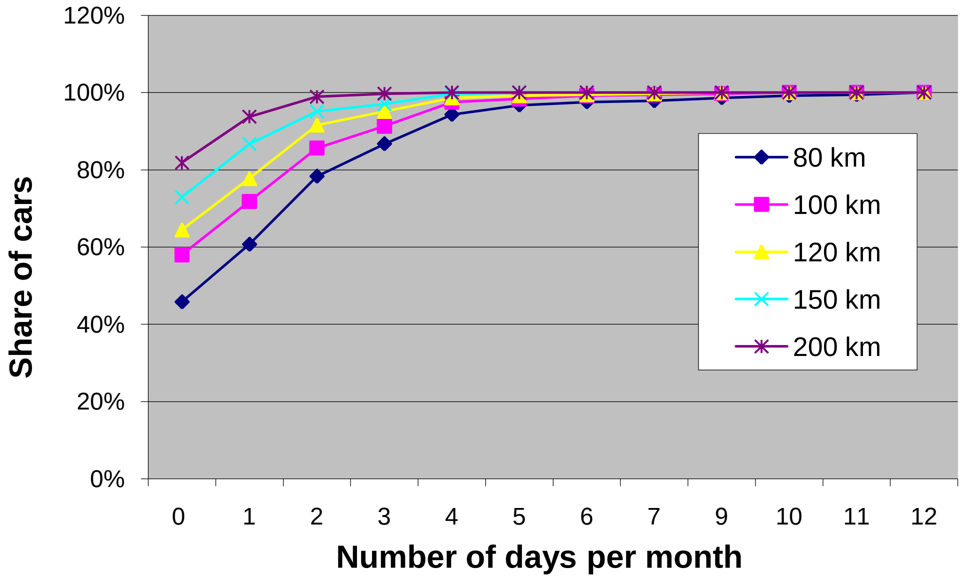

Figure 7 Share of cars that needs to perform fast charging within a month, on only a few or several days. Source: Akta data

Figure 8 shows 4 examples of optimal localisation of fast charging stations depending of the number of stations. It is clear that the fast charging points calculated from the trips follow the motorways from Copenhagen across Fyn and to the north and south in Eastern Jutland. The fast charging stations are following these motorways too with few stations. Not until about 50 stations are established the whole country is covered. Greater Copenhagen is not getting any fast charging station until 20 stations is established. The first and most important station is the one to the south of Copenhagen where the motorway to the west and to the south is spitting out.

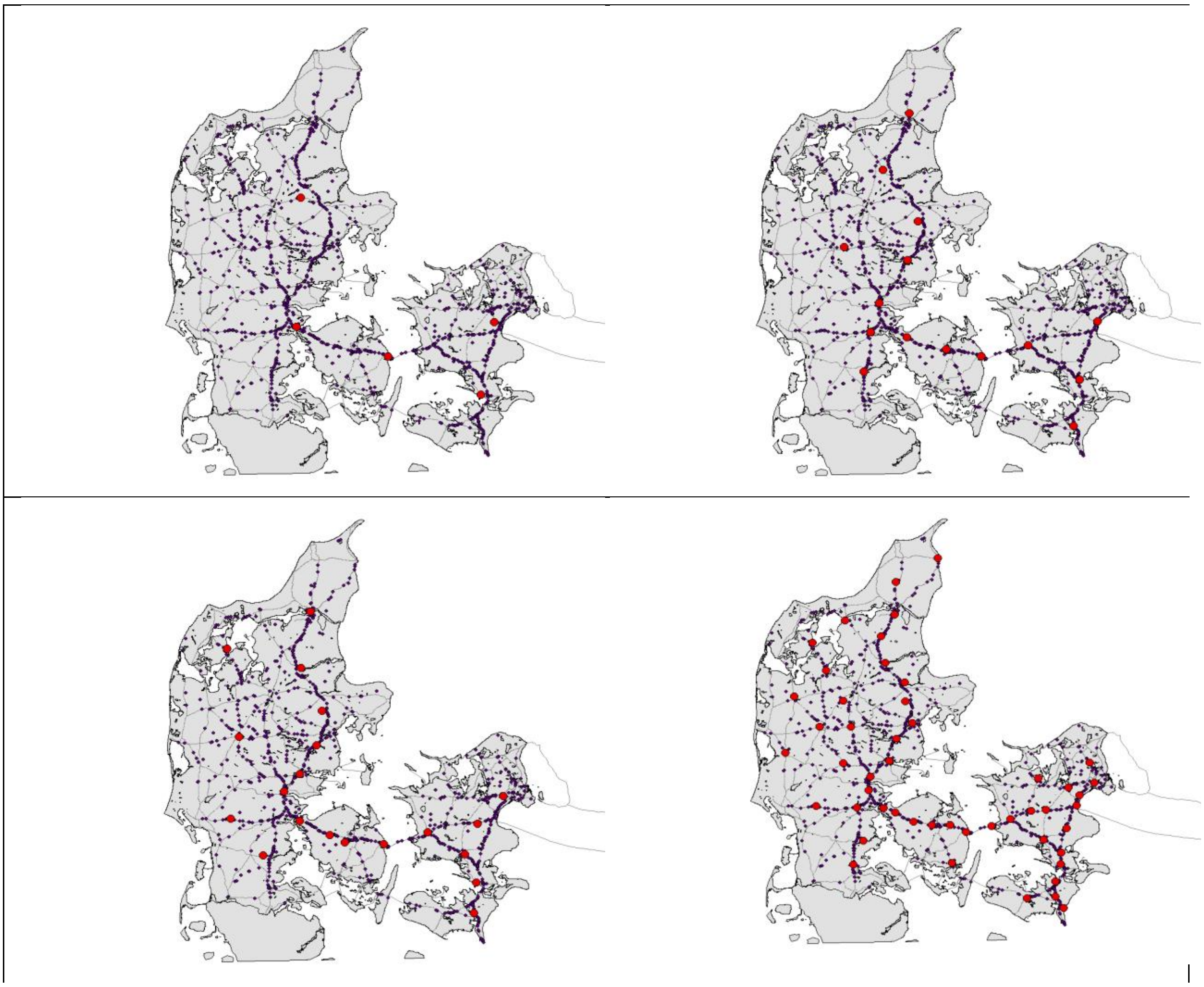

Figure 8 Localisation of 5,15, 20 and 50 fast charging stations calculated by the model. The black spots shows the Fast Charge potential Points from the trips

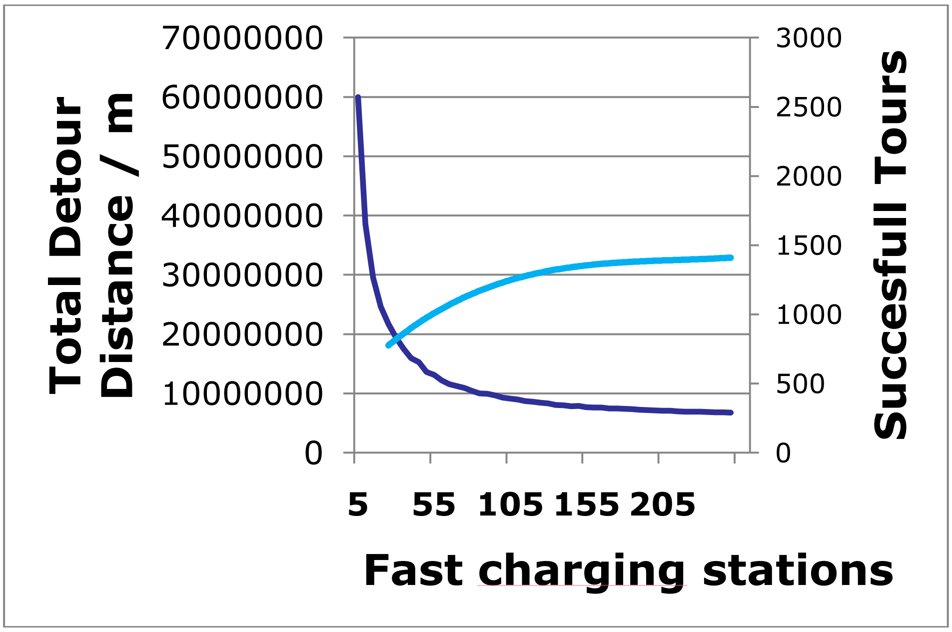

Figure 9 Total detour in meter depending of the number of fast charging stations, left axes. The number of tours which gets fast charging (1441 tours in all), right axes.

In figure 9 is shown the total detour distance of the drivers depending of the number of fast charging stations. On the right axes is seen the number of trips which cannot be served.

With around 100 fast charging stations close to all tours can be served. The mean detour for getting fast charged will be about 7 km. With 50 stations only 2/3 of the trips are served, and the mean detour distance of 25 km.

Discussion

The problem of using data for conventional cars for the analyses is that people may very well change their transportation pattern when they get used to an electric vehicle. And more important, it will not be a random selection of the population that will buy an electric car, but rather people who have a transport behaviour that is suitable for using EVs. This means that the analyses presented in this paper will not be representative for how electric vehicles in the car fleet will charge.

The available travel data can be used for analysing travel behaviour for two kinds of purposes. The first purpose is to elucidate how suitable EVs will be for fulfilling the need for travel behaviour. The other is how the EVs will interact with the electric grid. However, the answer to the last question is dependent on the future EV car stock and the behaviour of the EV car owners. And this depends on how inclined different groups are to buy an EV as the only or as the second car and how much they will drive. So the two questions are closely related. This paper only discusses the first question.

The analyses show that only very few one car owners can do without the possibility to charge outside home. Therefore development of a charging pole infrastructure will be an absolute prerequisite for getting the EVs spread in a mass consumption market. Until this will be the case it cannot be expected that even EVs with a large travel range of e.g. 160 km will be common.

On the other hand only around 5 % need to charge outside home at daytime the actual day. This means that about 5 % of all parking areas can be expected to need charging facilities. In the beginning the share of the parking lots is much smaller; they just have to be there.

Opposite to what is the common expectation it will not be at the working places the greatest needs for charging will be. If companies establish one or a few poles at their parking lots as a service facility for their staff it will be fully sufficient. The need for charging will in fact be bigger for their business guests and perhaps their repairing and service workmen.

The need for parking at charging poles in city centres is rather small. The need at shopping areas is underrepresented and will therefore be a little less than 5 % of the parking spaces. These facilities can be reused for visits for evening and night activities. The greatest needs for charging at shopping centres are assumed to be at the mega markets which attract costumers from long distances. They should in the long run equip more than 5 % of their parking lots with charging facilities.

In city centres and in other densely built-up areas without access to private parking the greatest needs is home parking for the residents through the night. 10 % of all resident apartments are located in these areas. Some might have access to private parking in the back yards but most needs to be parked at the streets. In the beginning when only few owns an EV it will be a special attraction that parking can be reserved at a charging pole. Later on when EVs will occupy a high number of parking facilities this will be a problem that needs to be considered seriously. The investments in public accessed poles will be substantial.

Other kind of parking in the city centres might reuse charging poles which are used during the night for residents. The need for the extra facilities for costumers and guests in the city centres and densely populated areas will therefore be small.

Another area that makes a problem is recreational trips in nature. The share of parking lots will only be little but the problem with establishing might be big because of little access to electricity.

Vans and small lorries are also potential EVs. A van can at the one hand carry more batteries than a passenger car. On the other hand it is less fuel efficient than passenger cars. Not to load the car with only batteries it is assumed that it will not have a driving range longer than passenger cars, around 120 km in practise.

The small lorries are often not carrying heavy goods. Their size is often more dictated from a need for volume transport. It might be possible that they can carry a little more batteries and in that way make it is possible that they can get a driving range of 160 km which means that up to 2/3 to ¾ might be potential electric vehicles as with the vans.

The most important problem for the spread of EVs is the need for charging at long distance travels. some car owners can do without fast charging facilities at least for a period of a week to a month. So the existents of only an extensive network of fast charging facilities will be enough for the first years. But of course this will result in much more EVs as car number two than the only car of the family.

The number of fast charging stations has to be around 100 before the country is covered and the detour distance will be acceptable for the costumers. This can be compared with 1200 manned filling stations and 2000 stations in all.

With about 50 fast charging stations only 2/3 of all tours are covered and the mean detour will be 25 minutes. Only tours along the motorway through the country from Copenhagen to Aarhus are served properly. The mean detour should be compared with the effect of a high voltage charging pole (400 Volt) with 2-3 phases which cost nearly the same as the actual poles for 10 Amp. 400 Volt with 2-3 phases are what is common for modern kitchen stoves.

According to table 3 in 3 hours which is much less than a normal working day, extra 115 km can be added to the travel distance with only one phase. With two phases half an hour will add 39 km to the travelling distance and make it possible to get home from a shopping trip for most people, if the battery was almost discharged when the car was parked.

Only really long distance travels for more than 100 km cannot be served by such heavy charging poles and the traveller need fast charging.

Table 4 Possible distance to travel after different charging periods with different current

Charging time	10 min	30 min	1 hour	2 hours	3 hours
10 Amp	4 km	12 km	24 km	48 km	72 km
16 Amp, 1 phase	6 km	19 km	38 km	77 km	115 km
16 Amp, 2 phase	13 km	39 km	77 km	155 km	Maximum
16 Amp, 3 phase	19 km	58 km	115 km	Maximum	Maximum

The methodology to optimise localisation of fast charging stations is in his paper based on the sum of shortest distances to a fast charging station which is optimizing the detour. This is resulting in charging stations as a string of pearls of along the motorways where the traffic is most intensive. The back side is that costumers in the thin populated areas of Denmark get few or no options for fast charging. This is of course a problem for families living in these regions who will not invest in an EV. But as they are few compared to the big cities it doesn't matter if the goal is to get a big share of EVs. But it might be a problem because families from the big cities who have summer houses or friends or relatives in these areas will find it inconvenient to have an EV too. The result is that it for a much bigger share of the Danish household will not be attracted to buy an EV. Another optimisation methodology could go for minimising the share of people who are not having access to a fast charging station on given distance from their trip. An alternative method for optimizing the charging stations can be found where less EVs will be unable to fast charge. But it might increase the detours.

Conclusion

The main precondition for the spread of EVs is establishing a network of charging poles because else will it not be possible to fulfil the travel needs of the car owners. The need is not many poles, even in the long run only 5 % of the public parking spaces need to be for EV charging. In the short run the need is a charging pole at a couple of reserved parking bays in the bigger parking lots of the city centres, shopping centres and big working places. In the dense residential areas with only street parking a more intensive network of charging poles are necessary when the EVs are spread in these areas.

When the charging poles are established an electric car will probably be an acceptable alternative to a conventional car. But only for families who need to fast charge less than every second week. This will be the case for more than half of the one car families even if they choose an EV with a short travel range. And families with a bit higher need for long distance travels will be able to fulfil their needs by buying an EV with a higher travel range. But of course the price will also increase then. The faster the charging takes place, the smaller the inconvenience for the driver will be. And the more will accept to buy an EV.

For some families who have two cars, the second car could be an EV. However, the 'husband's car' in a two-car family is used more than the car in the one car family car in average. And even the 'wife's car' in average drives more than a car belonging to a person living alone. So for many families who already have two cars it will not be attractive to have an EV as one of the cars if the charging infrastructure is not established. The risk is that EVs will only be cars which increases the mobility and the energy consumption.

Vans and lorries with a total weight under 12 tons are also potential EVs. It is estimated that at least two third are possible EVs. Typical EV vans and lorries will be workmen's cars and parcel distribution cars and other kind of transport and distribution in the cities. Those which are not the potential EVs are representatives driving long daily distances around the country with their articles. Lorries above 12 ton are neither potential EVs.