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The document describes the status of e-mobility in Denmark. It gives an overview of the current status of deployment of electric and plug-in hybrid vehicles. It reports the expected trend by 2030 and beyond, based on different suggested policies by the "Eldrup Commission" for the green conversion of passenger cars.

The current status of charging infrastructure both at the domestic and public levels is then discussed. Also with respect to the charging infrastructure, prospects for the 2030 scenario are given based on studies done by DTU and Dansk Energi.

A short overview of the ongoing research programs at DTU is given and three charger concepts are finally provided to conclude the document.

The Danish green transition

The transition to electric mobility reduces the carbon footprint of transport sector and in addition increases the efficiency of the vehicles in itself. However, for a successful penetration of electric vehicles, the accompanying charging infrastructure should be on very good level. One can say, there is not enough charging infrastructure if there are not enough electric cars and there are not enough electric cars due to not enough charging infrastructure. A loop that needs to be proper balanced for a successful transition to electric mobility.

The Danish government has set an ambitious goal of reducing greenhouse gas emissions in Denmark by 70 % in 2030 compared to 1990. Today, 4 out of 100 Danes choose an electric vehicle, meaning that in 2030, everyone should choose an EV when buying a new car.

The transport sector accounts for approx. a quarter of total Danish CO2 emissions, and the sector's emissions have been rising slightly in recent years. Passenger car transport accounts for approx. half of the transport sector's CO2 emissions, corresponding to approx. 7 mio. tonnes of CO2 annually. To achieve the CO2 reduction target, the transport sector must make a significant contribution.

The present report provides an overview of the current status of e-mobility in Denmark, including main activities necessary to succeed the Danish National goals for 2030. The work is mainly based on two documents, both published in Danish, regarding the proposed green car taxation (Kommissionen, 2020) *and the needs for charging infrastructures* (Jakobsen, 2019) *for 0.5/1 million electric cars in Denmark in 2030.*

Electric vehicle status

Despite the vehicle driving restrictions and the limited, but increasing, amount of low- and zero-emission car models (45 compared to the 300 models of conventional cars), in Denmark in 2019 the sale of electric cars and Plug-in hybrids amounted to 4.5 % of the total new registrations.

Table 1 Danish car sales in 2019 (Kommissionen, 2020).

	Conventional cars	**Electric vehicles**	**Plug-in hybrid cars**
Number of cars in total	206300	5500	3900
Number of models	290	15	30

Figure 1 shows the sales of electric cars in Denmark from 2009 to 2019. Before 2010 the sales of electric cars in Denmark were very limited, 500/700 vehicles per year in 2011 – 2013 and thousand vehicles after 2014. In 2015, the share of electric cars highly increased, especially for private owners, thanks to the political action on the electrical cars tax registration. In 2019 there was a significant improvement, probably due to the introduction of new electric car models on the Danish market, including the Tesla Model 3 (in the large segment) and Hyundai Kona (in the small segment). The Tesla Model 3 amounted to approx. 60 % of the Electric cars sold in 2019. Sales of micro and small electric cars between 2014 and 2017 were primarily made by businesses, public sector and home care municipalities. In 2019 tax exemptions and subsidies from state support schemes were applied.

Until the end of 2015, electric car owners were paying the registration tax (VAT was still applied), which in Denmark can be 150 % of the vehicle price, for large conventional cars. In 2016 the government decided to decrease the registration tax for electric cars with a gradual increase over the years: 20% of the full registration tax in 2016, 40% in 2017, 65% in 2018, 90% in 2019 and 100% in 2020. Nevertheless, due to the still high price of the vehicles, the electric car market stopped, thus to re-boot the market, in 2017 the Danish government introduced a deduction based on the battery capacity. At the same time the Government decided to maintain the registration tax for electric cars at 20% for two additional years and in October 2017 a new reduced registration tax for cars was enforced, which hold until the end of 2020.

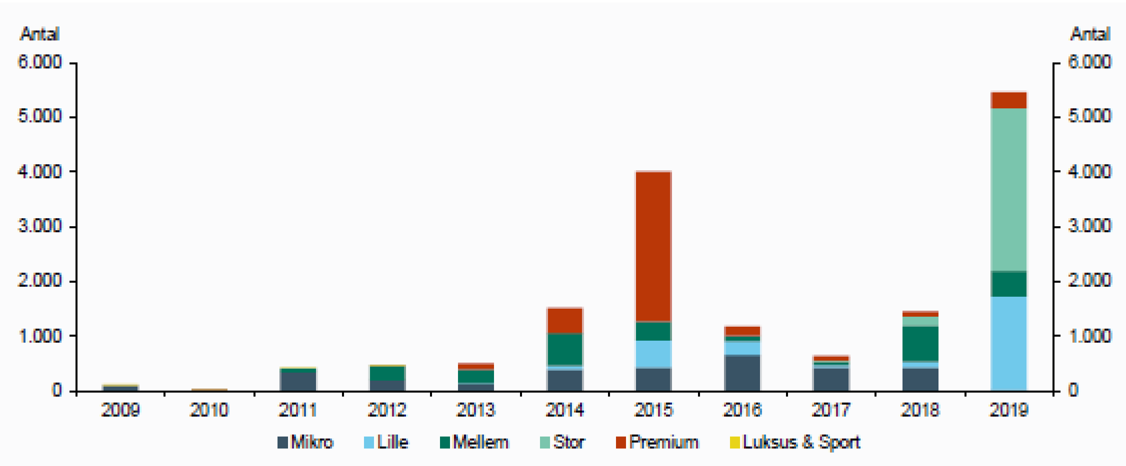

Figure 1 New registration of electric cars per size, 2009-2019 (Kommissionen, 2020).[1]

To better understand the difference in prices between conventional and electric cars, Table 1 compares the price of five conventional and five electric vehicles in Denmark, before and after the taxation in 2019.

Table 2 Comparison of prices before and after tax in 2019 for different vehicles sizes (Kommissionen, 2020).

Vehicle size	Micro	Small	Medium	Big	Premium
Conventional vehicles	*VW Up!*	*Hyundai Kona*	*Nissan Qashqai*	*Audi A5*	*Audi A7*
Pre-tax price (DKK)	76.500	120.300	159.300	248.400	471.400
Purchase price including tax (DKK)	115.900	211.500	283.300	499.800	1.063.300
Electric vehicles	*VW e-Up!*	*Hyundai Kona*	*Nissan Leaf*	*Tesla 3*	*Tesla S*
Pre-tax price (DKK)	200.500	311.700	281.600	468.500	708.600
Purchase price including tax (DKK)	200.500	311.700	281.600	484.300	803.600

Despite the price of the electric cars in the future may decrease, thank to both technology improvement and government incentives, electric cars still require a large initial investment. This results on a limitation of the spread of electric cars in the society, restricted to the population with larger income. Today households that own or lease an electric car, typically have two or more cars and independently from the income almost two

[1] MPVs and SUVs are ranked in the other segments depending on their sub-segment. For example, the segment "Premium" includes both "Premium", "Premium SUV" and "Premium MPV". "Luxury & sports" consists of "Luxury", "Sports" and "SUV Offroad". The "Other" segment is sorted out, as it mainly consists of ATVs, golf carts, etc., which are not actual passenger cars.

thirds of households with an electric car also have one or more conventional cars. This is because, in addition to the purchase price, electric cars have a number of challenges, which constitute barriers to a large spread in the short and medium term: range, charging speed, charging infrastructure. Range and charging speed are two related factors that influence the customer decision on buying an electric or a conventional car. Nevertheless, the technology of both is developing, and by 2030 the average battery size is expected to be equal to 70-80 kWh (IEA, 2020). Similarly, the amount of fast and ultra-fast charging stations will increase, resulting on shorter and less often charging events. Finally, the charging infrastructure has to be ready to satisfy the user charging needs, thus the present infrastructure and future scenarios will be further discussed in the report.

Electric vehicle scenario 2030

The average lifespan of passenger cars in Denmark is approx. 15 years. To shift from combustion to zero- and low-emission vehicles will take many years, therefore it is important to start the transition as early as possible. At the same time, since the price difference between electric and conventional (petrol and diesel) cars is still relevant while the battery price is expected to decrease in the next years, a quick conversion would be more expensive than a slow one. In the short term - including until 2030 – the increase of zero- and low-emission cars, could have a limited effect, because conventional cars will still represent the majority of the car fleet. In the longer term, 2035-2040, the shift to electric cars may have a significantly greater effect.

The idea of stopping the sale of new conventional cars before 2030 is not directly applicable, considering the guidelines of the EU directive 2019/631.Therefore, to achieve large low-emission car penetrations and succeed the EU's CO2 requirements for light vehicles, Denmark is considering other initiatives. Two main economic measures are for example:

1. making zero- and low-emission cars cheaper
2. making conventional cars more expensive in terms of total cost

To a large extent, these measures must be paid by consumers and/or the state. For the consumers, for example, the measures can be applied through higher prices, resulting also on consumers that may no longer afford a car. For the state (taxpayers), the applicable measure would result on a tax revenue loss, which could be filled for example by raising other taxes or duties.

In Denmark conventional cars are highly taxed and the tax differences between conventional cars and zero- and low-emission cars is already resulting on a high social cost. A further increase in the tax difference would lead to socio-economic costs and high costs on the CO2 reduction achieved, compared to other areas.

To promote the sale of zero- and low-emission cars, the Commission for the green conversion of passenger cars proposes a fundamental change in the taxation of the car sector. The Commission proposes to introduce in the registration tax a direct link to the CO2 emissions of cars. This would incentivize customers to choose cars that emit less CO2. The proposed extra charges are mainly focused on covering the average marginal damage costs of car traffic from accidents, congestion, air pollution, CO2 emissions, noise and wear and tear on the road network.

The main idea is focused on making the conventional cars more expensive, whereas zero- and low-emission cars should be initially cheaper. Then, the price of low-emission vehicles would be the result of a balance between two factors: a decrease thanks to the technology improvement, and an increase due to the gradual addition of the registration tax. The registration tax would be gradually introduced, in a slower way than the current framework.

Assuming the current tax rules, which entail a full phasing in of the registration tax and a lapse of the battery deduction, the zero- and low-emission cars are expected to amount to approx. 35-40 % of the new registrations in 2030, and the total stock of zero- and low-emission cars will be around 400000 in 2030. In 2035, zero- and low-emission cars are estimated to account for just over 60 % of new sales if the existing tax rules are maintained, as reported in Figure 2.

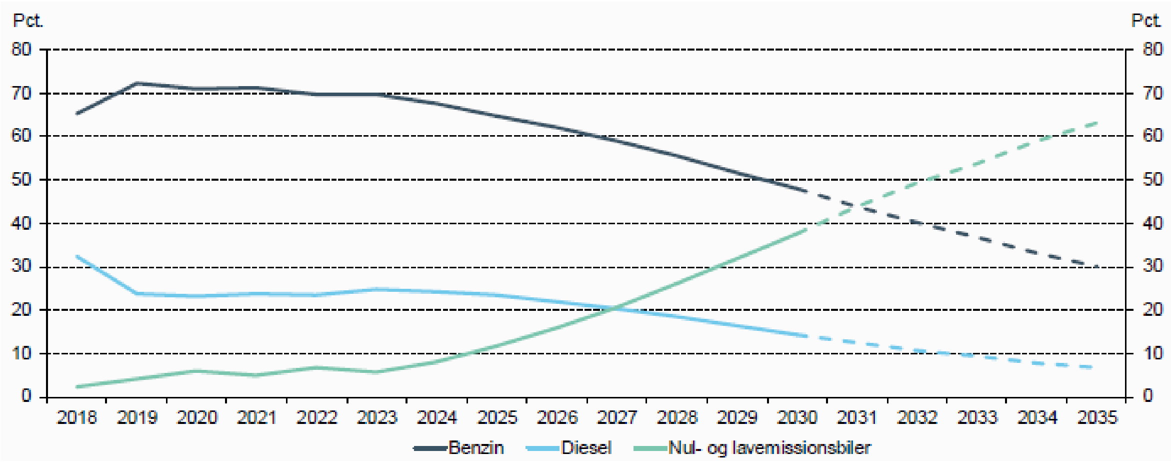

Figure 2 Prediction of new car registrations (Kommissionen, 2020).

It is relevant to observe that greener car taxations are related with conflicting considerations:

- Desire to increase zero- and low-emission cars
- Desire to reduce significantly the CO2 emissions
- Desire to limit the government financial consequences
- Desire to limit the socio-economic costs of the restructuring
- Desire to maintain a similar distribution profile

In Denmark the registration fee is paid for new registrations of cars, regardless of whether it is a new car or a used car imported into Denmark. The current registration tax is a combination of a value-based tax and a technical tax, of which the value-based tax constitutes the main share. This means that the tax is calculated on the basis of the car's price, but deductions or surcharges are granted depending on various technical parameters regarding safety equipment and fuel efficiency.

Since it is not possible to completely ban the sale of conventional vehicles in 2030 and to meet the government goals with the current tax rules, in light of the conflicting consideration above, four main tax models are proposed by the Commission. The tax models aim at achieving between 0.5 and 1 million zero- and low-emission cars in 2030:

1. Tax model 1: 500000 zero- and low-emission cars. Incentive to choose zero- and low- emission cars, maintaining the state's revenue and minimizing the socio-economic costs.
2. Tax model 2: 600000 zero- and low-emission cars. Further relaxation of the taxes on zero- and low-emission cars, while keeping taxes on conventional cars virtually unchanged. The larger reductions for zero- and low-emission cars increase the socio-economic costs by the tax model and also put more pressure on government revenue.
3. Tax model 3: 750000 zero- and low-emission cars. Higher prevalence of zero- and low-emission cars is desired than in tax models 1 and 2, achieved by combining tax reductions for zero- and low-emission cars with further tax increases for conventional cars, including an increase in the fuel tax of 1 DKK/litre. The tax increase for conventional cars will have to be weighed against the distributional and socio-economic considerations. This can be achieved in different ways: the cost of deploying zero- and low-emission cars is paid by society as a whole rather than owners of conventional cars, the CO2 reduction increases but fiscal and socio-economic costs increase, the phasing-in of zero- and low-emission cars in registration tax increases towards 2030, but the spread is supported by a subsidy.
4. Tax model 4: 1 million zero- and low-emission cars, financed through increases in the registration tax on petrol and diesel cars. This may result on largest amount of zero- and low-emission cars, but also on large societal costs.

It is relevant to observe that tax model 1 does not meet the necessary reduction in CO2 emissions, whereas tax model 4 has huge large socio-economic costs.

For more information regarding the proposed tax models for electric cars please refer to (Kommissionen, 2020).

Charging infrastructure status

Both politicians and car manufacturers are showing a clear decision towards the electric transportation. Large electric vehicle penetration requires a charging infrastructure that satisfies the transport needs. Therefore, we must find ways to push development, and we must be quick to identify and remove obstacles.

Figure 3 shows the maximum charging power and charging time, which is expected to be delivered at a charging point depending on the location of the charger. It is expected that new electric vehicles in 2025 will be able to charge with three phases, 16 amps corresponding to 11 kW (AC), and that more owners will have home chargers that can deliver 11 kW. Since most households have 25 amps available in three phases, a home charger can be set up without the high cost. Although, on the one hand, it is still not clear how many EV users will really need such charging level at home. And on the other hand, a large deployment of 11 kW chargers will require a reinforcement of most local grids (Calearo, Thingvad, Ipsen, & Marinelli, 2019) (Calearo, M.Sc. thesis in Sustainable Energy, Flexibility procurement by EVs in a Danish active distribution network: Study cases from the island of Bornholm, 2018), putting pressure on utilities and ultimately disincentivizing the installation of such large home-charging level. Furthermore, the large change in charging power is expected to be mostly delivered at charging stations/charging parks with lightning charging (larger than 50 kW), whereas a mixture of 11, 22 and 50 kW charge will be used at the other locations. When fast charging DC is used, there is no power limit on the vehicle (Jakobsen, 2019).

	Destinationsopladning			Ladedestinationer	
Ladelokationer	**Hjemme**	**Arbejde**	**Andet**	**Vejkant**	**Stationer**
Naturlig parkeringstid					
Normal <= 22 KW AC **Hurtig** 50-150kW DC **Lyn** >= 150 kW DC					
2020	2.3-11 kW	11-22 kW	11-50 kW	11-22 kW	50-150 kW
2025	11 kW	11-22 kW	11-50 kW	11-22 kW	50-150 kW
2030	11 kW	11-22 kW	11-50 kW	11-22 kW	50-350 kW
Maks. Ladehastighed (km/ladetime) 200 Wh/km - 2030	55 km/lt	55-110 km/lt	55-250 km/lt	55-110 km/lt	250-1750 km/lt

Figure 3 Charging power and charging time at different charging locations (Jakobsen, 2019).

Since 2006, DTU Management has collected knowledge about the Danes' transport habits in the Transport Habits Survey (TU). The interviewed persons are selected so that they constitute a representative sample of the Danish population, and the survey can give a true and fair view of the total travel activity for Denmark as a whole in an average day. As the interviewees come from all parts of Denmark, TU offers the opportunity to investigate regional differences (The Danish National Travel Survey, 2020).

The average number of vehicles per household in Denmark is 1.02 and in the Danish island of Bornholm it is 1.03. Bornholm is often considered as representative Danish tested island, thanks to its electric system ability to be operated in islanded mode (Østergaard, 2013). In Denmark there is a significant difference of car ownership and usage between municipalities. The lowest car ownership is in the municipality of Copenhagen with 0.47 cars per household, the highest is Hedensted with 1.41. The national driving average distance per day is 45.5 km per car (Calearo, Thingvad, Suzuki, & Marinelli, 2019), with 21.5 km as average in Ærø and 56.5 km in Holbæk (Jakobsen, 2019).

The Transport Habits Survey shows that 68% of people in Denmark can park on their own land, and thus have the opportunity to establish their own charging stations (home charging). 20 % use parking space on / by the property - including Danes who live in multi-storey properties with shared parking facilities. These have only possibility of charging if the landlord, the cooperative housing association or the board of the housing association decides to set up charging infrastructure. The remaining 12 % only have the option to park at curbs, public charging stations or workplace. Charging at residence is, by now, the most convenient and cheapest way to satisfy the charging needs of electric cars. Almost 7 out of 10 Danes have immediate access to home charging and if home charging is allowed at shared/shared parking facilities, the number increases to 9 out of 10.

Table 3 provides the amount of charging points present in Denmark in public spaces in 2019.

Table 3 Charging points in Denmark in public spaces per charging level (Jakobsen, 2019).

	2019
Ultra-fast charging point long trips (150-350 kW)	148
Ultra-fast charging point everyday charging (150 kW)	0
Fast charging points for everyday charging (50 kW)	474
Normal charging point for everyday charging (22 kW)	3152
Total	3774

Charging infrastructure scenario 2030

The Danish municipalities will play a central role in relation to the establishment of both the publicly accessible infrastructure in the cities and along the surrounding road network. At the same time, the municipalities[2] must find solutions for the infrastructure that must be accessible to, for example, residents in apartments and other buildings where private charging facilities cannot be established.

Likewise, Danish companies, housing associations, the state, etc. come to play a role in relation to ensuring well-designed supply of rest areas and good use of areas, e.g. charging parks, common guidelines, the right to set up a charging station in the parking lot if you live in a condominium and buy electric car, voluntary schemes for companies where they (perhaps with subsidies) offer employees to charge in the company's parking lot.

It is the industry's best estimate that electric cars (middle class) in 2030 have an average battery capacity of 80 kWh, an average charging power at lightning charge of 100 kW and a maximum charging power of up to 250 kW.

Considering this background and a scenario with 1 million electric cars in 2030, 40 % electric car penetration compared to the current amount of vehicles, it is relevant to know how many public and semi-public chargers should be installed to satisfy the user charging needs.

Today home charging together with the workplace one represents 90% of the worldwide chargers (IEA, 2020). Furthermore, each home has the minimum infrastructure - compatible electrical socket and charger plus – to charge an electric vehicle. Thus, to understand how much energy should be provided by public chargers, the study in (Jakobsen, 2019) was developed into two analyses: long distance charging based on country needs and everyday charging based on municipality needs, mostly for the population that does not have access to private parking.

It is found that to satisfy 1 million electric vehicles in 2030 there is a need for a total of 25-30000 public charging points, which should be installed in the public space, on the state road network, at workplaces and in parking lots at multi-storey properties, shopping centres, etc. and should be shared by several electric cars. This corresponds on having between 33 and 40 electric cars per charging point. Of these, some of the charging points, as mentioned, will not be accessible to everyone because they are located by companies and housing associations' car parks and are used by residents and employees. If it succeeds in offering home charging for all the 20 % who park in a car park by multi-storey dwellings, etc., the need for public charging points will fall to approx. 10000, which corresponds to 100 electric cars per charging point.

[2] Ref. (Calearo & Marinelli, Strategic manual for EV charger installations, 2019) provides a tool to help municipalities, without deep knowledge on charging infrastructure, during the installation of EV chargers.

Table 4 reports the expected break-down between the various charging levels.

Table 4 Need for public charging points in Denmark (Jakobsen, 2019).

	2019	2025	2030
Ultra-fast charging point long trips (150-350 kW)	148	600-650	1800-2000
Ultra-fast charging point everyday charging (150 kW)	0	100-150	350-450
Fast charging points for everyday charging (50 kW)	474	450-550	1300-1600
Normal charging point for everyday charging (22 kW)	3152	7000-8000	20-25000
Total	3774	8150-9350	25000-30000

The vast majority of the need for public and semi-public charging infrastructure is located in cities and workplaces. Urban dwellers in particular are expected to have lower access to home charging, but in return they have fewer cars and drive less than the rest of the country. The challenge is diminished further, if charging is established at workplaces, location where cars spend most of the time expecting home. It is therefore recommended to utilize the potential of using charging in workplaces - but also other parking destinations such as shopping, rides, etc.. All electric car owners, regardless of residence type and address, will depend on the ultra-fast chargers for long trips (more than 200 km in a day). Based on the cost of establishing charging infrastructure, it is estimated that charging stations for everyday charging will cost a total of 1-2 billion DKK until 2030. Other 2-2½ billion DKK should be added for ultra-fast chargers along the motorway network. The total investment amount to 4 billion DKK, to be considered from today until 2030. Largest part of the investment takes place on market terms, and is set up and operated by private charging operators. But public support is needed to speed up investments in the beginning, as well as to support areas where the market cannot by itself lift the task.

For more information regarding charging infrastructure and future needs please refer to the report (Jakobsen, 2019).

In order to promote the spread of zero- and low- emission cars, and to succeed on the development of the charging infrastructure, the Danish Commission for the green conversion of passenger cars has also developed some recommendations (DELRAPPORT 2 - Veje til en veludbygget ladeinfrastruktur, February 2021).

First, recommendations regarding the state, municipality and tender roles are provided. For what concerns the state, the roll-out of charging infrastructure on the state's land has to be based on tenders, to ensure that competition and different providers have access to the same public road network to set up charging infrastructures. For what concerns municipalities, collaboration with charging operators to locate the charging infrastructure is necessary. Tenders can be carried out for the construction of charging infrastructure on locations, and municipalities can carry out tenders to establish publicly available infrastructure at municipalities' buildings, where necessary. Furthermore, during the planning municipalities have the opportunity to set requirements for the installation of charging infrastructure. To avoid improper use of parking and charging infrastructure, parking rules will have to be the same for all types of fuel, so electric cars can no longer park for free in cities. For what concerns tenders, these have to be open, with free competition and hold by the municipalities. The tenders include requirements and they are won by the operator who is willing to invest in those that provide the most attractive (economic) terms. It is important to store the charging data for investigation and improvement of the grid, in this regard the public sector tenders need to provide data to the public sector.

Different recommendations are then provided for underground investments, tender duration contracts, electricity market. Also, private customers, depending on the household connection may have different taxation, which are discussed in the documentation.

It is relevant to deeply analyze the results from the roll-out of the technology, both in technical and economic terms, to understand the technology and the consequences the specific taxes and schemes may have on the transportation electrification, as for example congestion taxes and/or road pricing schemes. Specific areas and municipalities (e.g. Copenhagen) will be taken as example for distinct investigations, and the share of information with other municipalities will be necessary to succeed on the electrification of the transportation sector.

For more information and details regarding the recommendations from the Commission please refer to (DELRAPPORT 2 - Veje til en veludbygget ladeinfrastruktur, February 2021)

Research programs

In order to support the increase of electric vehicles and predict the impact on those in the power grid, different projects have been undertaken in the last 10 years, both by public entities and private companies.

Different projects are focused on public and private users, targeting businesses, municipalities, city cars, car-share schemes, parking and electric buses (Sørensen, 2020).

The Technical University of Denmark has been carrying on different projects regarding electric vehicles and their integration on the power system: *Nikola* (Nikola project, 2016), *Parker* (Parker, 2019)*, ELECTRA* (ELECTRA, 2018)*, ACES* (Across Continents Electric Vehicle Services, 2020)*, CAR* (CAR - Creating Automotive Renewal, 2018), *ACDC* (ACDC project, 2020), FUSE (FUSE - Frederiksberg Urban Smart Electromobility, 2020). These projects intend to investigate technical and economic system benefits and impacts caused by large scale electric vehicles integration in Denmark, considering real usage patterns, grid data and field testing.

The Across Continents Electric Vehicle Services (ACES) project involved publicly and privately owned vehicles and vehicle-to-grid chargers, for proving that electric cars can be used for balancing the system. Indeed, today Denmark is one of the few countries where vehicle-to-grid is an ancillary service technically and economically approved and provided by approx. 50 vehicles distributed in the country.

The ongoing project Autonomously Controlled Distributed Chargers (ACDC) is inspired by the Danish government goal to achieve 0.5/1 million electric cars on the Danish roads, which may result on reduction of safety margins of the grid components. This leads to the importance of controlling the charging process, which could provide large flexibility to the electricity system and support the integration of more renewable sources. However, the control infrastructure behind the chargers needs to be sufficiently simple and cost-effective in order to make the process both technically and economically successful. Ideally, the process must become autonomous and this is what the ACDC project is investigating (ACDC project, 2020).

For what concerns the charging infrastructure, the purpose of the FUSE project is to develop a charging infrastructure for urban areas, which can satisfy the charging needs of the city's inhabitants, with a charging infrastructure that allows communication with the electricity grid and smart charging. During this project, the share of public and semi-public charging stations presented above will also be determined.

CAR (Bornholm) charger concept

The initial idea of the CAR project in Bornholm in 2018 was to install fast charging stations. Subsequently, a 50 kW fast charging stand was installed in Rønne, and it is expected to cover the need for inbound and outbound traffic from Rønne. Furthermore, the dialogue with charging station suppliers and electric vehicle user groups, made it clear that Bornholm's infrastructure does not necessarily require lightning chargers (motorway chargers). On the other hand, the real need is where many private individuals, businesses and tourist do not have the opportunity for charging with a private box. This was also accepted by the tourism industry and the taxi organization.

To provide charging options for electric cars in the entire Bornholm island, nine locations were selected. Since Rønne, largest and most central city, was already covered with 22 kW and 50 kW charging stations, the locations were chosen outside Rønne and they are provided in Figure 4

Figure 4. Charging points at the end of year 2020.

9 22 kW AC chargers with 2 Type2 sockets and 2 outlets 60/30 kW DC charging stations with 2 CCS Combo sockets were installed at the end. The 22 kW can be used by both private and business for charging on site. The 60/30 kW charger covers the need for faster charging, especially on commercial vehicles (taxis).

In order to understand and carry out the entire installation of the chargers, Bornholm municipality collaborated with lawyers and charging station operators. The operator was and still is responsible for setting up and operating the charging stations, whereas lawyers helped to develop the tender material, which is available to help other municipalities on performing the same process.

Everyone has access to the charging stations, through subscription schemes or with recognized purchasing methods. The infrastructure consists of public parking spaces with concrete foundations for charging stations. From the concrete foundation, traction pipes for electrical cable and internet cables were mounted, and those end in a transformer/engineering cabinet.

The municipality collaborated also with the electricity grid owner and supplier, which are El-Net Øst and Bornholms Energi & Forsyning respectively. Indeed the infrastructure of a charger is financially "burdened" by two factors: the connection fee to a transformer, which is settled on the basis of the required amperage; the placement of charging stations in relation to the transformer, the shorter the distance, the cheaper the excavation and re-establishment. The dialogue with the electricity grid supplier helped to optimize decisions regarding the charger location and thus to lower the costs.

Figure 5. Infrastructure and electric grounding works.

The possible load of the charger was also investigated, to prepare the electrical grid to be able to handle peak loads at most common charging time. The location of the chargers is also chosen on where the electric cars come almost all year round and where they are evenly distributed over the day.

Different charging possibilities were also considered during the decision making. It was found that electric cars commonly charge with AC Type 2 connectors, but the cars' current charging technology is not the same, some charge with single-phase AC, whereas most models can also charge with three phases, meaning potentially three times charging speed.

The charging stations will be operated by the organization, FDM/Spirii, which won the tender as operator. The CAR project public funds helped with the initial investment for the expensive underground work. This is a good solution that FDM/Spirii would like to see in several places in Denmark, as it may increase competition between operators and give consumers lower prices for charging (TV2, 2020).

Figure 6. FDM operated chargers.

For what concerns the costs, in Nexø three charging stations with double outlets were installed, each stand with 22 kW and possibility for load sharing between the two stands (provided by Spirii). Each charging station costs approx. 20 000 DKK, including post. 2 x 8 000 DKK for each outlet and 4 000 DKK for the post. In addition, purchase of connection fee, electrician work and earthworks should be considered.

ACDC charger concept

The government can provide incentives to purchase electric cars and provide social benefits, but it has also to deal with the charging infrastructure development. To succeed with this, it is possible to let the market and the industry find a solution, or to help with government incentives to speed up the infrastructure deployment (Navarro, 2020). Most commonly adopted chargers are the “dumb” chargers, which function as a unidirectional unit, delivering power from the grid to the electric vehicle, similarly to a phone charger but on a larger size. The projections for a mass adoption of electric cars into our society requires a smart approach of the charging methodology, to avoid excessive loading of grid components or voltage unbalances (Calearo, Thingvad, Suzuki, & Marinelli, 2019). This highlights the importance of charging services and control logics of the chargers. Figure 7 shows a technical categorization of electric vehicle chargers, aiming at regulating and setting set-points for a better grid integration (Landi, 2020).

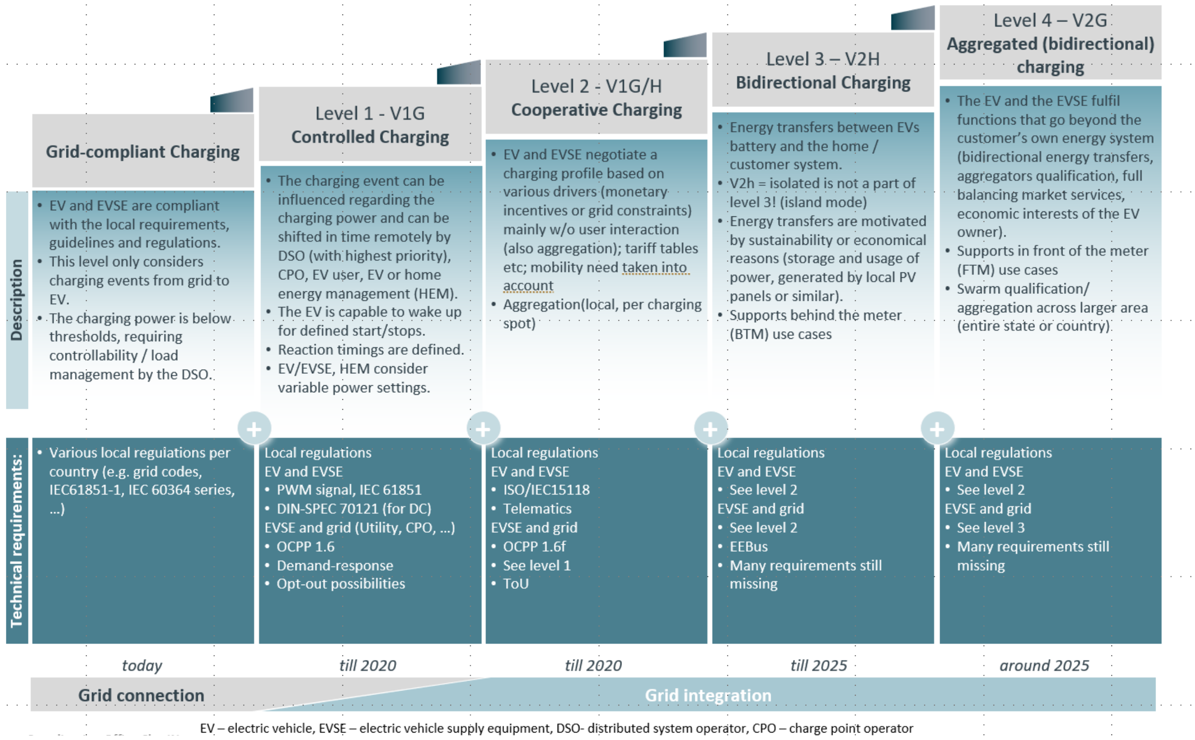

Figure 7. Chargers grid integration levels- definitions after focus group survey (Landi, 2020).

In order to grid integrate the Electric cars in the power system, management and control charging operation (Level 1 and 2 V1G) of smart chargers is considered. With the possibility to control the chargers arises another dilemma: should we maintain a control based on a distributed or centralized (cloud) manner? Each method has pros and cons that are elaborated in the literature (Richardson, 2012), (Ziras, 2019), (Lee, 2017). For an unfamiliar eye, the difference between the approaches can be compared with a philharmonic orchestra. In the distributed approach each member represents a charger acting autonomously to a signal delivered from the conductor (virtual aggregator). In the centralized approach the conductor is in a different room than the orchestra, and is giving signals via cloud services.

The common goal of the different approaches is to achieve the control of charging operation in a reliable and cost-effective way. As a rule of thumb, the reliability of a process deteriorates with the increase of the components in the system.

The ACDC project investigates the smart charging (V1G) operation, with the ambition to develop a novel autonomous smart charge controller together with a virtual aggregator operating on a distributed manner. The keywords are simplicity, reliability, cost-effective and user/grid friendly charging operation. The technology relies on a virtual aggregator that broadcasts a signal (representing a dynamic power threshold) to the set of autonomous chargers.

The signal is followed by each charger (modulating their rate of charge) to meet the requirements set by the virtual aggregator. On a situation of multiple chargers, every charger collaborates for keeping the grid on a "good status". Figure 8 describes the smart charging architecture. The most important thing is the need for a deep interconnection between different actors and layers (market and physical electrical grid layer). Furthermore, it explains which actor is participating on each operation and their roles. The smart electric vehicle charger controls the charge rate based on a decision made taking under consideration data from the grid, the electric vehicle and the owner. In the same time the smart charger monitors the energy consumption, metered consumption and can disaggregate a charger from the pool of chargers.

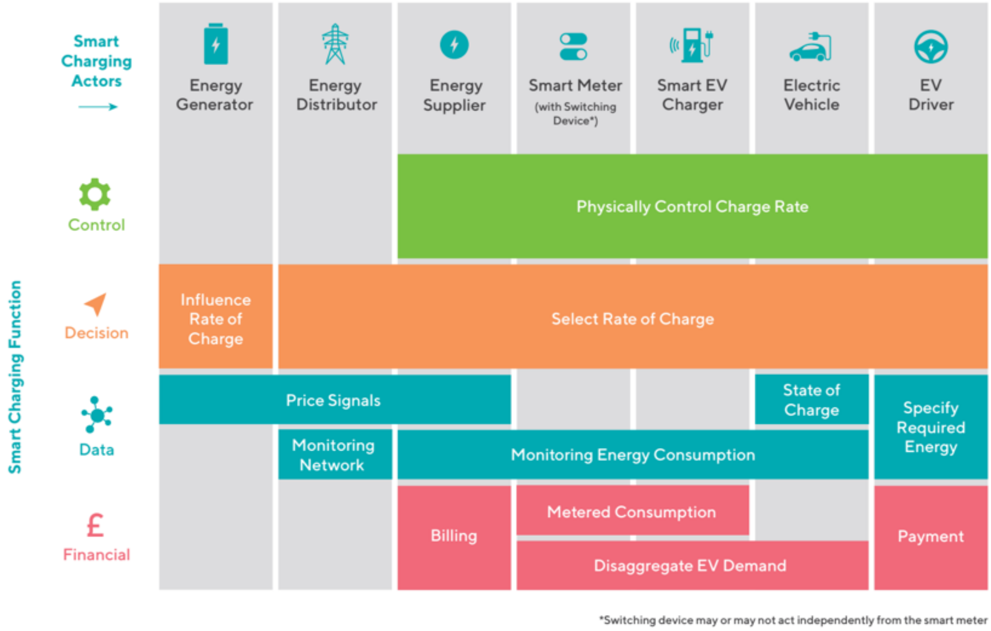

Figure 8. Smart charging architecture (Landi, 2020).

When dealing with V1G chargers, the following points are observed to be relevant (Sevdari, 2020):

- The most used charging power ranges between 3.7 and 7.4 kW for single-phase and at 11 or 22 kW for three phase connection.
- The majority of the chargers are AC type, whereas DC type is used when larger charging power (above 22 kW) is necessary.
- The predominant communication standard is OCPP 1.6 and early signs of OCPP 2.0 are encountered.
- In Denmark there is a limited range of products, which go from 9000 to 11000 DKK (including VAT).

Two examples of V1G chargers that can be deployed on private, semi-public and public locations are presented in Table 5:

Table 5. Examples of V1G (smart) chargers.

Charger	***Power [kW]***	***Current [A]***	***Delayed charging***	***Load sharing***	***Dynamic charging***	***Power limitation***	***Price [$]***
Zappi smart	7.4	32	Yes	Yes	Yes	Yes	1100-1800
Zaptec	7.4	32	Yes	Yes	No	Yes	1450

An example of a smart charging solution was developed by *Myenergi*, which relies on combining different units to provide a smart charging operation focused on three strategies:

1. *Eco*: this mode is a mixture of both green energy and energy imported from the grid. It minimizes the use of grid power and can use 100% green energy. The charging power is continuously adjusted in

response to changes in generation or power being used elsewhere in the house. If the surplus generation drops below 1.4 kW (minimum charging power accepted by the IEC standard (International Electrotechnical Commission)), a share of the power will be drawn from the grid.

2. *Eco +*: the charging power is continuously adjusted in response to changes in generation or power consumption elsewhere in the house. The EV charger will charge only if there is a surplus of power available, otherwise will enter in the pause mode.
3. *Fast*: the vehicle is charged at maximum power. This charging power can come from a renewable energy source or simply from the grid.

Figure 9 introduces the interface of the *myenergi* solution. The smart charging solution, with virtual aggregator and relying on cloud services, is an example of what is called home energy management system (HEMS).

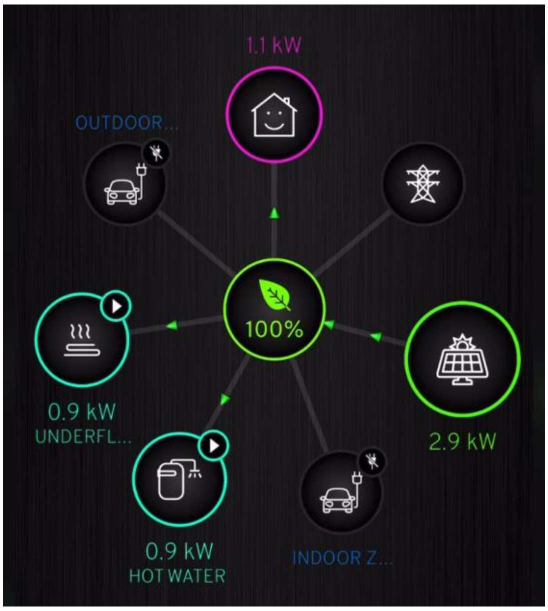

Figure 9. Myenergi app showing the power flow for a prosumer with installed heat pumps, underfloor heating, battery storage and EV (myenergi, EV Charger zappi, 2021).

In the ACDC project, a similar approach is considered, where a virtual aggregator, a charger, and measurement components are located on the same unit, but differently from previous technology they do not rely on cloud services. The autonomous smart charger control receives inputs locally, from the grid and the electric vehicle owner. Then it couples charging operation with demand response signals, like price/CO2 signals, self-efficiency, and flexibility markets, to provide grid services and defer costly grid upgrades. Ref. (Salge, 2020) and (Everoze Partners Limited, 2020) show that smart charging is the cheapest solution to help the electric vehicle increase grid integration, and electric vehicle demand response is the lowest CO2 emitting technology. The ACDC prototype can be directly compared to the *Zaptec* charger, which is considered in the FUSE project and is further discussed in the next section.

Finally, a total cost comparison between smart chargers and dumb chargers is here provided. First, Table 6 provides the costs of deployment for a smart charging unit, second Figure 10 provides examples of total costs for dumb charging. In both cases the fuse upgrade from 25 Amps to 40 Amps counts for a large share of the investment. Furthermore, type 2 cable expands from 6-8 meters.

Table 6. Cost of deployment for a smart charging unit (Sevdari, 2020) (LADELØSNING, 2021) (JET Charge one. Charger prices., 2021).

Type	Charger price [DKK]	Installation + type 2 cable [DKK]	*Fuse upgrade for regular houses [DKK]	Total cost [DKK]
Smart charger	9 000 – 11 000	5 200	13 000	14 200 – 29 200

*According to Danish legislation a regular house is supplied by a standard 25 Amps tariff fuse. When the charger current exceeds 25 Amps, a one-time fee of ~1000 DKK per Amp is applied (El-net Øst A/S, 2021) to upgrade the tariff fuse.

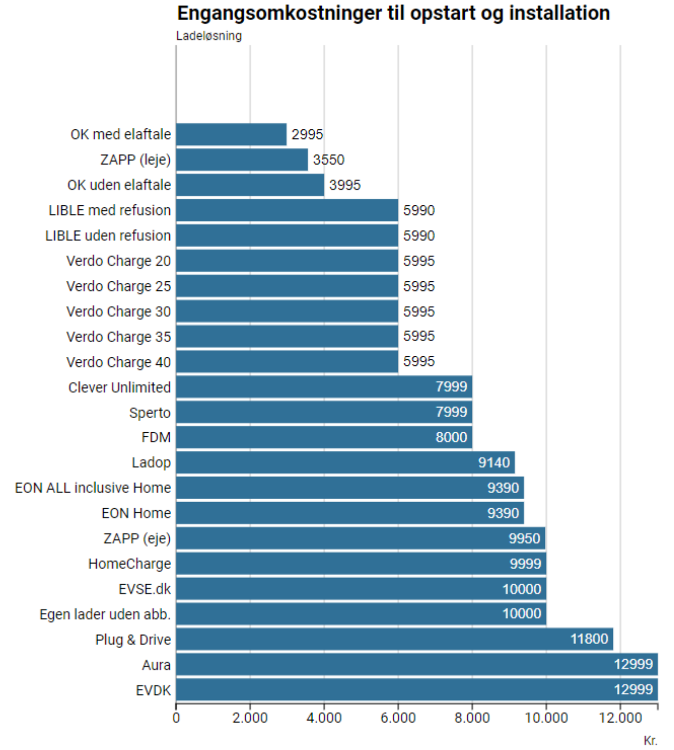

Figure 10. One-time total fee [DKK] for a dumb charger (exclude Aura, Plug&Drive and EVDK) in Denmark (LADELØSNING, 2021).*

To summarize, Table 7 compares the costs for the two kinds of charger. The current situation offers a wide range of dumb chargers and a limited range for smart charging solutions, which costs are still high, when the only initial investment is considered.

Table 7. Total cost comparison between smart and dumb chargers with charging power from 3.7 to 22 kW.

Charger type	Charger price + installation cost + type 2 cable [DKK]	Fuse upgrade above 25 A [DKK]	Total cost [DKK]
Smart	14 200 – 16 200	13 000	14 200 – 29 200
Dumb	3 000 – 10 000	13 000	3000 – 23 000

FUSE charger concept

The FUSE research project aims at designing a masterplan for semi-public and public charging infrastructure, where the transport model is compared with the electrical grid. The transport model simulates driving patterns and fluxes, to determine the location of charging demand. This result is then used to model and simulate the grid in different scenarios and considering various constraints.

The FUSE investigation will look at dumb charging and smart charging. Zaptec charger is initially considered as the smart charger (Figure 11), but it will then be compared with the ACDC charger, thanks to the strict collaboration between the two projects. Zaptec measures the power consumption for the entire building and automatically allocates more power to EV charging, when the building is using less. The certified Zapter power meter is installed in the main board. Through it, ZAPTEC Portal continuously receives measurement data from the building and adapts the charge current to the electric vehicle charging stations (*Zaptec*, 2021).

Figure 11. Zaptec Pro smart charger (Zaptec, 2021)

Main features of the Zaptec Pro charger are:

- *Installation circuit*: Max. 63 A serial fuse on installation circuit for charging stations.
- *Load balancing*: the available power will be distributed between the devices and phases.
- *Phase balancing*: the charging station selects any single-phase or three-phase in a system with other ZAPTEC Pro charging stations, depending on the available power. However, due to IEC 61851 standard limitations, control of each phase is not possible.
- *Intelligent and focusing on the future*: the charging station supports ISO 15118, which makes it ready for Plug & Charge, state-of-charge options and other features that will investigated to improve the user experience.

Figure 12 shows how the load sharing works throughout an entire day, depending on the power consumption of the building.

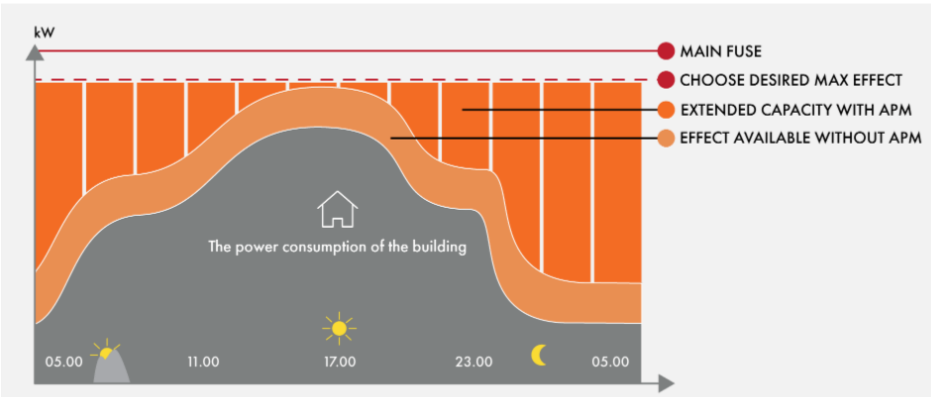

Figure 12. Load sharing visualization of Zaptec charger.

Finally, to highlight the importance of the load management, an investigation performed by ABB Ability on load management for fast chargers (50 kW) showed that the peak consumption can be largely decreased, saving up to 55 % of the annual energy cost, see Figure 13 (ABB, 2020).

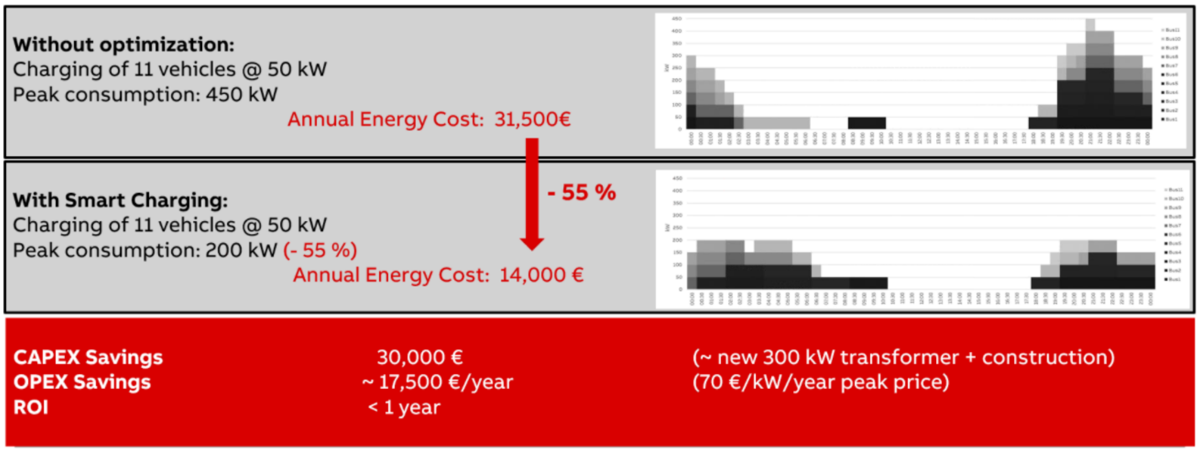

Figure 13. ABB Terra fast chargers load management investigation via cloud services (ABB, 2020).

This report provided a short overview of the current status of e-mobility in Denmark, including main activities necessary to succeed the Danish National goals for 2030.

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