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Technology and implementation of electric vehicles and plug-in hybrid electric vehicles

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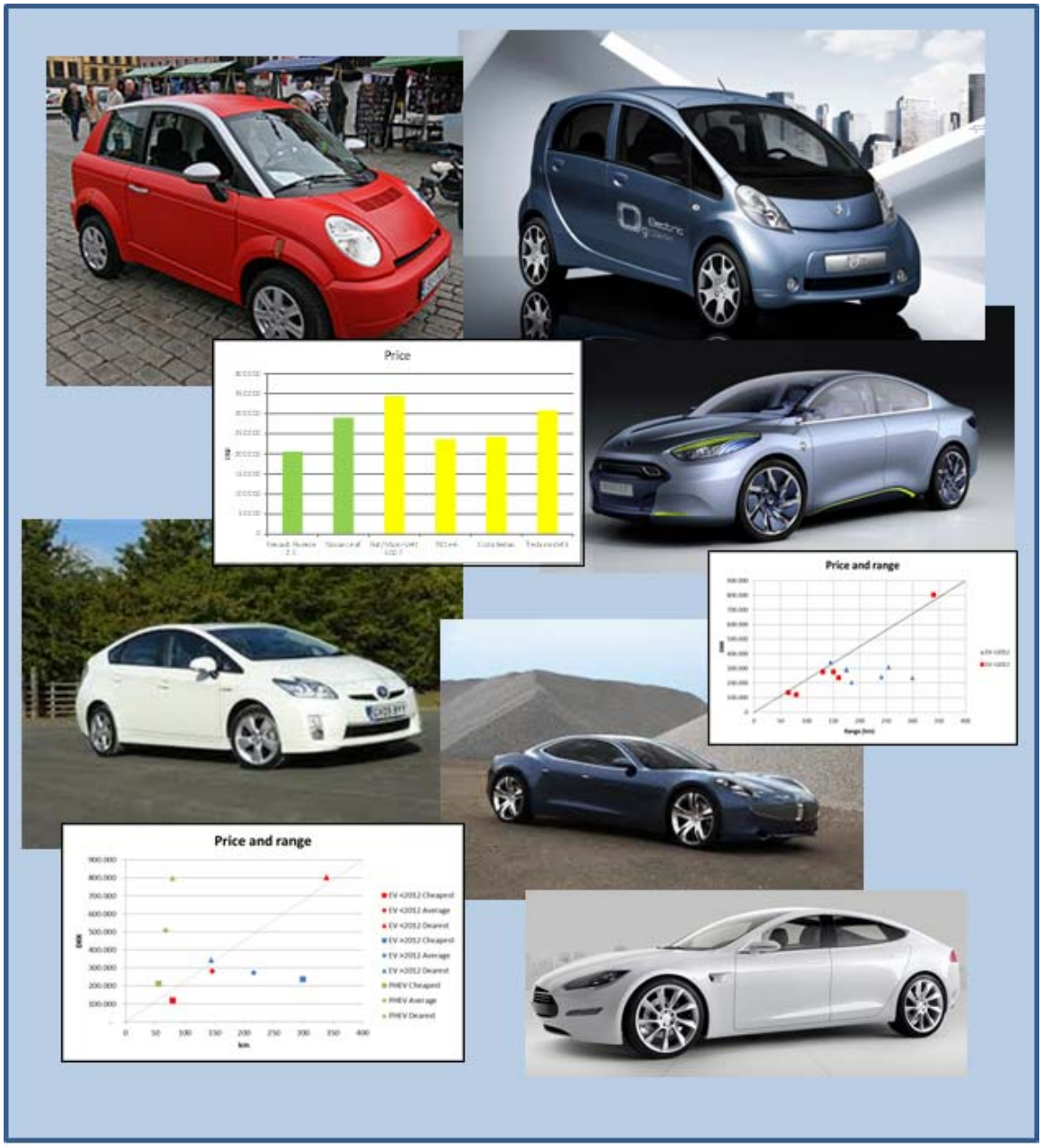

Abstract

In this report state of the art electric vehicle and plug-in hybrid electric vehicle technology is presented to clarify the current and near term development. The current status of diffusion for electric vehicles in Denmark, Sweden and internationally is presented as well as the expected developments. Different business models and policies are also outlined along with a description of the on-going research and demonstration projects.

An analysis of the current and near term electric and plug-in hybrid electric vehicles indicate that the cost for family cars will not change much, while the ranges of electric vehicles will increase and may even double for some family cars compared to the existing models. The average driving range in this report increases from around 150 km for existing electric vehicles to more than 200 km for near term electric vehicles (expected new models in 2012-2013). Also the power capabilities may increase meaning that e.g. acceleration capabilities will improve as well as the top speed. This development occurs due to new battery technology that may experience substantial improvements in the coming years. When looking at plug-in hybrid electric vehicles the electric range are significantly lower than for pure electric vehicles, but have in turn a higher top speed and power capabilities.

Contents

Nomenclature

Abbreviation	Description
EV	Electric vehicle
PHEV	Plug-in hybrid electric vehicle
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
EDV	Electric drive vehicle
EV V	Electric van
EV T	Electric truck
GHG	Greenhouse gasses

In this report the following definitions apply:

- "Model" refers to the specific car model (e.g. Mitsubishi, Tesla, etc.)
- "Vehicle type" refers to the category of car (family car, sports car, urban car)
- "Family car" is a car with at least four seats and has the ability to drive according to different driving patterns due to power performance, range etc. The family cars are often more expensive than urban cars, but cheaper than sports cars.
- "Urban car" is a car typically small in size and with a limited driving range. The urban cars are often cheap in investment cost.
- "Sports car" is a car with focus on performance (e.g. power) and high top speed. Sports cars have often higher investments costs than other vehicle types.

1. Introduction

The purpose of this study is to determine the current (before 2012) and near term (2012 on forward) electric vehicle technology. Analyses of differences between models as well between technologies are carried out to clarify the expected near term developments.

The report is structured in the following way:

A definition of the different types of vehicles and their technology is determined as well as descriptions of the advantages and challenges for electric vehicles and plug-in hybrid electric vehicles.

The status of electric-drive vehicles in the Danish, Swedish and the International car fleet is presented. The future development in technology is described along with the potential growth rates for the different vehicle types.

Business models connected to EVs and PHEVs are presented as well as the existing taxation and subsidy framework for Denmark and Sweden to give a brief overview of the public regulation.

Furthermore a description of the policies developed to promote the diffusion of electric vehicles is outlined on a national and international scale and the ongoing research, development and demonstration projects are explained.

An analysis of the current (<2012) and near term (>2012) technology is carried out to cast light on what technology is available on the market and what will be in the near term and which improvements could be expected. The analysis focuses on comparisons between the individual models, the current and near term technology for EVs and the differences between technology (EV and PHEV).

2. Electric vehicle technology

This chapter includes a description of different types of vehicles including electric vehicles, plug-in Hybrid electric vehicles and hybrid electric vehicle. These three types of technologies can collectively be described as electric-drive vehicles (EDVs). Hybrid vehicles can be divided into different subcategories but have not been in this report. The main focus will be on EVs and PHEVs.

2.1. Electric vehicles

EVs (Electric vehicles) get all of their motive and auxiliary power from the power in the batteries, which are recharged from grid electricity and brake energy recuperation. This technology may provide zero emissions of GHGs and air pollutants. The very low energy and power densities in the batteries is however today an issue that holds back further spreading of this technology. An average driving range for an EV is expected to be around 150 km after completely recharging (International Energy Agency 2011). The review in this report confirms that this is the case currently in 2011. Already in the new vehicles in 2012 the range is expected to increase as well as the size of available vehicles.

An example of a typical 50 kW electric drive system is shown below.

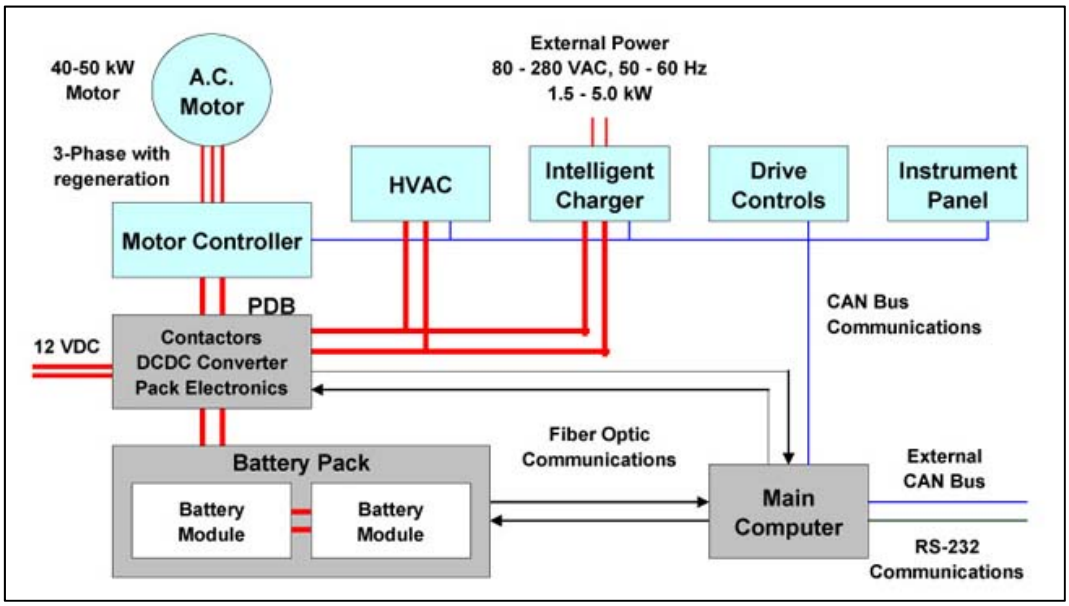

Figure 1: A typical 50 kW electric drive system (American Electric Vehicles 2011)

2.2. Plug-in hybrid electric vehicles and Hybrid electric vehicles

PHEVs (Plug-in hybrid electric vehicles) may in some cases retain the entire ICE system but have been added more battery storage capacity than traditional ICEs and may thereby travel on electricity provided by the grid, instead of solely on the internal recharging system in the vehicle. After a complete recharge the electricity range is expected to be around 20 to 80 km. The batteries in PHEVs are oriented for power instead of for energy unlike in pure EVs which makes the batteries in PHEVs more expensive per kWh capacity. IEA estimates that the battery costs for PHEVs are 1.3 to 1.5 times higher per kWh than those for EVs (International Energy Agency 2011). A PHEV can also be constructed in a way that the ICE produces electricity for the electric engine instead of retaining the ICE drivetrain. In this study this is included in the PHEV category, but may other places be referred to as electric vehicle extended range.

A simplified representation of a PHEV can be seen in Figure 2.

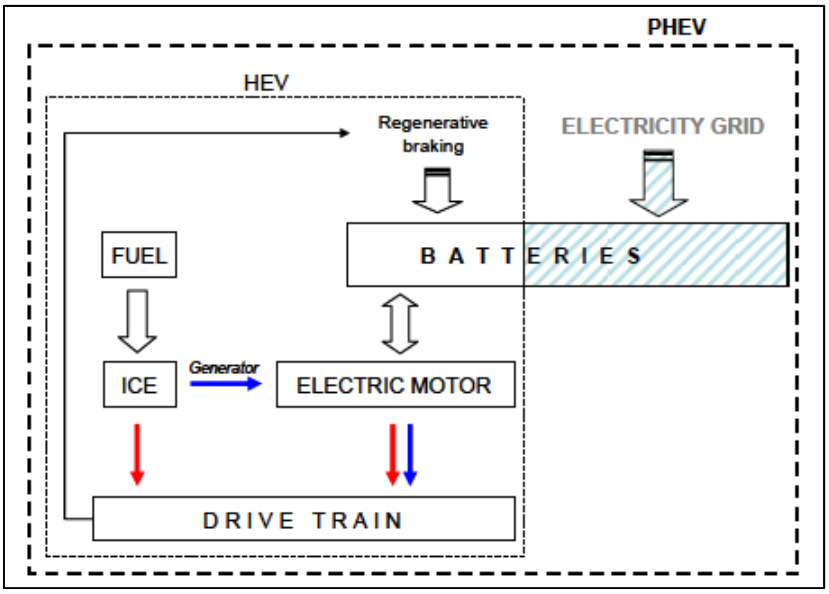

Figure 2: A simplified representation of the components a PHEV (Nemry et al. 2009)

HEVs (Hybrid electric vehicles) use both an engine and motor that is able to store electricity generated by the engine or by brake energy recuperation. In some cases the engine may be turned off and the electricity will be the only drive fuel, but only at low speeds (International Energy Agency 2011). This type of vehicle exists in different forms according to the role of the ICE and has thereby different features, but will not be explained further here.

2.3. Battery technology

Batteries are the key to a quick development and spreading of EVs and PHEVs and much research and development is therefore focusing on this component in the electric cars.

The key parameters for batteries include:

- Energy storage capacity (kWh) that determines the distance electric cars can drive. Typical storage capacities currently are around 1-2 kWh for HEVs, 6-30 kWh for PHEVs and 30-50 kWh for EVs with existing technology.
- Peak battery power (kW) depends on the range, the total weight of the vehicle and the mode of driving.
- Life time (years) can be divided between calendar life and cycle life, determining the years or the micro and full discharge cycles. 10-15 years is generally assumed to be a sufficient calendar life while the target for the number of deep discharges should be around 3-5,000 (Nemry et al. 2009). There are different battery duty cycles. PHEV batteries experience more deep discharge cycles in addition to frequent shallow cycles, while EV batteries are subject to deep discharges without as many shallow cycles. These are both very different from the demands used in conventional ICE-HEVs and leads to different degradation rates.
- Cost of the battery pack (USD/kWh) which increases with extended electric range. Batteries are the main reason behind the high investment costs for EVs and must be developed further to continue the diffusion of EDVs.

- Safety and thermal requirements for batteries needs to follow certain international standards that also apply for other car technologies.
- Recharge time (h) is an important measure and also affects the life time of the battery. Charging implies transmission and distribution, which in general leads to a loss around 8% (Nemry et al. 2009). The supply capacity (A), the effect (W) and the number of phases defines the time needed for charging. The charge times given below are for a 10 kWh battery and the voltage is the same as in EU.
    - Level 1 (220 VAC, 1 phase, 10-13 A, 4-8 hours): It is possible to do a slow charging, e.g. overnight. The values used for charge time in this study are the standard level 1 type. This type of charging facility may be private.
    - Level 2 (240 VAC, 3 phases, 16-64 A, ½-3 hours: It is however also possible to do a quick charge for some models, which will reduce the charge time significantly and may be as low as 30 minutes for some models. This type of charging facility may be private or collective.
    - Level 3 (480 VAC, 200-400 A, <10 min.): New technology may allow constant charging, which will reduce the charge time to under 10 minutes. The technology is still under development and the charging facility is regarded as collective but may have higher costs than other charge levels.
    - Battery swap may also be an option that could solve the solution with long charge times. The battery swap time will be around 5 minutes at battery swap stations and this technology is being developed by actors like Better Place and Renault.

(Nemry et al. 2009, Danish Transport Authority 2010)

Different types of battery technologies can be used in EVs and PHEVs. Table 1 gives an overview of the different types and their features according to (Danish Transport Authority 2010). Nickel Metal Hydride are the current typical batteries for HEVs (e.g. Toyota) while different types of Lithium-ion technologies are expected to be the preferred type for EVs and PHEVs in the short to medium term (Nemry et al. 2009, Divya and Østergaard 2009).

Table 1: Features current battery technologies (Danish Transport Authority 2010)

Battery technology	Power density	Energy density	Life time	Price/kWh
	W/kg	Wh/kg	Discharges	DKK
Lead acid	<350	25-30	300-500	1,000
Nickel Metal Hydride	250-1,300	40-90	500-1,000	2,500
Salt-Nickel	170	120	>1,500	2,500
Lithium-ion-cobalt	500-2,000	150-175	>1,000	3,500
Lithium-ion-phosphate	500-3,000	100-150	>2,000	2,000

Power density is central for cars with hybrid technology as batteries with high power can deliver lot of power for a short while. The energy density indicates if a car has a long range and is central for EVs and PHEVs. When combining the power and energy density the current technology with the most potential is the lithium-ion technology, as can be seen in Figure 3.

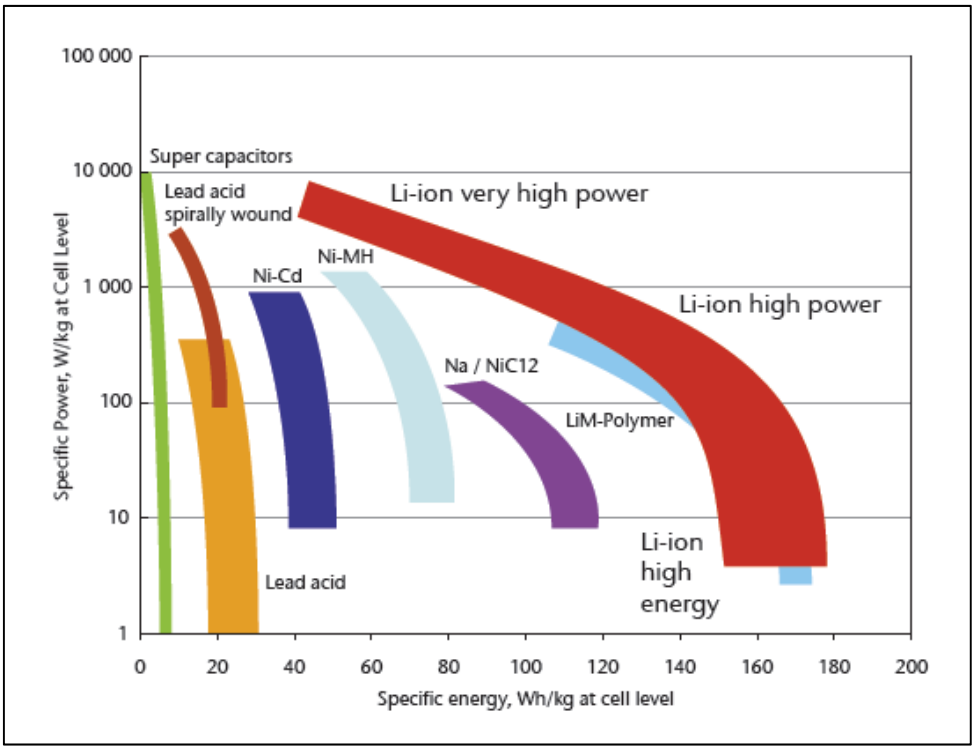

Figure 3: Comparison of power and energy density between different battery technologies (International Energy Agency 2011)

Concepts like charging the car when driving via the road markings and thereby using inductive charging have also emerged. However, this technology will result in large energy losses and may only be applied in urban areas and thus the technology needs further development to become a real alternative to other forms of charging (Connolly et al. 2011). For more information about the expected development for batteries for EVs see 6.4.

2.4. Electric drive vehicle control systems and characteristics

Several electric car manufacturers (BMW, Daimler, Toyota etc.) are developing advanced IT-systems for electric cars to assist the driver. The systems determines battery status, traffic, distances, and help to find battery charging stations by using GPS. Other companies (e.g. GARO) are developing options that allow drivers to pay for charging via their cell phones and receive information about when their charge is complete. Likewise are different applications for smartphones being developed and released development to increase the service in EVs and ease the payment (ElFORSK et al. 2010).

One of those released with different charging features is the Nissan Leaf. In this vehicle it is possible to follow energy consumption and regeneration as you drive, turn different applications such as air conditioning on/off. A clear picture of the range and the charging stations available is provided. Also it is possible to set a timer for the air-conditioning to turn on when the vehicle is connected to the grid and to set the timer for the full charge time each day of the week. These and other features can also be controlled with a smart phone app. See Figure 4.

Figure 4, Features from the Nissan Leaf controls, Copenhagen September 2011

3. Advantages and challenges for electric vehicles and plug-in hybrid electric vehicles

In this chapter the different impacts from changing to electric vehicle driving is outlined in form of advantages and challenges compared to driving in conventional ICE cars.

3.1. Reduced CO_2-emission

EVs can in theory drive without emitting any CO_2, but this requires that electricity production is from renewable energy sources, which not always is the case. In Table 2 the emissions from ICEs, EVs and PHEVs are compared in a Danish context by the Danish Transport Authority. In this report EVs have the lowest emission, even if emissions from electricity production is included, followed by PHEVs. In the future these emissions are reduced even further as more wind power is installed in the energy system, most likely 50% wind power in 2020.

Table 2: Average CO2-emissions from different technologies in Denmark (Danish Transport Authority 2010)

Type of car and size	From car	From electricity production	Total
	g/CO_2	g/CO_2	g/CO_2
Petrol, medium	150	0	150
Diesel, medium	140	0	140
Petrol, small	119	0	119
Diesel, small	109	0	109
EV, small	0	61	61
PHEV	40	59	99

The Boston Consulting Group estimates that the CO_2 emission by using EVs in Europe is 55-60% lower than using a conventional ICE car. In the next decade this number will even improve as the electricity is expected to be greener (Boston Consulting Group 2009). The think tank CONCITO estimates that the CO_2-emission from EVs in Denmark will be around 55 g/km (calculated for a Renault Megane) (CONCITO 2009).

3.2. Reduced air pollution and noise

EVs do not make any noise when driving which could improve the local conditions and reduce the discomfort from transport in areas with much traffic. Actually the silent noise may cause some safety issues as pedestrians and cyclists are not able to hear the cars approaching and hence their safety may be worsened. This is solved by some car manufacturers (e.g. Toyota) by adding automatic sound generators at low speeds (Fernandez 2010). Local pollutants in traffic are eliminated when the driving is conducted with the EC drivetrain.

3.3. Increased energy efficiency

The energy performance between different car technologies is outlined in Figure 5 but may vary according to driving patterns, electricity production, etc. However the overall picture is that PHEVs and EVs are more efficient technologies and that the energy consumption for conventional ICE technology is around 2-5 times higher than all sorts of PHEV and EV technologies. The efficiencies presented in the figure below are from a data collection from 2006 from the European Commission with actual driving values. The numbers are not adjusted for average driving patterns, charge patterns, etc.

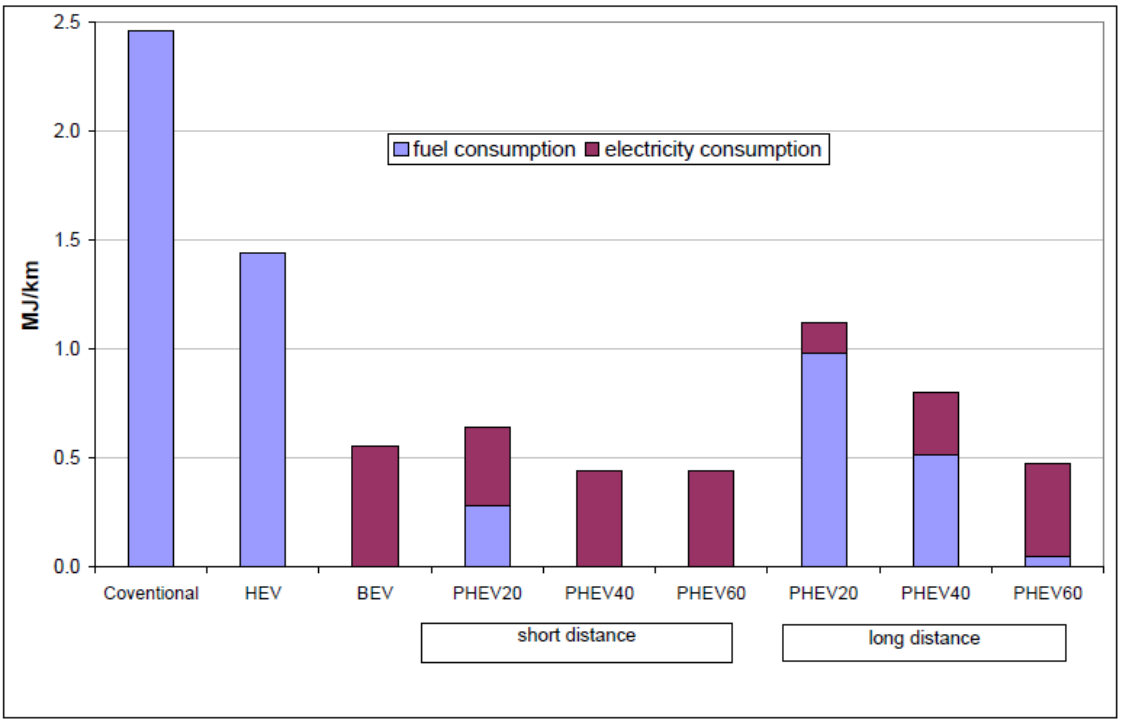

Figure 5: Energy performance between different car technologies. The figure is based on data from the European monitoring database from 2006 and is not adjusted for different drive patterns, charging patterns and driving cycles in the population. 20, 40 and 60 indicates the all-electric range in miles. Short distance = 40 km and long distance = 100 km. BEV = EV (Nemry et al. 2009)

3.4. Reduced operation cost

The operation cost for EVs and PHEVs compared to ICE vehicles is expected to be reduced, mainly because of lower fuel costs. From a socio-economic perspective analyses indicate that the costs are similar to regular vehicles but that the operation costs are lower. In Figure 6 and Figure 7 an analyses of the socio-economic costs of EVs illustrates that the operation costs are lower and that the overall costs are the simular when taking into account the lifetime of the technologies.

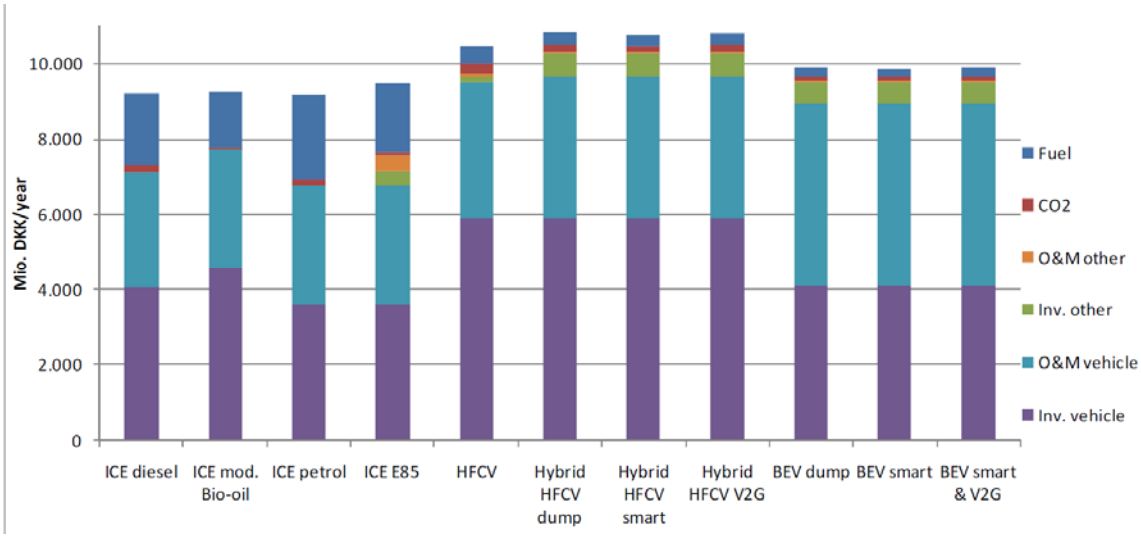

Figure 6: Socio-economic costs in a 2012 energy system with fuel prices equivalent to 87$/barrel (Mathiesen 2009). Includes ICE, fuel cell vehicles EV and hybrids.

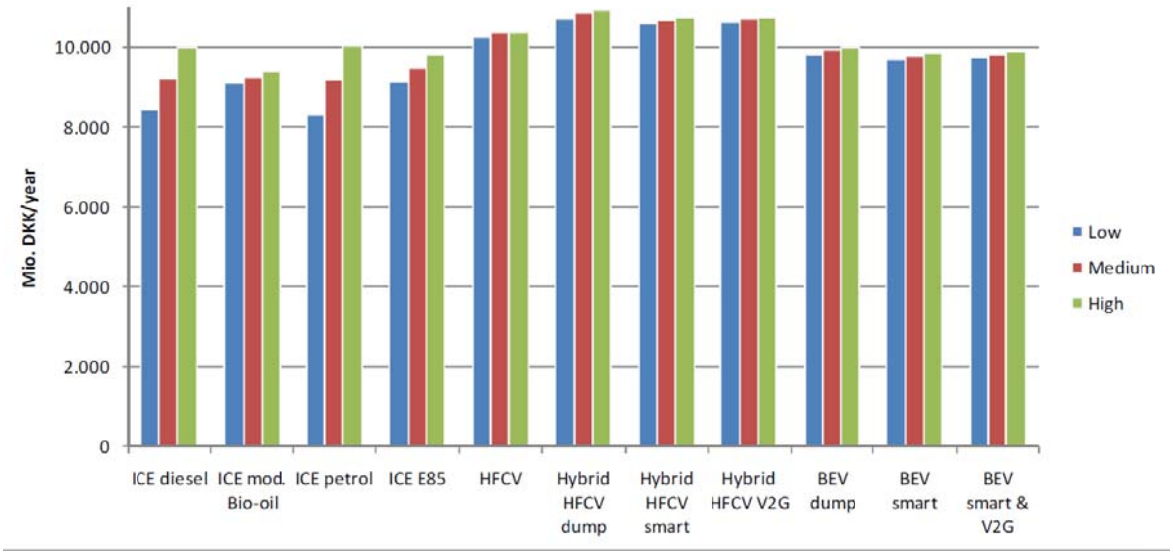

Figure 7: Socio-economic costs in a 2012 energy system with fuel prices equivalent to 47, 87 and 129$/barrel (Mathiesen 2009).

The cost reductions are however different throughout different regions of the world due to gasoline prices and electricity prices as well as taxes and levies. **Fejl! Henvisningskilde ikke fundet.** can give an indication of where the incentives may be highest because of the gasoline prices and taxes and the following potential operation savings. It is illustrated that the gas prices including taxes are highest in Sweden and Denmark when comparing to the EU and G7 (Department of Energy and Climate Change 2011).

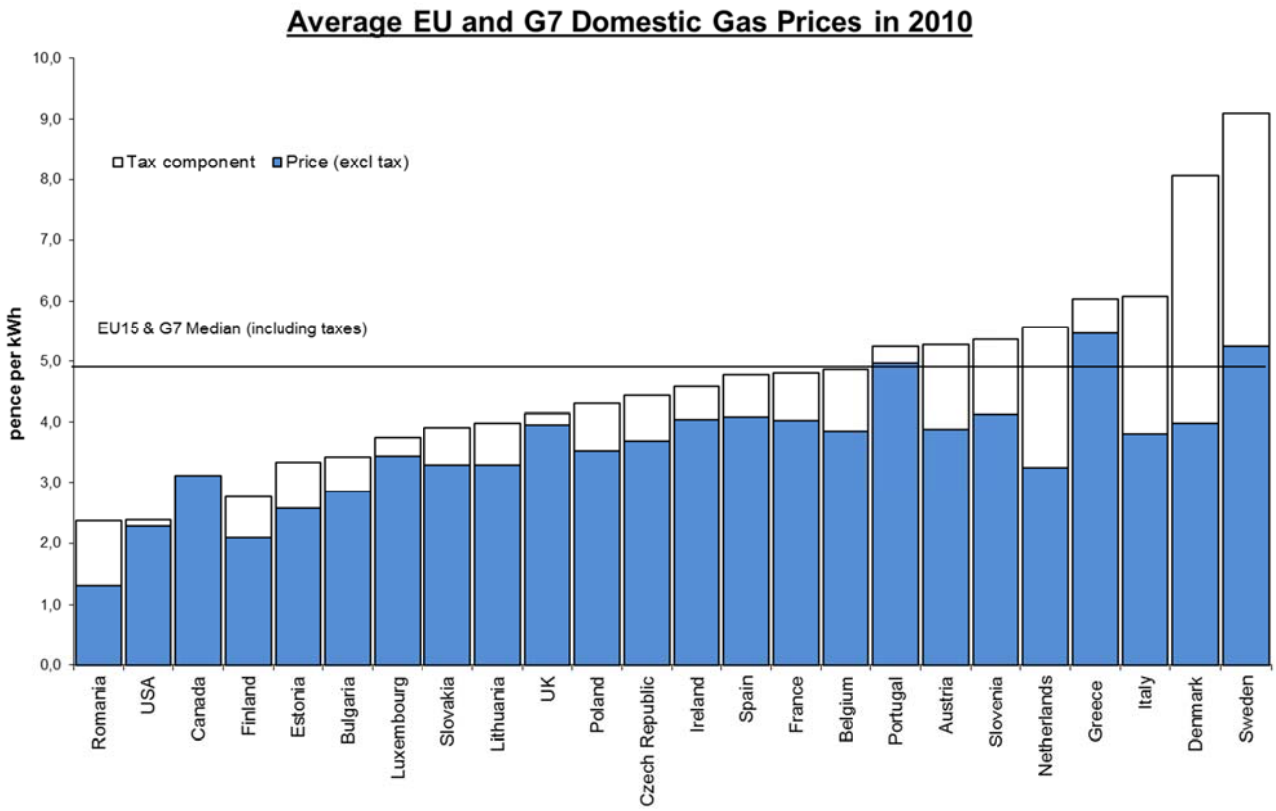

Figure 8: Gas prices for EU and G7 (Department of Energy and Climate Change 2011)

Other factors that may influence the overall costs per km for different types of vehicles include maintenance, fuel, and depreciation values for the car, drivetrain and battery.

3.5. Reduced maintenance costs

The operation cost for EVs is expected to be reduced compared to ICEs and estimates performed by the Danish Technological Institute indicate that the cost for maintenance for an EV will be 50% lower than for an ICE car from 2015 or when more mass-produced models are introduced on the market (Danish Transport Authority 2010). All-electric vehicles require less maintenance because the battery, motor and electronics do not require regular maintenance and break wear is significantly reduced because of regenerative breaking. Furthermore only few moving parts exist in EVs compared to gasoline engines. (U.S. Department of energy 2011)

3.6. Use of excess wind energy production

In theory EVs and PHEVs are supposed to recharge in periods of excess electricity production from wind turbines, which would lead to a more efficient usage of the energy outside peak load hours and reduce the use of fossil fuels. The EVs may lead to greater flexibility in the energy system if recharging is carried out at appropriate periods by intelligent charging that takes capacity in the grid, prices, source of electricity production etc. into account (Danish Energy Agency 2010). The connection between power supply and demand is however still a matter of research, but may potentially benefit the overall energy system through vehicle to grid models and vice versa. The concepts V2G (Vehicle-to-grid) and G2V (Grid-to-vehicle) enables load distribution of the day and is being tested at the moment in conjunction with the electric vehicle demonstration project on Bornholm.

3.7. Reduce dependency on imported fuels

The main environmental argument about EDVs is that they should use energy sources without any GHG emissions, i.e. renewable energy (Nemry et al. 2009). This would decrease the dependency on fossil fuels from today's levels and increase the security of supply as the energy may be produced locally.

3.8. Market drivers

Some of the market drivers that may promote the process for new technologies in the transport sector are:

- Oil resources and price
- Limitation of access (Paris, London)
- Mega cities
- Taxes
- EU CO_2-legislation
- Green image

(Kümpers 2010)

3.9. The range of EVs

The typical range of an EV is around 150 km with the current technology while the electric range for a PHEV is between 20 and 80 km (International Energy Agency 2011). A large share of the daily commuting and driving may be covered with these ranges, but in cases where larger ranges are needed charging stations or battery swap stations are required. Consumers may be scared by the low range for EVs, often known as "range anxiety". At DTU Transport the Danish Transport Research Institute performs National Travel Sur-

veys for passenger transport. In Figure 9 the datasets from 2006 is used to illustrate transport habits based on app. 2.000 persons transport habits. This dataset contains detailed information about modes of transport, length of trips, transport times, purpose of trips, age, income, residence etc. In regards to range anxiety the most important data is on the length of trips in road transport, however data on other modes of transport is also available. The category "driving car" the transport demand from trips below 50 km represents more than 60 per cent of the km travelled. Approx. 95 per cent is represented in trips below 150 km (Mathiesen 2009).

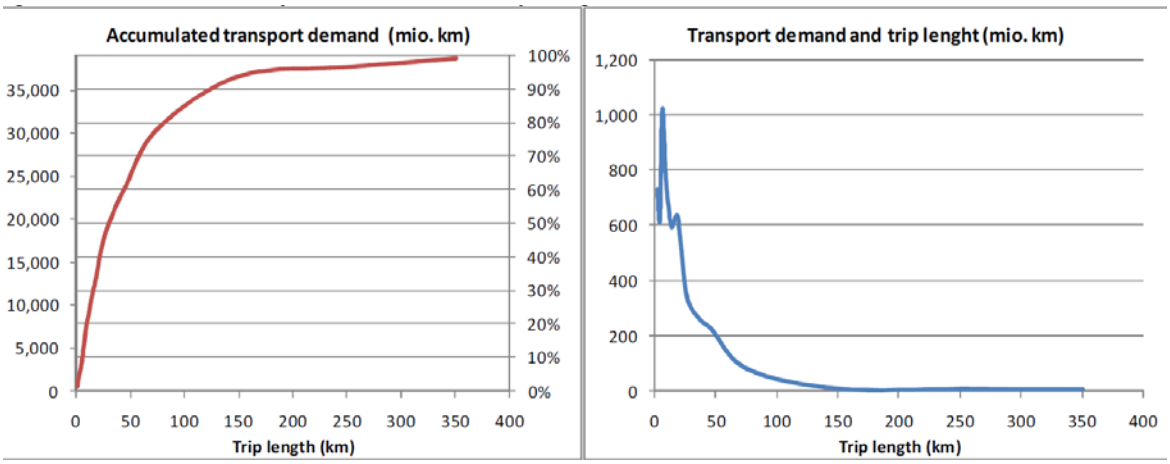

Figure 9, Vehicle transport demands and trip lengths in 2006 (Mathiesen 2009).

3.10. High investment costs

One of the main factors for the slow spreading of electric drive vehicles is the up-front investment cost. An overview of the component costs for EVs and ICEs are shown below. The table indicates how much the costs are for producing the components, even without the battery. However, automakers believe this comparison is not likely to hold once EVs are produced in higher volumes, which is expected to happen within a few years. Battery cost is still however one of the largest investments for an EV.

Table 3: Cost of EV-specific components excluding the battery, compared with cost of ICE components unnecessary to an EV (Deutsche Bank 2009)

ICE-only components	USD per unit	EV-only components	USD per unit
Engine, exhaust, fuel system	2,000	Motor/ Transmission	1,400
Transmission	800	Power electronics	1,200
Other components	200	Charger/Junction box	700
		Wiring harness	600
		Heating/cooling	400
		Regen. breaking	100
		Other components	600
Total	3,000	**Total**	5,000

3.11. Development of international standards for plugs and charging

It is necessary to develop international standards to secure an efficient production system for EDVs. It is important to harmonize following aspects:

- Charging plug and wire. According to the Danish Energy Authority, it is expected that the Mennekes plug (32/63A) will be standard in Europe.

Figure 10: The Mennekes plug that can be used for electric vehicles

- Communication between EVs and charging stands.
- Communication between EVs and operators.

It is expected that standards for plugs and communication will be announced within 1-2 years. (Energinet.dk 2010)

3.12. Infrastructure must meet the demand for charging

The transmission and distribution systems will be impacted if a larger number of EDVs are integrated in the transport system. The transformers could be subject to increased average operating temperatures, which could shorten their life and add extra cost to the electricity grid required. Infrastructure costs will be increased caused by the required charging facilities. This can either happen through private charging facilities or collective stations or battery swap facilities.

3.13. Safety and comfort in the vehicles

At collision the batteries in EDVs may cause fire due to the high energy content and thus the mass-produced batteries have to develop a high level of security through various control systems. Extra training and development may therefore be required (Danish Transport Authority 2010).

3.14. Consumer knowledge, attitudes and expectations

A survey performed by Deloitte indicates that the most significant considerations when purchasing an EV are the vehicle price, reliability, cost to charge and convenience to charge. Other factors like fuel cost and environmental impacts were assessed as being less important. The two factors that discourage people from buying EVs are, that they are more expensive and have a limited range (Deloitte 2010). Also spreading the knowledge about new models and technology is a major issue to increase consumer knowledge (Danish Transport Authority 2010).

3.15. Battery technology

Batteries must be improved in a number of parameters with durability and life-expectancy as the two biggest technical hurdles. Other improvements could be regarding costs, energy and power density, recharge time and temperature sensitivity. Batteries for EVs must in general optimize their energy storage capacity, while batteries for PHEVs must be designed to optimize their power densities. This could lead to different battery technologies in the different vehicle types or a compromise that can be used in both car types where some parameters like power density is reduced.

New battery chemistries with significant higher energy density must be developed to create EVs and PHEVs with a longer electric-range. By incorporating high-capacity positive electrode materials, alloy electrodes and electrolytes that are stable at 6 Volts the existing chemistries are expected to be outperformed. Better battery technology will in result lead to lighter, smaller and cheaper EVs and PHEVs (International Energy Agency 2011). See more about battery technology in 2.3.

4. Compilation of models

A compilation performed by Deutsche Bank including all HEV, PHEV and EV models from 2008-2012 can be seen in Table 4 (Deutsche Bank 2009). The values indicate the total number of models available in the given year. This compilation was developed in 2009 and new models can be launched.

Table 4: The total amount of models for each car technology (Deutsche Bank 2009)

Type	2008	2009	2010	2011	2012
HEVs	13	21	47	65	68
PHEVs	0	1	4	7	14
EVs	0	7	20	26	37
Total	13	29	61	98	119

Only the PHEV and EV models are mentioned by name in Table 5 as the number of HEV types increases significant from 2009-2010. The table only mentions the new models launched every year, i.e. the models from past years are still available but only mentioned in the year they were launched. The models included are produced in all areas of the world and several models are not currently for sale in Europe (De Danske Bilimportører 2011). It is important to stress that other models may be launched beyond the presented mentioned in Table 5.

Table 5: The new PHEV and EV models launched every year from 2008-2012 (Deutsche Bank 2009)

Type	2008	2009	2010	2011	2012
HEVs	13	8	26	18	3
PHEVs	-	Subaru Stella	BYD F6DM Fisker Karma VW Golf	GM Volt GM Small CUV Toyota	Fisker Nina Ford Escape Hyundai Peugeot SAIC Roewe VW Audi Sport Volvo V70
EVs	-	BYD e6 Mitsubishi iMiEV Tata Indica Tesla Roadster Tianjin Messenger Th!nk City Zotye Auto	BMW Mini-E Chrysler / Fiat Coda Sedan Ford Transit Connect Geely EK-1 Great Wall Oula Lifan 320 Nissan Leaf Peugeot Ion Peugeot Berlingo Renault Fluence Tata Nano Tianjin Siabao	Daimler B-Class Ford Focus Nissan Van Renault Kangoo Th!nk Ox Volvo C30	BMW MegaCity Changan EV Chery ZC7050A Chrysler / Fiat Daimler Smart Fortwo GM / Reva JV Nissan Infiniti Renault City Tesla Model S Toyota VW Up

In addition to the above mentioned models more than 19 different electric car models by 8 different car manufacturers are being produced in China. These models are however not all being produced in large scale production and may only exist in a relatively limited amount (ElFORSK et al. 2010).

5. Status on diffusion of electric drive vehicles

The sales of EDVs have been very limited in most parts of the world. Below is a brief description of the status of EDV diffusion in Denmark, Sweden, and internationally.

5.1. Introduction of new technology

The introduction of new technology can in general be divided into five different phases, which electric vehicles also may follow (Swedish Energy Agency 2009):

In *the preparation phase* different actors and market players gather together and form groups and try to build up knowledge about the market and the technology. A small test fleet exists, but only in small volumes. In *the introduction phase* development and preparation are the main issues before a growth may occur. Vehicles are available on the market, but all technical problems have not been solved. The cost is still high and standardizations have not been applied on the market. In *the growth phase* major obstacles have been eliminated and regulation is being harmonized. More suppliers are being introduced to the market, but the cost is still high. In *the breakthrough phase* the sales figures are increasing and many varieties of the technology are launched. There is a general good understanding of the new technology. The *commercialization phase* is reached when the market can continue on its own merit without independent support (e.g. in form of control measures).

Electric vehicle technology is according to these definitions in the first phases of preparation and introduction.

5.2. Denmark

In Denmark the first mass-produced EVs was introduced in the beginning of 2011 with models from Mitsubishi, Citroën and Peugeot. In the first half of 2011 less than 300 cars were bought and mainly by the company ChooseEV, that needed them in the "TestEnElbil" demonstration project.

As of October 2009 253 EVs were registered in Denmark (Udvikling A/S 2009) and new registrations in the next years can be seen in Table 6.

From January-September 2011 the amount of new registered EVs and PHEVs in Denmark are divided between following models:

Table 6: The number of EVs and PHEVs sold in Denmark in 2009-2010 and in the first nine months of 2011 (De Danske Bilimportører 2011)

Car model	2009-2010	2011 (January-September)
Peugeot iOn (EV)	-	112
Mitsubishi iMiEV (EV)	-	93
Citroen C-Zero (EV)	1	70
Nissan Leaf (EV)	-	8
Tesla Roadster (EV)	22	6
Think city (EV)	-	3
Kewet Buddy (EV)	-	2
Fisker Karma (PHEV)		1
Total	23	290

In the period from January-September 2011 the total amount of new registered cars in Denmark was 127,211. This means that the share of EVs and PHEVs in this period was 0.0023% ~ 2 per thousand and even lower in the earlier periods. Only one PHEV was sold in the period from 2009-2011.

The total amount of EVs in Denmark is below 1,000 vehicles according to the chairman of the Danish alliance for electric cars (Hedegaard 2011).

5.3. Sweden

In 2010 the total amount of electric vehicles was around 100, but is expected to rise fast, as in other parts of the world (ElFORSK et al. 2010). In Sweden 148 EVs were registered in the period from January-September 2011 and 11,665 ethanol-hybrid E85 cars according to (Trafik analys 2011). Furthermore 2,334 other hybrid cars were sold in Sweden in the same period. In 2010 12 EVs were sold, in 2009 it was similarly 12 and in the years before that, the average amount was 1-2 per year (Trafik analys 2011). The total amount of cars registered in the first nine months of 2011 was 245,390 which mean that the share of EVs in this period was 0.0006% ~ less than one per thousand for each new registered car.

Based on these publications the total amount of EVs in Sweden can be estimated to be below 500 vehicles according to the Swedish national program for evaluation of EVs and charge infrastructure and the new registered cars in 2011 (ElFORSK et al. 2010, Trafik analys 2011) ….

5.4. International

In 2010 the total number of passenger-vehicles sold was around 44.7 million units of which 954,000 vehicles employ some type of battery propulsion system. This corresponds to approximately 2.2% of the global share (J.D. Power and associates 2010).

The cast majority of these or more than 900,000 are mild hybrids (HEV) or similar such as Toyota Prius, Honda Insight, Volkswagen Touareg Hybrid, etc. The hybrid electric vehicles have been for sale in the last decade and have now a market share of around 3% in the developed countries. In the past decade more than 1.5 million hybrid vehicles were sold.

For EVs the total global sales in 2010 was around 23,000 vehicles, with highest sales figures in Japan and China. In 2011 it is assessed that the sales will be around 54,000 vehicles and still Japan and China have the highest sales figures around 18,000 vehicles each and with around 5,000 sold vehicles in Europe (Omotoso 2010).

Some demonstration projects with PHEVs have been initiated, but the market share is near zero. No manufacturer produces PHEVs on a commercial scale, but a larger production will start within a few years. (International Energy Agency 2011)

A possible ramp-up of the future development in EVs and PHEVs is outlined in Figure 11. This development requires however a large consumer demand to support the rapid increase (International Energy Agency 2011).

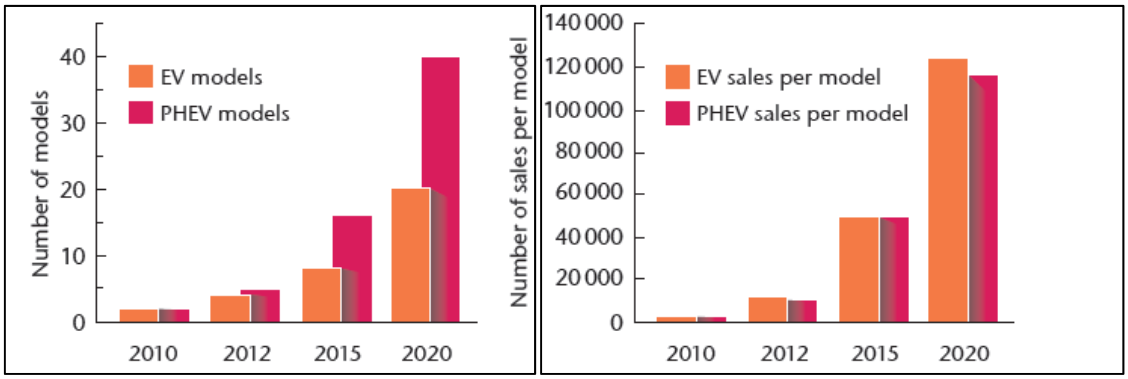

Figure 11: Possible ramp-up of EVs and PHEVs according to IEA (International Energy Agency 2011).

6. Future development

The future expected development for EVs and PHEVs are described below.

6.1. Danish development

In Denmark the spreading of electric drive vehicles has been accelerated within the few last years, with the introduction of mass-produced models as the single most important factor. Also the creation of the required infrastructure is being developed by different private companies like Better Place etc. Denmark is along with Israel chosen by Better Place to be a test site for the development of electric vehicles due to different reasons. According to (Udvikling A/S 2009) Denmark have good conditions for introducing electric vehicles for a number of reasons:

- No taxes on EVs
- Short distances
- Well-developed electric infrastructure
- Large share of electricity from wind power
- Mild climate
- Political goodwill

Because of this the EV market share may increase to 15% in 2020 or even more according to Udvikling A/S.

Assessment of EV potential in Denmark:

Year	Market share
2010	< 1%
2012	2 – 5%
2015	5 – 8%
2020	10 – 15%

(Udvikling A/S 2009)

A report from the Danish green Think-tank CONCITO assesses that 25 % of person kilometers can be driven by electricity in 2020, depending on the long-term framework conditions (CONCITO 2009).

In the strategic research project CEESA the assessment is that 10% of vehicles could be EVs in 2020 and another 15% ICE-hybrids (Mathiesen et al. 2012).

6.2. Swedish development

Sweden has a long experience with producing cars and innovative transport solutions and may hence be ready to transform their transport system.

Furthermore in Sweden a roadside network of more than 600,000 engine heating charging posts is already constructed and could be combined with charging stands for EVs. This would however require expansions in the power grid.

A projection of the future EV fleet in Sweden has been developed by ELforsk, divided into four different pathways depending on the control measures implemented. The scenarios vary from almost no further incentives and development to a very high increase in development and cost reduction.

Number of electric vehicles (EV and PHEV) in the Swedish passenger car fleet			
Scenario	**2010**	**2020**	**2030**
Current control measures Current incentives remain but no further measures are taken	600	42 000	480 000
Mid-Range Incentives continue to develop at the same rate as today The life cycle cost of electric vehicles is at parity with conventional vehicles in 2015 .	800	125 000	650 000
High-Range The charging infrastructure is broadly accessible in cities, suburbs and some smaller towns. The life cycle cost of an electric vehicle is at parity with a conventional vehicle in 2015 and battery leasing is a realistic alternative.	800	240 000	1 780 000
Extreme Range The demand for electric vehicles becomes extremely high and is limited in the short term only by the availability of vehicles.	800	480 000	3 270 000

Figure 12: Different scenarios for the future electric vehicle fleets in Sweden (Swedish Energy Agency 2009)

The total Swedish car fleet was as of November 2011 around 4.42 million cars (Statistics Sweden 2011). In Figure 12 different scenarios for the EV development in Sweden is outlined in connection to different incentive schemes.

6.3. International development

Today the global car fleet is around 800 million vehicles and is expected to increase to around 2.4 billion in 2050 so the potential for new electric vehicles will also increase due to the large amount of new cars (ElFORSK et al. 2010).

The market share of EVs and PHEVs are very low at the moment, partially since mass-produced vehicles have only recently been introduced on many markets or will be in the coming years. It is however expected that the market share of EDVs will increase in the coming years because the emission of CO_2 must be limited to a maximum of 95 g/km in 2020, as proposed by the EU (J.D. Power and associates 2010). Deutsche Bank expects that the market share of full hybrids (HEVs) will be relatively limited and that the need for PHEVs will be larger with a market share in Europe of 14%. EVs will in the same period increase to a market share of 5-6% in Europe in 2020. However, governments' aggressive push and new technologies could lead to significantly higher growth trajectories for EVs (Deutsche Bank 2009).

In other markets like Japan the combined market share of EVs and Hybrids could reach more than 30% in 2020 and in China the potential for growing is also large, giving that they already have a tradition for using electric motorcycles and scooters with 20 million sold units in 2008. Deutsche Bank therefore projects an EV market share of 9% in 2020 and 6% for PHEVs in China.

The projections for electric drive vehicles are outlined in Figure 13 and Figure 14, showing which types has the largest potential and where the growth will occur.

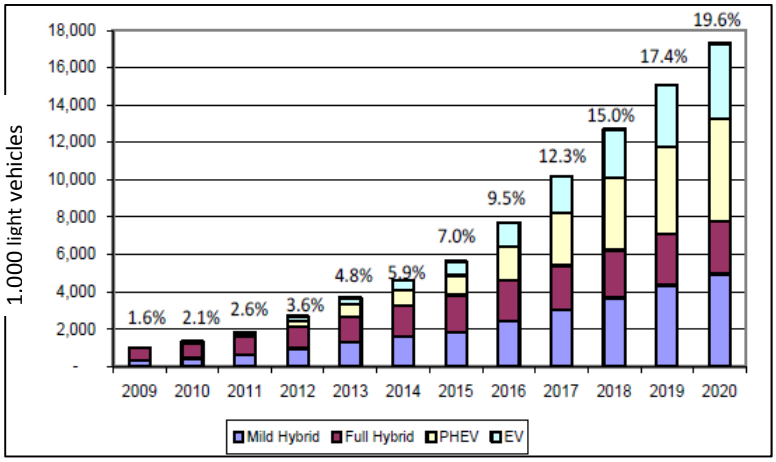

Figure 13: The amount of HEVs, PHEVs and EVs globally (Deutsche Bank 2009)

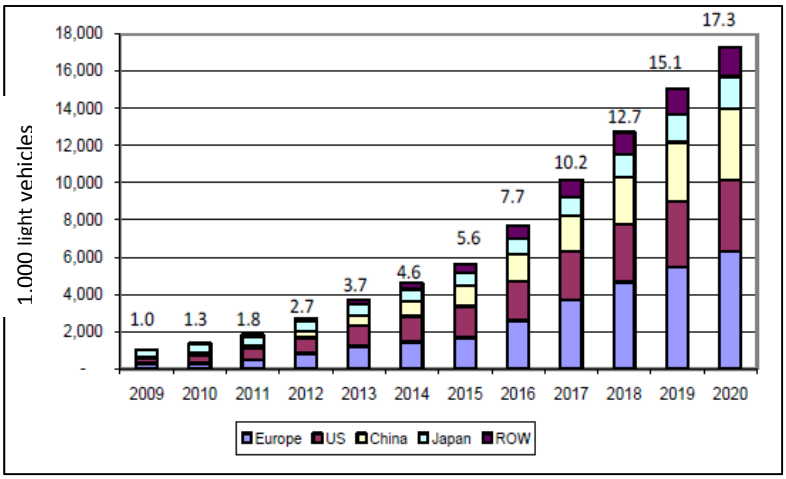

Figure 14: Shows where the projected growth of EDVs will occur (Deutsche Bank 2009)

As seen in Figure 13 the growth in PHEV sales is larger than other growth rates and the total share of electric drive vehicles is projected to be almost 20% in 2020.

The increase of EDVs will primarily happen in the EU-countries, USA and in China. The total amount will in 2020 be more than 17 million as seen in Figure 14.

The Boston Consulting Group expects that the sales of electric and hybrid cars in 2020 will increase to around 14 million cars and 70% of these will use lithium-ion technology. The remaining 30% will use Nickel Metal Hydride batteries, mainly in the smaller and lower-cost vehicles (Boston Consulting Group 2010).

A smaller EDV growth can be found in the projection from 2010 performed by J.D. Power and Associates that assesses the market potential for EDVs. In this assessment 5.2 million battery-powered units will be sold in 2020, representing around 7.3% of the global passenger-vehicle sales (J.D. Power and associates 2010).

An overview of the projection is outlined in the table below, indicating the global sales of HEV/PHEVs and EVs from 2007 to 2020.

Table 7: Global projected sales of HEV/PHEVs and EVs from 2007 to 2020 (J.D. Power and associates 2010)

	2007	2010	2015	2020
HEV/PHEV	515,000	935,000	2,800,000	3,900,000
EV	436	20,000	640,000	1,300,000
EDV	516,000	955,000	3,440,000	5,200,000
Total PV sales	49,000,000	45,000,000	61,000,000	71,000,000
HEV/PHEV %	1,1%	2,1%	4,5%	5,5%
EV %	0%	0,05%	1,05%	1,85%
EDV %	1,1%	2,15%	5,55%	7,35%

If looking at the different EV manufacturers and their expected sales, different factors like investment in R&D and whether they are early-movers have an impact on future sales. More than 30 vehicle automakers may in 2020 produce EVs competing for market shares. An estimate of the sales of EVs is seen in Figure 15. In addition more than 55% of the expected sales of EVs are expected to be in Europe, followed by China with around 20%.

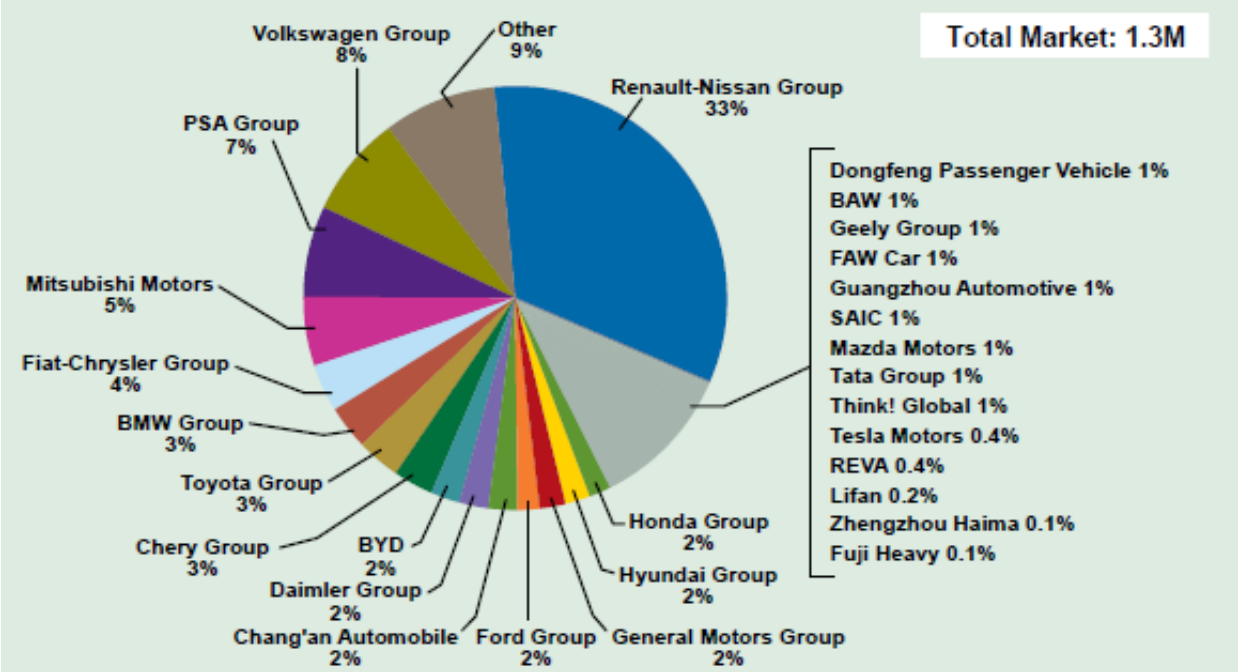

Figure 15: Estimate of the EV market share divided by auto manufacturers in 2020 (J.D. Power and associates 2010)

In general the following parameters and actors are important if a diffusion of EVs and PHEVs is to continue:

- Oil price
- Policies
- Technology
- Auto manufacturers
- Customers (Private)

(Udvikling A/S 2009)

6.4. Batteries

The U.S Department of Energy expected in 2010 that certain types of EV battery costs could be reduced with up to 70% before the end of 2015 and the same cost reductions would apply for PHEVs. This is caused by the government supported advanced vehicle technology program that supports investments with USD 12 billion, including USD 5 billion to electrify the American transport sector.

The forecasted cost of a typical EV battery is shown in Figure 16 according to the U.S. Department of Energy.

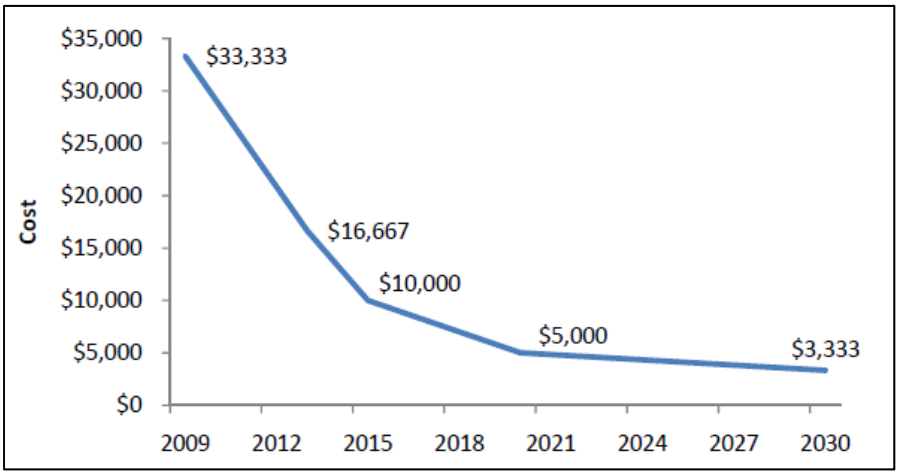

Figure 16: The graph shows the expected cost for a typical EV battery (U.S. Department of Energy 2010). The forecast assumes 3 miles (4.82 km) per kWh and a 100 mile (160.93 km) range.

Deutsche Bank projects that prices per kWh will decrease by 25% from 2010 to 2015 and 50% from 2010 to 2020. A total battery system will in that way cost around USD 8,125 for a 25 kWh battery in 2020, the same as around USD 325 per kWh (Deutsche Bank 2009).

The Boston Consulting Group has in their models forecasted the price for a 15 kWh battery pack in 2020 to around USD 6,000, equal to around USD 360-440 per kWh (Boston Consulting Group 2010).

The prices from the different forecasts are not directly comparable but the price ranges are quite similar for future battery costs.

Other factors including the weight of an EV battery is forecasted to decrease to one sixth in 2030 compared to 2009 and the expected lifetime will increase by 3.5 times before 2015 for EV batteries (U.S. Department of Energy 2010).

These large battery improvements may sound very optimistic but a lot of large battery producers are funding huge investments in battery development. A graph of the battery manufacturers' investments from 2009-2012, only in the lithium-ion technology, is presented in Figure 17. The total investments exceed SEK 100 billion.

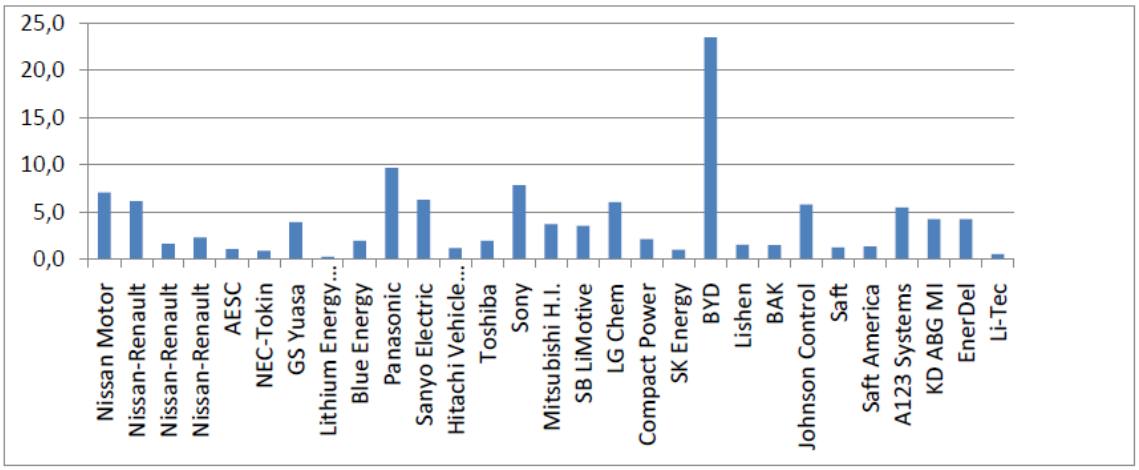

Figure 17: Battery manufacturers' investments from 2009-2012 in lithium-ion battery technology in billion SEK (ElFORSK et al. 2010)

Future battery technologies are expected to include Lithium-titanium, which currently is in production in some areas. This technology could reduce the charging time, but the materials are very costly. Other technologies are Zinc-air, which are under pre-production, with a high power and energy density, but the life time is only a few hundred discharges. Research is currently investigating the possibility for introducing Lithium-silica and especially Lithium-air technologies that may have the ability to increase the driving range to 200-400 miles (320-640 km) (Danish Transport Authority 2010, Rahim 2010). Such ranges would not be necessary for most transports demands though.

7. Business models

Instead of purchasing an electric car it is also possible to use other business models, e.g. leasing or signing a membership contract that provides you with some advantages as an electric car owner. The different business models include battery leasing, vehicle leasing and car clubs.

Companies dealing with electricity could see an advantage in renting the battery to the consumers. This is due to the fact that the companies might achieve economic advantages by avoiding payments for any imbalances in relation to the size of the declared purchase to the TSO (Danish Energy Agency 2010). The EV batteries are thereby used as electrical storage capacity for the grid.

7.1. Better Place

Better Place is a company that offers solutions for electric car owners. As an electric car owner it is possible to buy a membership and Better Place will then provide the needed electricity for your car, a private charging stand and access to the public charging stands, a battery for your car and the possibility for unlimited changes and service and support. The membership prices changes according to the amount of kilometers driven. Two different options are available with Better Place in terms of battery solutions. The first one is with a replaceable battery meaning that the battery can be switched at a battery swap station lasting under 10 minutes. Better Place is planning to have established 20 battery swap stations in Denmark before the end of 2012. The other option is with a fixed battery that may be charged at fixed charging points, typically related to work places and private homes. This charge may be performed with a normal charging (4-8 hours for complete charge) or a quick charge (80% complete under 30 minutes, but more expensive). The prices for both options are illustrated in the tables below.

For a replaceable battery the monthly prices are:

Distance (km)	Up to 10,000	Up to 15,000	Up to 20,000	Up to 30,000	More than 30,000
DKK	1495	1695	1895	2495	2995
DKK/km above distance limit	2.24	1.70	1.42	1.25	-

Figure 18: The first Better Place battery swap station located in Tokyo (ElFORSK et al. 2010)

Better Place is planning to establish the first battery swap station in Copenhagen in 2012.

For a fixed battery the monthly prices are:

Distance (km)	Up to 15,000	Up to 20,000	Up to 25,000	More than 25,000
DKK	995	1195	1395	1795
DKK/km above distance limit	1.00	0.90	0.84	-

(Betterplace 2011)

Better Place has so far attracted more than DKK 4 billion in venture capital of which more than DKK 700 million is from Denmark. These funds are reserved for expanding the charging infrastructure in Israel and Denmark and later on in countries like Japan, USA, and Australia (ElFORSK et al. 2010).

7.2. ChooseEV

ChooseEV is another company where you can sign a membership and use all the advantages that the company provides you with in Denmark. It is possible to choose a membership including leasing an electric car or a membership without a car. The membership without a car includes a private charge stand, access to the national network of charging stations and service and support for the price of 479 DKK/month for public institutions or 599 DKK/month for private consumers.

ChooseEV also offers a leasing option for the three models Mitsubishi iMiEV, Peugeot iOn and Citroen C-Zero. This option, including the membership advantages mentioned above, has a cost of 4,574 DKK/month for a leasing period of 60 months for a limit of 10,000 km/year.

(ChooseEV 2011)

7.3. Move About

In Denmark (Copenhagen) and in Sweden (Gothenburg) it is possible to sign a membership for car sharing for electric vehicles from the company called Move About. When you are a member it is possible to rent a car on a daily/weekend basis from different locations. The prices in Denmark are DKK 299 for half a day,

DKK 499 for one day and DKK 799 for a weekend. Besides, it is necessary to pay a monthly fee of DKK 99 to be able to rent a car, also including DKK 99 credit for driving. The prices in Sweden are excluded VAT SEK 79 for one hour, SEK 259 for a half day and SEK 399 for one day. It is also necessary in Sweden to pay a monthly fee of SEK 99, excluding VAT to be able to rent a car.

The cars are of the THINK City model and include unlimited driving limited though by the range.

Move About is planning to begin expansion with a target of more than 50 cities in 2013.
(Move About 2011)

8. Taxation and subsidies for electric drive vehicles

The current taxation and subsidy levels play an important role for setting up the required framework conditions to promote the diffusion of electric vehicles. This is pointed out by the founder and CEO of Better Place in an interview:

"Government is critical to creating the market conditions for mass-market adoption of EVs. For EVs to scale and become mass market, it will be critical that they help support the deployment of charging infrastructure" (J.D. Power and associates 2010).

The existing legislation for electric vehicles in Denmark and Sweden is described below.

8.1. Denmark

Denmark has some of the highest taxes for vehicles in the EU and the fiscal income from motor vehicles is more than 5 billion euros per year. Especially the income from registration tax stands out with an annual income of around 1.6 billion euros when comparing to other major EU countries. The country with the second highest income from this type of tax, Holland, has an income of around 300 million Euro/year. Also fuel taxes and annual ownership taxes have high incomes. As of 1st of January 2011 the fuel taxes in Denmark is for unleaded petrol 571 euros/1,000 litres and 386 euros/1,000 litres for diesel (European automobile manufacturers' association 2011b). Only the Netherlands has higher fuel taxes on petrol in the EU.

Vehicle taxes in Denmark include:

- ACT/vehicle excise duty (vægtafgift)
- fuel tax (brændstofforbrugsafgift)
- particle emission tax (Partikeludledningsafgift)
- registration tax (registreringsafgift)
- vehicle registration law (køretøjsregistreringsloven)
- Civil liability insurance act (Ansvarsforsikringsloven)
- Road use tax (vejbenyttelsesafgifts)

In Denmark it is necessary to pay registration tax according to the price of the purchased vehicle. The tax on the first DKK 79,000 is 105% while you have to pay 180% on the price above DKK 79,000 (The Danish Ministry of Taxation 2011). Furthermore an allowance of DKK 4,000 is granted for cars for every kilometer in excess of 16 km/l petrol they can run for and 18 km/l diesel. A supplement of DKK 1,000 is payable for every kilometer below 16 km/l petrol they can run and 18 km/l diesel (European automobile manufacturers' association 2011a).

However electric vehicles do not have to pay registration tax or ACT/vehicle excise duty in Denmark and the exemption expires at the end of 2015. The exemptions do not apply for hybrid vehicles (HEVs). (Danish Government 2011)

An example of how evident the tax registration may be to the price differences between EVs and ICEs is illustrated below. This is an example of a typical mid-sized ICE car with a price around 250,000 DKK with all taxes included:

Vehicle price before registration taxes	**DKK**
Supplier sale price excl. VAT	97,061
VAT – 25%	24,265
Vehicle price incl. VAT (1)	121,326
Deductions from taxable value	
Radio	-1,000
Airbag no. 3 to 6	-5,120
ABS	-3,750
ESP	-2,500
Max. NCAP-stars	-2,000
Taxable value (2)	106,956
Registration tax	
Tax of taxable value (2) over 79,000 DKK (180%)	50,321
Tax of taxable value (2) under 79,000 DKK (105%)	82,950
Deductions from registration tax	
Low energy consumption, e.g. 17 km/l petrol	-4,000
Seat belt reminders (3 units)	-600
Total registration tax	128,671
Car price on the street excl. delivery costs (1) +(3)	**249,997**

(The Danish Ministry of Taxation 2011)

The registration tax is around DKK 130,000 or more than half of the price.

8.2. Sweden

Sweden has like Denmark a high income from taxes on motor vehicles with a total income of more than 10 billion euros per year. More than half of this income is from fuel tax that exceeds 6.5 billion euros per year. Another taxation with a high income is the annual ownership tax. In Sweden you do not pay registration tax on vehicles unlike in many other countries in the EU (European automobile manufacturers' association 2011b).

For some vehicles a five year tax exemption might be applied to promote efficient vehicles and vehicles driving on renewable energy. The car must be used for the first time in Sweden. The exemption only applies for motor vehicle tax (fordonsskat) and not for other taxes like Road registration fee (vägtrafikregistera-vgiften) that still must be paid. This tax exemption for certain vehicle types was adopted 1st January 2010 but applies for all vehicles from 1st July 2009 and replaces the previous green car rebate. The exemption is connected to the vehicle and not the car owner, so even if the vehicle may change owner the exemption is still valid for the specific vehicle.

The technical specifications:

The specifications that must be reached to receive the tax exemption is given below.

Specifications for conventional vehicles:

- Vehicles driven by petrol must not exceed 120 g/km CO_2 emission at mixed driving.
- Vehicles driven by diesel must not exceed 120 g/km CO_2 emission at mixed driving and the emission of particles must not exceed 5 mg/km.

Specifications for vehicles driven by alternative fuels other than petrol, diesel or LPG (often ethanol or bio-gas):

- Fuel consumption at mixed driving must not exceed 0.92 L petrol/mil or 0.97 m^3 gas/mil.
    - Note. Consumption figure in liter refers to the consumption of gasoline and not ethanol. The reason for this is that the data on consumption of ethanol is not registered in the vehicle registry.

Specifications for electric vehicles:

- Electricity consumption per 100 km must not exceed 37 kWh, specified by the manufacturer or distributor.

(Swedish Transport Agency 2010)

Older cars that can be driven by E85 (85% ethanol and 15% gasoline) and vehicle gas also get a reduced motor vehicle tax based on the emission of CO_2 and other aspects. The taxation follows a CO_2 charge of 20 SEK per gram CO_2 over 100 gram collected from July 2009. The charge for vehicles driven by E85 and gas is 10 SEK per gram CO_2 over 100 gram.

In Sweden alternative fuels are tax-subsidized except electricity when used as fuel. The taxation consists of a CO_2 and an energy tax and additionally a VAT (25%) on all fuels (Miljöfordon.se 2010). The fuel taxes in Sweden as of 1st of January 2011 are 542 euros/1,000 litres of unleaded petrol while it is 425 euros/1,000 litres for diesel (European automobile manufacturers' association 2011b).

9. Policies

To promote the implementation of EVs and PHEVs, different policies and roadmaps have been developed, both on a national and an international scale. These policies present the planned initiatives that will improve the knowledge and information about EVs and the actions that are needed to increase the share of EDVs.

9.1. Denmark

In January 2011 the Danish plan for initiatives for promoting EVs and PHEVs by the transport ministry was presented. The plan covers the period until 2013, with focus on gathering and communicating knowledge about EVs to different actors such as municipalities, dealers and suppliers, authorities and research communities.

Some of the actions initiated by the transport ministry are:

- To gather and communicate activities about EVs, mainly from Denmark but also internationally.
- Develop materials describing the activities in Denmark and the potentials and challenges for the use of information in the EU. The target is to anchor knowledge about the possibility of Denmark being a test-laboratory for EVs.
- Create a network of different stakeholders to secure synergy and sharing of knowledge.
- Communication and counseling about purchase, operation and maintenance of EVs for municipalities and regions.
- Cooperate with the car industry and consumer organizations about promoting the communication about EVs and PHEVs to potential buyers.
- Cooperate with the auto mechanic industry to investigate the need for increasing the knowledge and education in relation to service and repair of EVs and PHEVs.
- Map specific events about accidents with EVs.

Further actions can be added to the plan if necessary.

9.2. Sweden

In Sweden a large number of organizations and companies (Svensk Energi, supply companies, Power circle etc.) have agreed on a common offensive vision for electric vehicles, including an electric vehicle fleet in 2020 of 600,000 or what will be equal to 15% of the total car fleet (ElFORSK et al. 2010).

The official Swedish target from the Government is that the Swedish car fleet in 2030 is independent of fossil fuels. Another target is that the share of renewable energy in the transport sector in 2020 should be minimum 10% (Regeringskansliet 2010).

The Swedish Government published in 2010 a roadmap with 68 different initiatives to promote green growth.

The initiatives within the transport sector address the following issues:

- Increase the use of renewable energy including EVs and PHEVs.
- EVs (and other green vehicles) are exempted from car taxation the first five years.
- EVs are reduced to 60% of the benefit value for the nearest comparable conventional car.

9.3. International

An international roadmap has been developed by the International Energy Agency (IEA) to point out the necessary actions required to continue the implementation of EVs and PHEVs (International Energy Agency 2011). The energy technology perspective 2008 BLUE map scenario sets an overall target of reducing the global energy related CO2-emissions by 50% in 2050 compared to 2005. Transport must contribute with 30% of this overall reduction and can be achieved by accomplishing an annual sale of 50 million EVs and 50 million PHEVs per year in 2050. The technologies for light-duty vehicles can be seen in Figure 19.

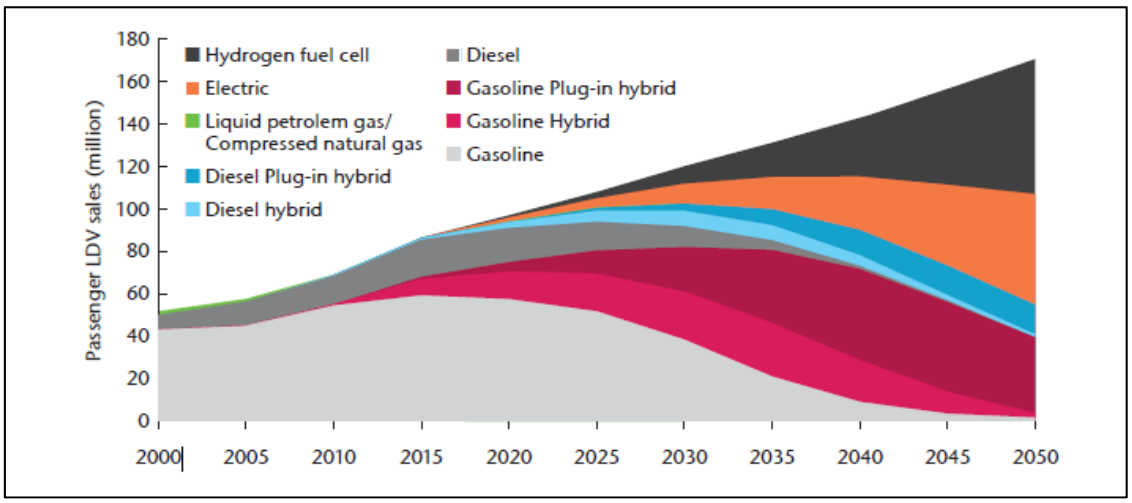

Figure 19: The light-duty vehicle sales towards 2050

The sales of EVs and PHEVs will occur in all major regions of the world, incl. OECD-countries of Europe, North-America and the Pacific as well as in India and China. If the national sales targets based on national announcements are achieved the total stock of EVs and PHEVs will be around 4 million in 2020.

Some of the key findings to achieve the main target in the roadmap include:

- Setting up targets for sales of EVs and PHEVs.
- Developing strategies to support the introduction of electric-drive vehicles.
- Improving industry understanding of consumer needs and behaviors.
- Developing performance metrics including metrics about vehicle performance and technical characteristics.
- Launch initiatives regarding research, development and demonstration to reduce battery costs.
- Developing and implementing the necessary recharging infrastructure according to the number of EVs and PHEVs.

Some additional recommendations to achieve the target are:

- Using a comprehensive mix of policies that establish a clear policy framework, promoting good performances (energy, CO2) instead of specific technologies.
- Governments and industry can work together internationally to lower costs and accelerate diffusion.
- Governments should work together by formulating common goals, targets and plans.

10. Research, development and demonstration projects for electric vehicles

A number of different ongoing projects are gathering knowledge about future electric vehicles and showing that electric vehicles can be integrated in the transport system.

Some of the largest research and demonstration projects are outlined below with the main focus on Denmark and Sweden.

Table 8: Research, development and demonstration projects for electric vehicles

Project	Country	Partners	Principal aim	Budget	Duration
TestEnElbil (TestaElectricCar)	Denmark	ChooseEV, DTU Transport and Etrans	Gathering experiences with EVs in everyday life	DKK 75 million (EUR 10 million)	fall of 2010 → end of 2012
Udvikling af infrastruktur til elbiler (development of infrastructure for electric cars)	Denmark	Better Place Denmark, Copenhagen Municipality, DSB, DTU and some international partners	Develop new infrastructure for electric vehicles regarding battery replacement and charging stations	DKK 74 million (EUR 10 million)	June 2011 → December 2013
Edison – Electric vehicles in a distributed and integrated market using sustainable energy and open networks	Denmark	A lot of different partners including Danish Energy Association, Dong Energy, Energinet.dk, IBM and Siemens	Contribute with solutions about infrastructure for electric vehicles in Denmark by controlling the vehicle charging	DKK 49 million (EUR 6.6 million)	February 2009 → December 2011
Green eMotion	Denmark	Danish partners: Bornholm Municipality, Copenhagen Muni-cipality, Danish Technological Institute, DTU and Better Place	Support the spreading of electric vehicles in Europe by developing and demonstrating the necessary technological solutions for using electric vehicles across national borders	DKK 315 million (EUR 42.3 million), mainly supported by the EU Commission	March 2011 → March 2014
PowerLabDK	Denmark	DTU, Copenhagen University College of Engineering, Risø DTU and Østkraft	Developing and testing Smart Grid technologies for the future energy system to integrate fluctuating power from wind turbines	DKK 138 million (EUR 18.5 million)	July 2011 → September 2014
Elbilsupphandling (Electric cars Procurement)	Sweden	Vattenfall and Stockholm Municipality	A large demonstration project for electric vehicles in Stockholm	-	2010 →

Project	Country	Partners	Principal aim	Budget	Duration
E-mobility Malmö	Sweden		Showing that EVs can be integrated in a sustainable transport strategy	EUR 4 million	2009 → 2012
Fordonstekniska Försöks programmet (FFI) (Strategic Vehicle Research and Innovation Initiative)	Sweden	Swedish Government and the automotive industry in Sweden	Funding of joint research, innovation and development with focus on climate and environment and safety. Make growth in the Swedish car industry	SEK 1 billion each year (EUR 110 million)	2009 → 2012
BISEK	Sweden	-	Focused on how the social conditions in cities and in rural areas, are affected by the economic conditions of owning and driving a car	SEK 15 million (EUR 1.7 million)	second phase BISEK 2 2011→ 2015
European Green Cars Initiative	EU	-	Research about heavy cars based on ICEs, Research about electric and hybrid cars and Logistic and intelligent transport systems	EUR 5 billion	-
Test program according to the Recovery act from July 14th 2010	USA	-	Support the development, manufacturing and deployment of batteries, components and chargers necessary to put millions of EVs on the roads	USD 12 billion, including USD 5 billion to electrify the American transport sector	2010 → 2013

Project	Country	Partners	Principal aim	Budget	Duration
Support for EVs	France	-	Promote EV diffusion. Support of EUR 5,000 to vehicles with a CO2-emission below 60 g/km	EUR 2.7 billion, support purchases of vehicles with a maximum emission of 60 g/CO_2/km with 5,000 euros	
Support	China	-	Stimulation of EV development	EUR 1.1 billion	-
Support programs	Germany, Great Britain, Portugal Spain, Israel, etc.	-	pioneering within electric car development	-	-

(Danish Transport Authority 2011, Stockholm Municipality and Vattenfall AB 2011, Sonnenschein 2010, Vinnova 2010, BISEK 2011, ElFORSK et al. 2010, U.S. Department of Energy 2010)

11. Current and near term technology

In this chapter a comparison of the different EDV models is carried out, to show the current and near-term technology. Not all data was available for all models.

The number of selected models could be expanded as new models almost are announced on a daily basis (Hazeldine 2009), but the models included are considered to be the ones representing the technology. The data have been accessed from the individual car companies and since not all models have been launched small changes in the specifications may occur when introduced on the market.

It is also important to note that price data for some models included here may be changed when imported to Denmark or Sweden because of different taxes etc. Furthermore the reliability of the references used for price data are uncertain for some models as no data could be obtained from Danish distributors. Hence a rating of each price data source was carried out going from strong, medium and low. The rating is illustrated in the investment price data graph by adding a green (strong), orange (medium) or yellow (low) color to each pillar.

The comparison will be divided into following categories: EVs <2012, EVs >2012, PHEVs, HEVs, EV vans (EV V), and EV trucks (EV t). The EVs are divided between the models launched before 2012 and the models expected to be launched in 2012 or later. The specifications for each vehicle can be found in Appendix A.

11.1. Electric Vehicles <2012

The existing vehicles can be divided into three different groups of cars: family car, (Mitsubishi iMiEV, Peugeot iOn, Citröen C-Zero) Sports car (Tesla Roadster), and urban car (Kewet Buddy Basic, Think City, Mega City, REVA). Different groups of EVs were chosen for the analysis as the only mass-produced cars are family cars on the market. The selected models for the existing technology overview may be extended as other car models are available. For instance small productions of several models are constructed in China.

The models will be compared within investment costs, range, energy storage, and power capability as these all are significant specifications for EVs.

11.1.1. Price

The price for EVs <2012 varies from around DKK 300,000 for family cars to DKK 800,000 for a sports car and to between DKK 100,000-230,000 for urban cars.

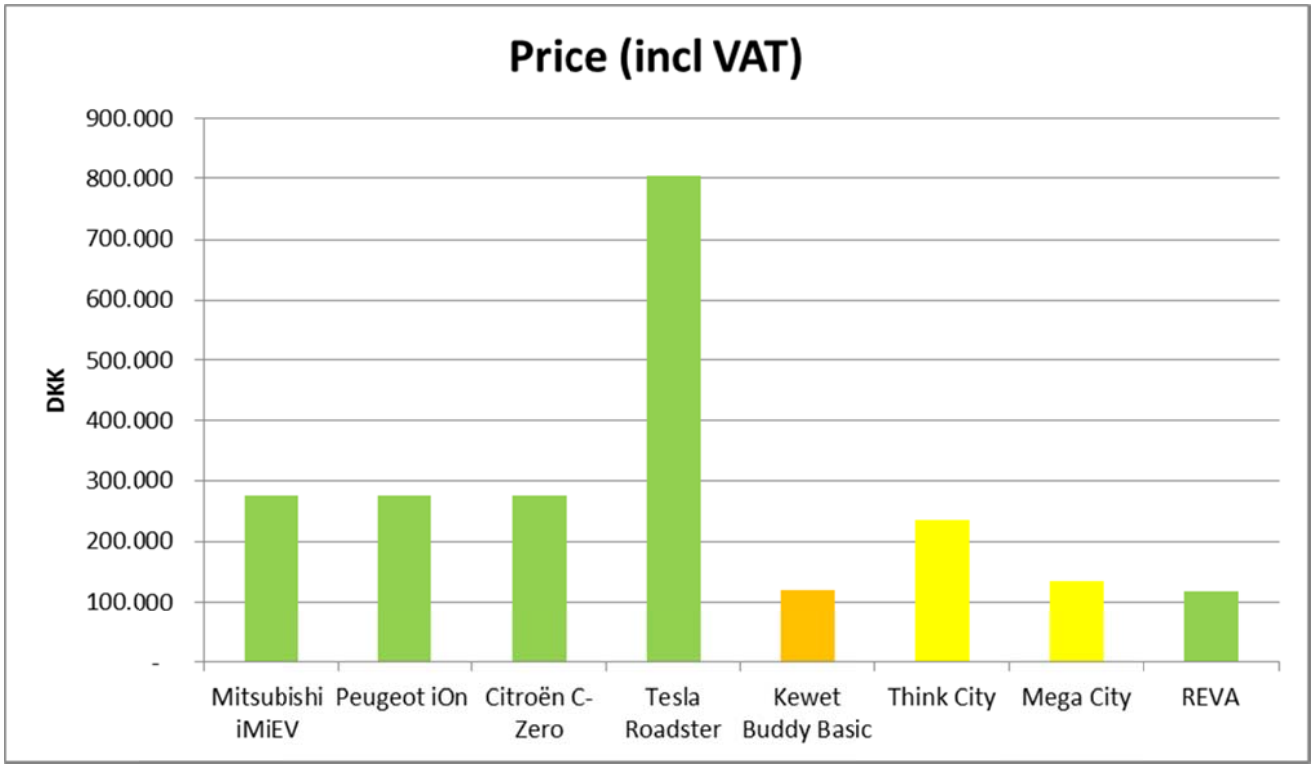

Figure 20: Prices for EVs available. The bar colors indicate the price data reference reliability. (green = strong, orange = medium, yellow = low – estimated price)

11.1.2. Range and energy storage

Range of electric cars and their energy storage are connected as an increased storage capacity will increase the electric driving range. This is also evident from Figure 21 where the sports car has the longest range and also the largest energy storage capacity. The smaller urban cars have lower ranges, often not exceeding 100 km/recharge.

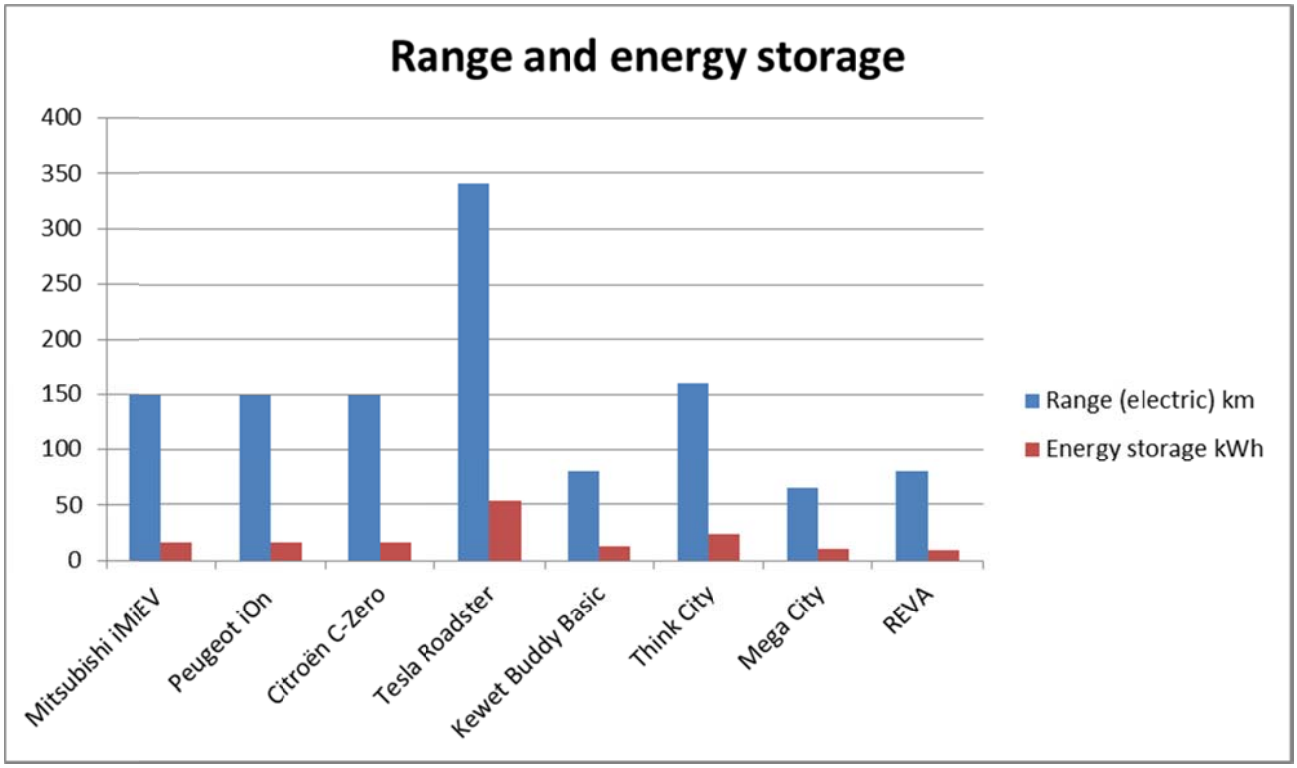

Figure 21: Range and energy storage capacities for EVs <2012

If including the price and comparing with range urban cars have the lowest cost per km, while the sports car has the highest costs.

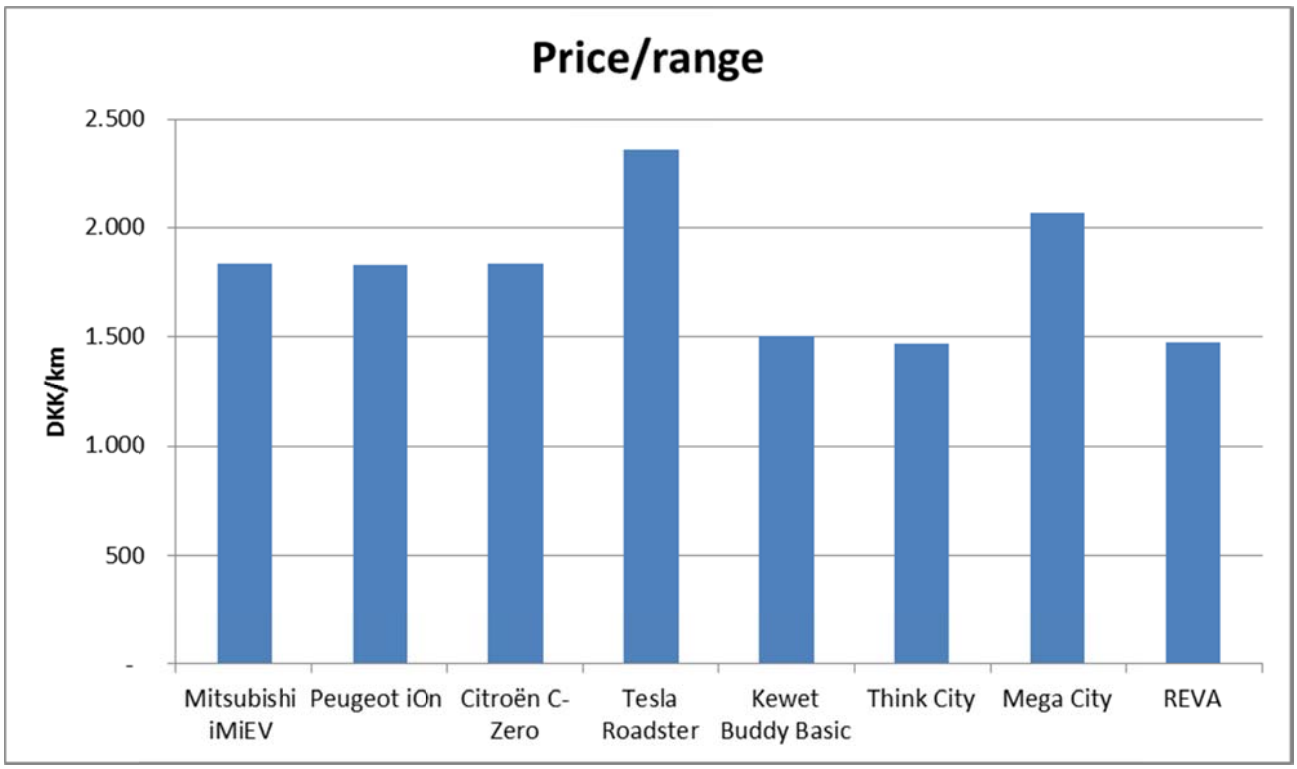

Figure 22: The price compared to driving range

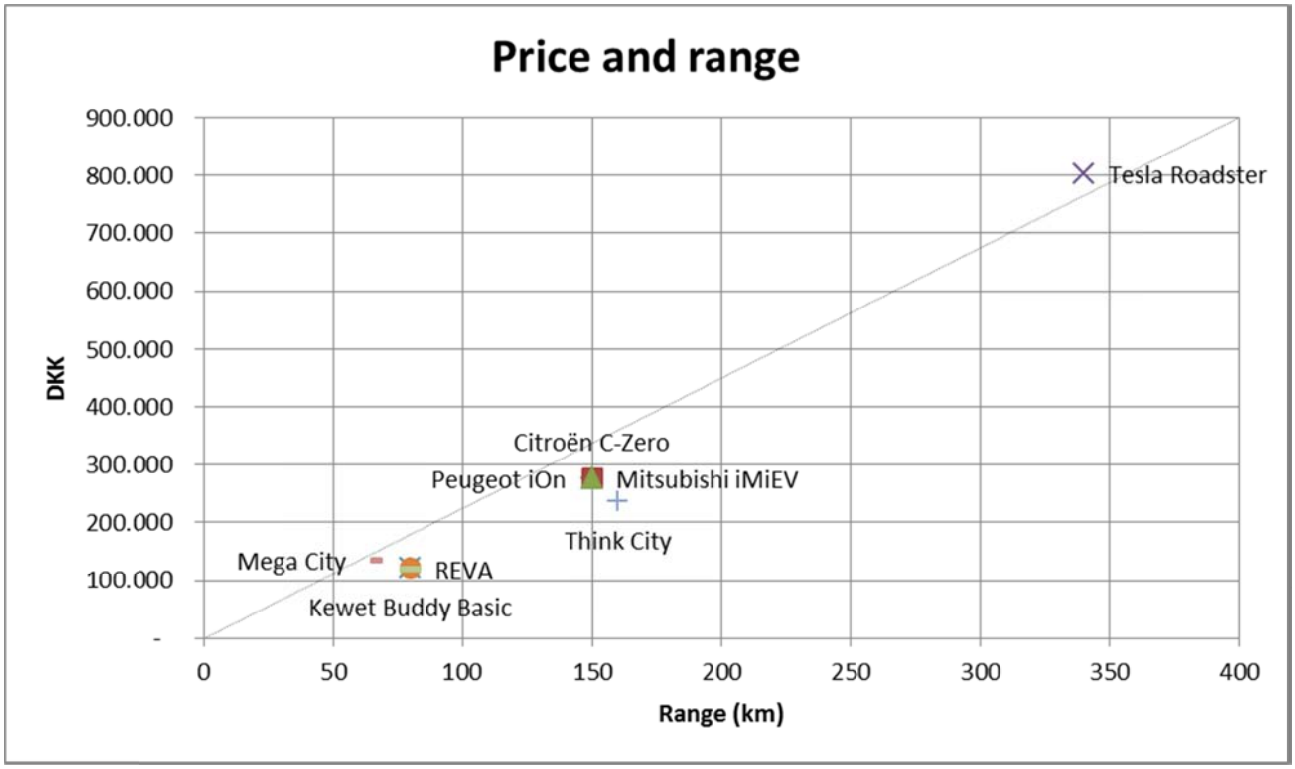

Figure 23: The price and range

11.1.3. Power and top speed

The power capability of a vehicle influences e.g. the acceleration and top speed and other parameters. When comparing the power capability there are huge differences between the sports car and the urban cars, with a factor of 6-15 in difference. The family cars may perform 50 kW, also less than the sports car that thereby offers a high top speed and fast acceleration.

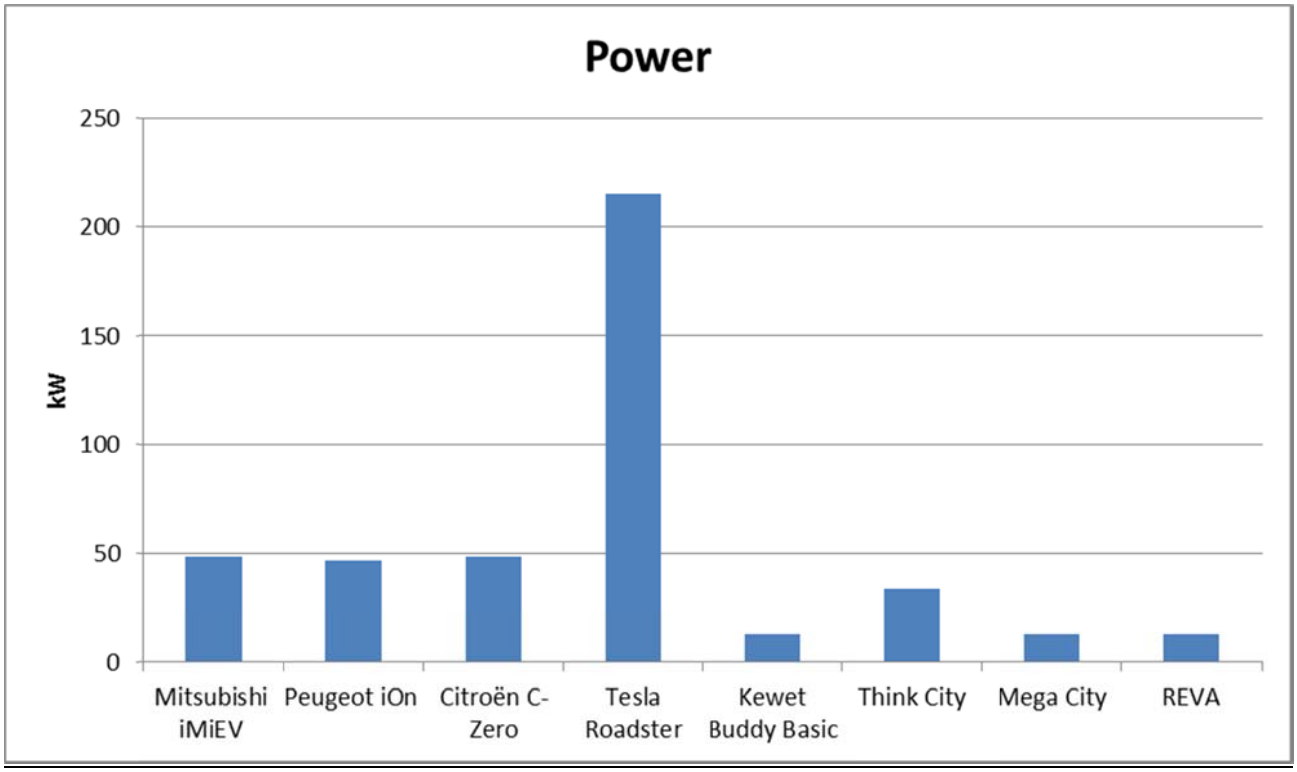

Figure 24: Power capabilities for current electric vehicles

Also when comparing the power capabilities with the price of the vehicles, the sports car has the lowest costs, despite its high investment price. The price per kW for the sports car is around 4,000 DKK/kW, 6,000 DKK/kW for the family cars and between 7,000-10,000 DKK/kW for the urban cars.

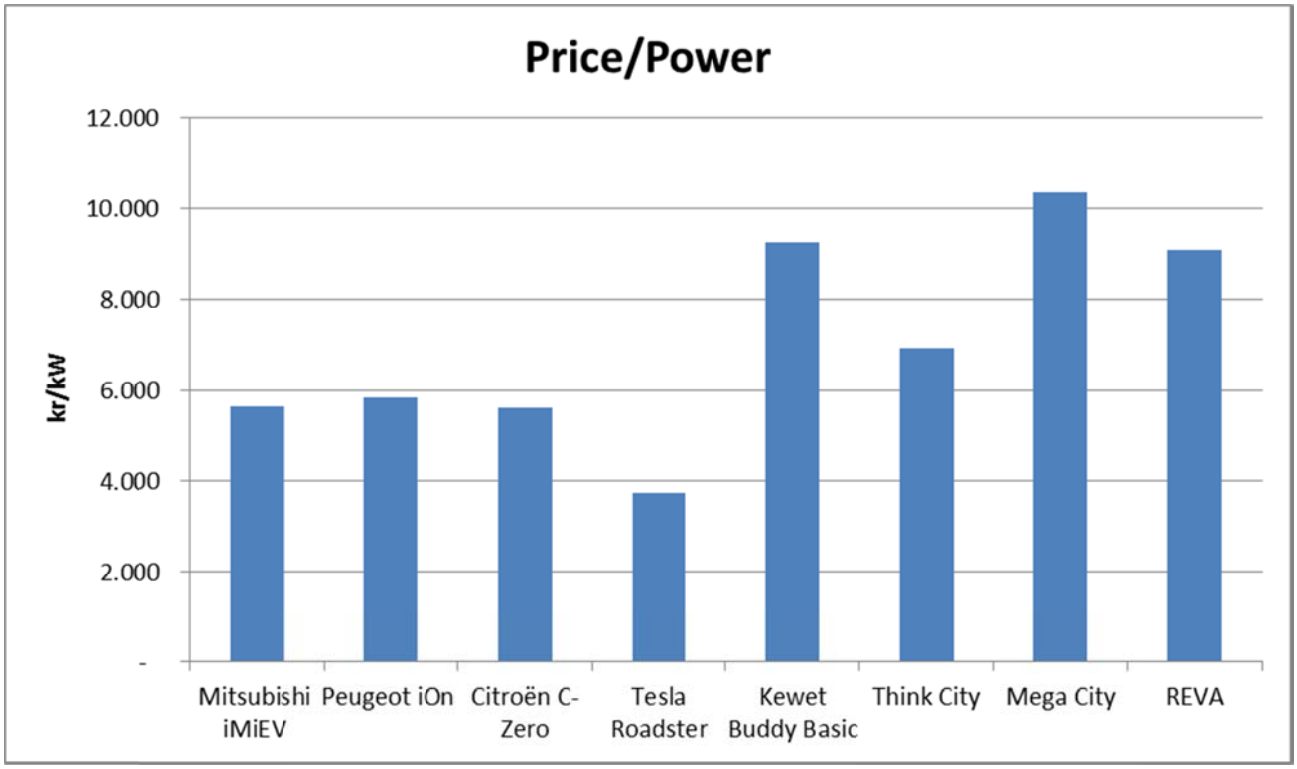

Figure 25: Comparison of price and power

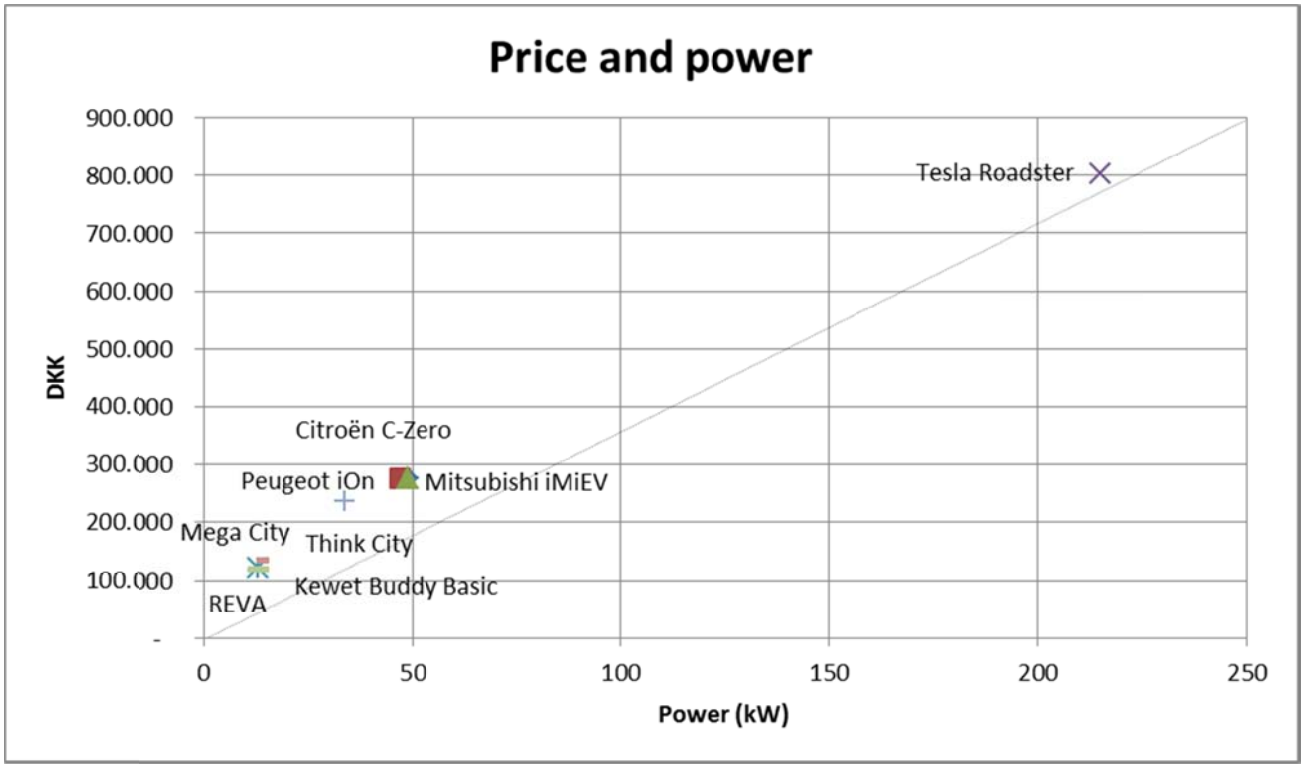

Figure 26: Illustration of price and power

The top speed for EVs are for urban cars not exceeding 100 km/h, while it increases to 135 km/h for family cars and is around 200 km/h for the sports car.

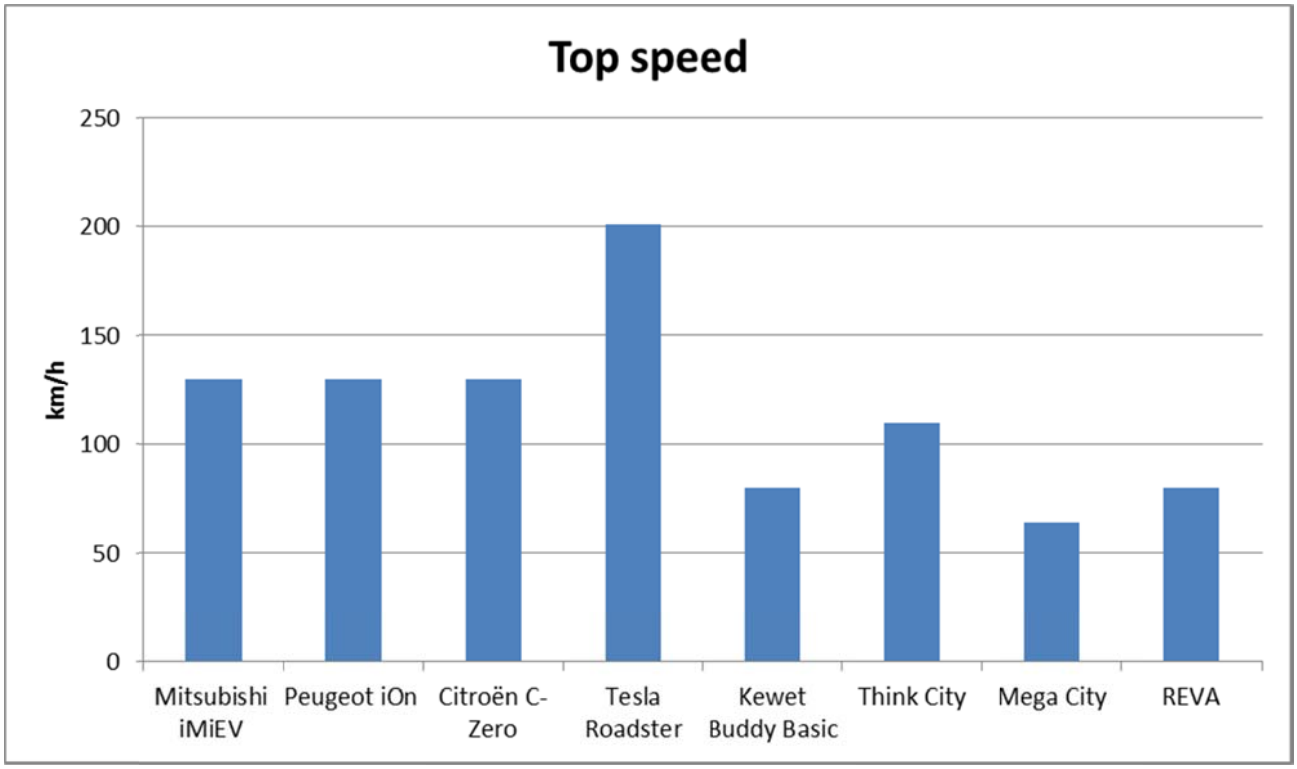

Figure 27: Top speed for EVs <2012

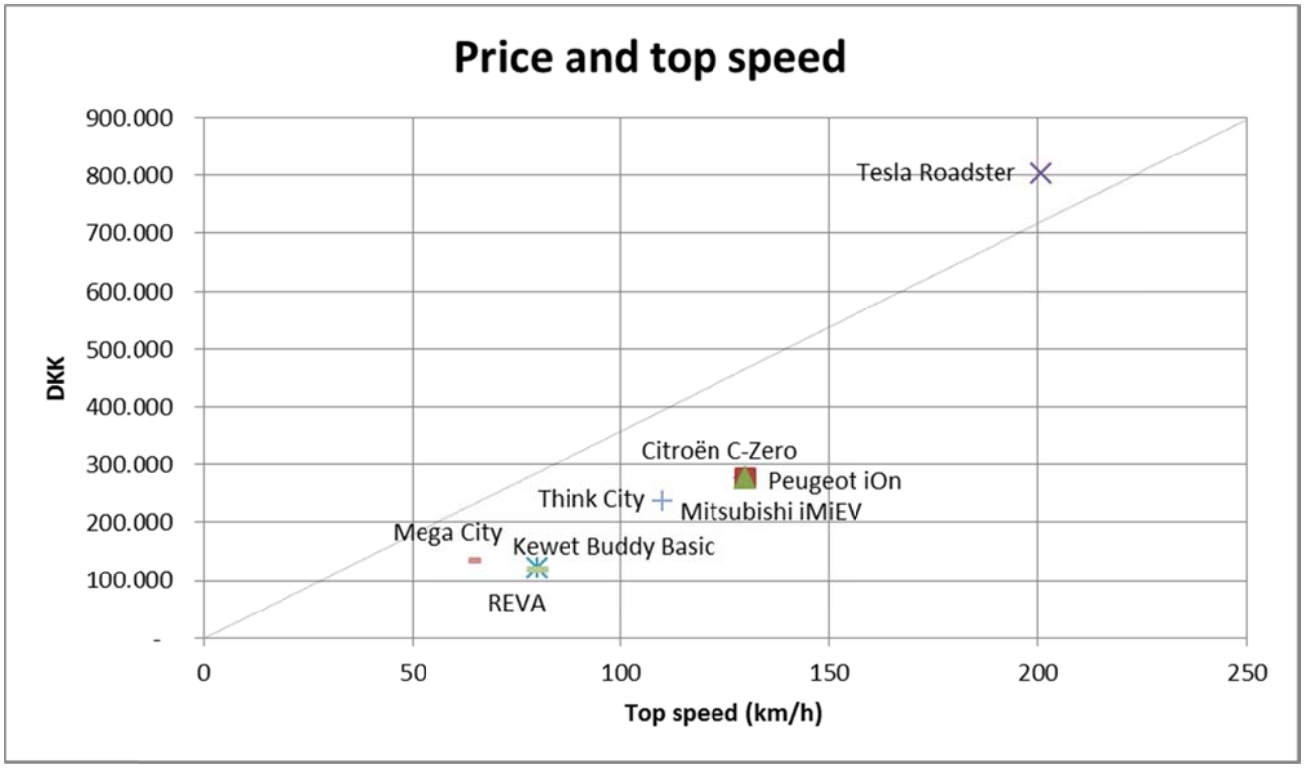

Figure 28: The price and top speed

11.1.4. Energy consumption

The energy consumption describes the fuel efficiency for a vehicle and higher efficiencies might improve the driving range. The energy consumption varies between 120 Wh/km to 190 Wh/km and there are no general tendencies between the different types of vehicles.

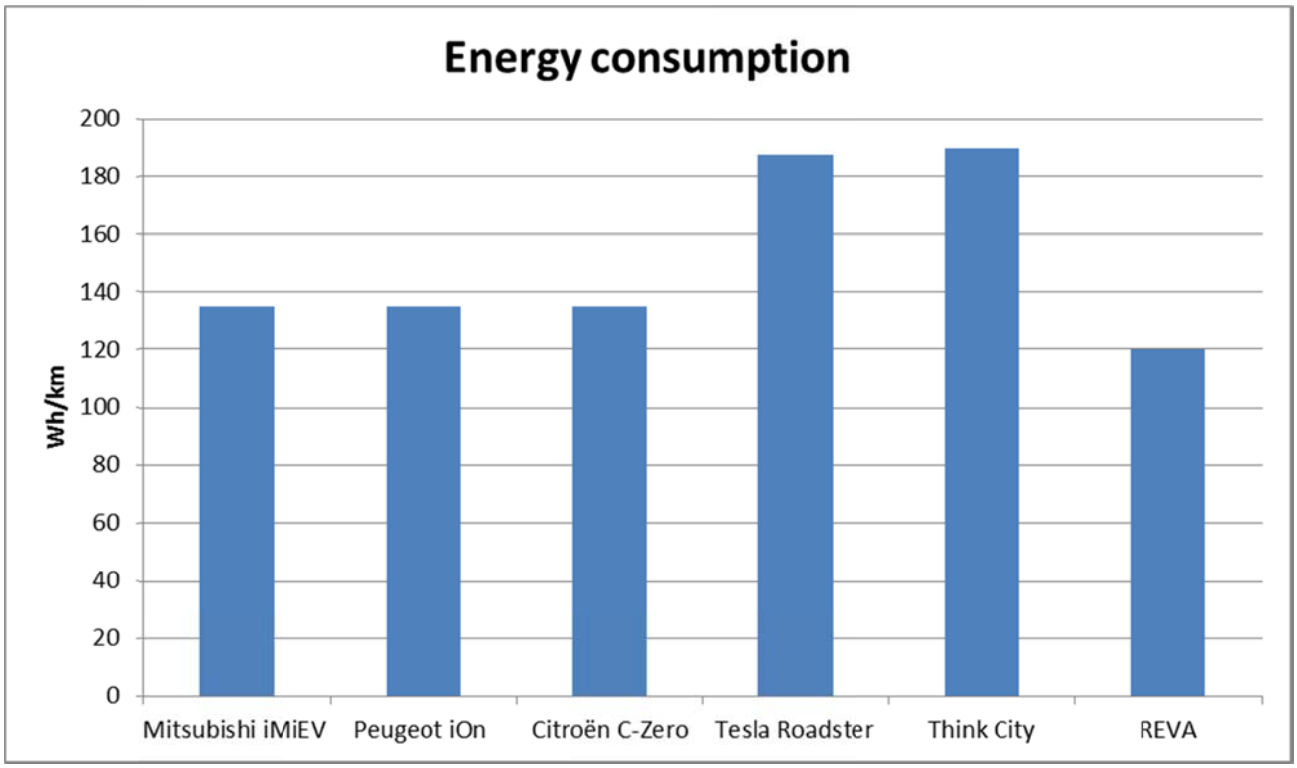

Figure 29: Energy consumption for the different models. Data was not available for all models.

11.2. Electric Vehicles >2012

The development of EVs in the near term can be deducted from the models expected to be launched on the market within a few years. The selected models are expected to be introduced in 2012 or 2013 and further models could possibly have been included. All of the models can be included in the family car category. The model specifications can be found in Appendix A. The models will be compared within investment cost, range, energy storage, and power capability.

11.2.1. Price

The price of the near term EVs is expected to be in the range of DKK 200,000 to 350,000.

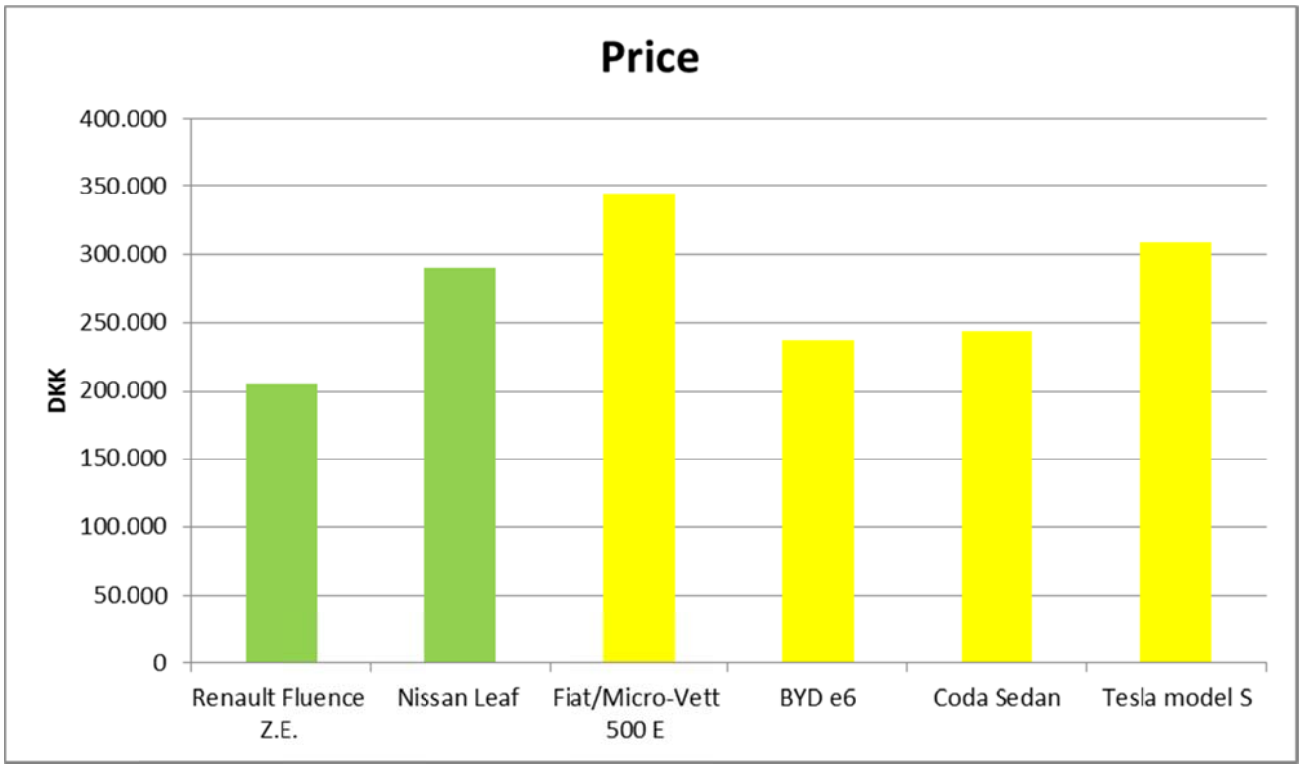

Figure 30: The investment price for near term EVs. The bar colors indicate the price data reference reliability. (green = strong, orange = medium, yellow = low – estimated price)

11.2.2. Range and energy storage

The range and energy storage is also for the near term EVs connected, but is expected to increase slightly from the current technology. Ranges increases to around 300 km for some models of family cars while the energy storage capacity is up to 48 kWh for BYD e6.

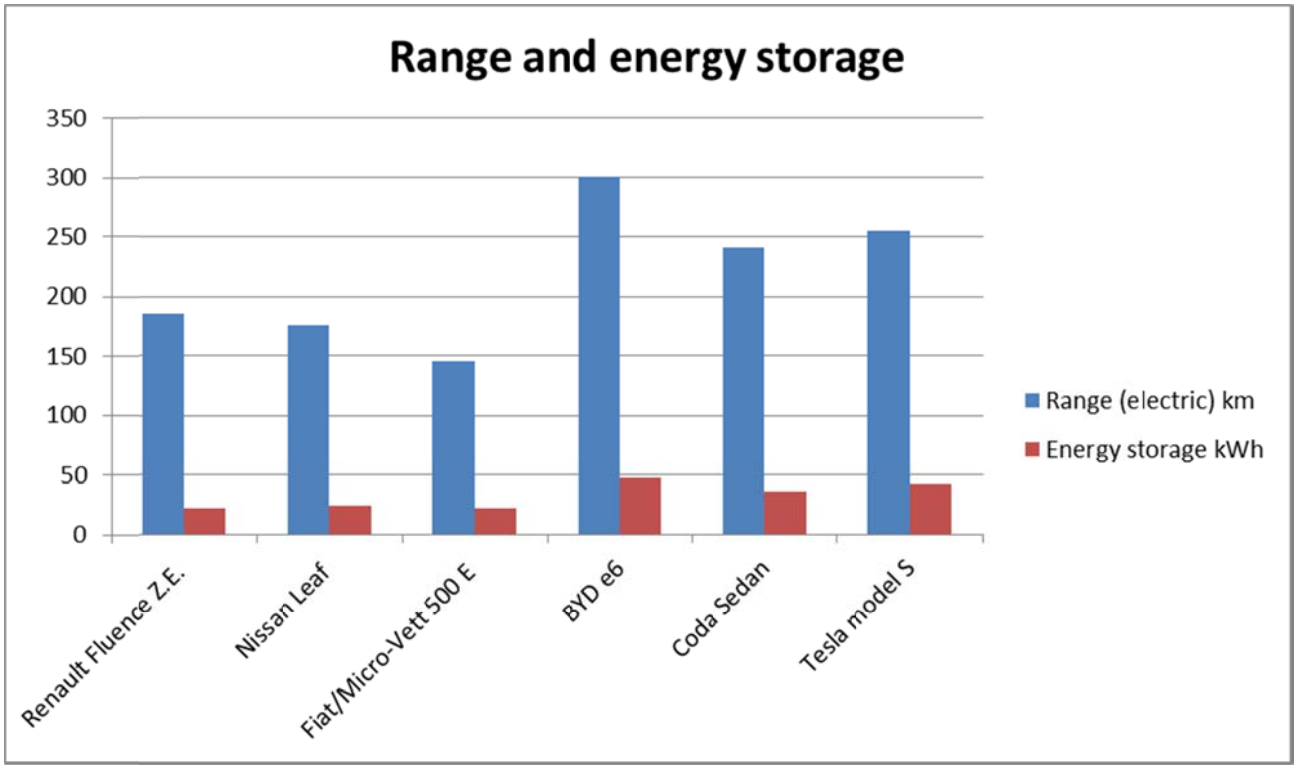

Figure 31: Range and energy storage

As some of the models with the highest range and energy storage capacity also have the lowest investment cost large differences exist when comparing these measures. Especially the BYD e6 model has lower costs than other models per kWh. Actually the dearest car has the lowest range, while the cheapest car has the longest range for EVs >2012.

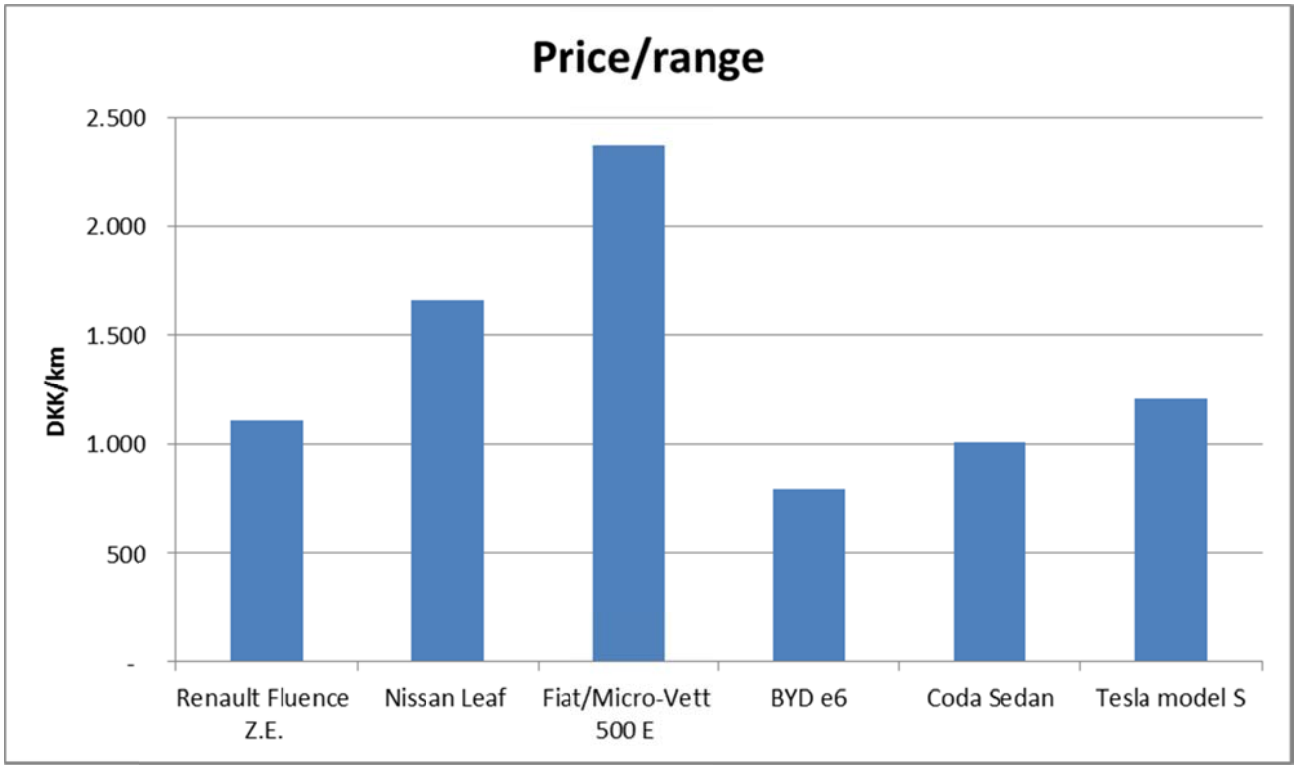

Figure 32: Comparison of price and range

Figure 33: Price and range

11.2.3. Power and top speed

The power capabilities also increase from the current technology as most models can perform more than 60 kW.

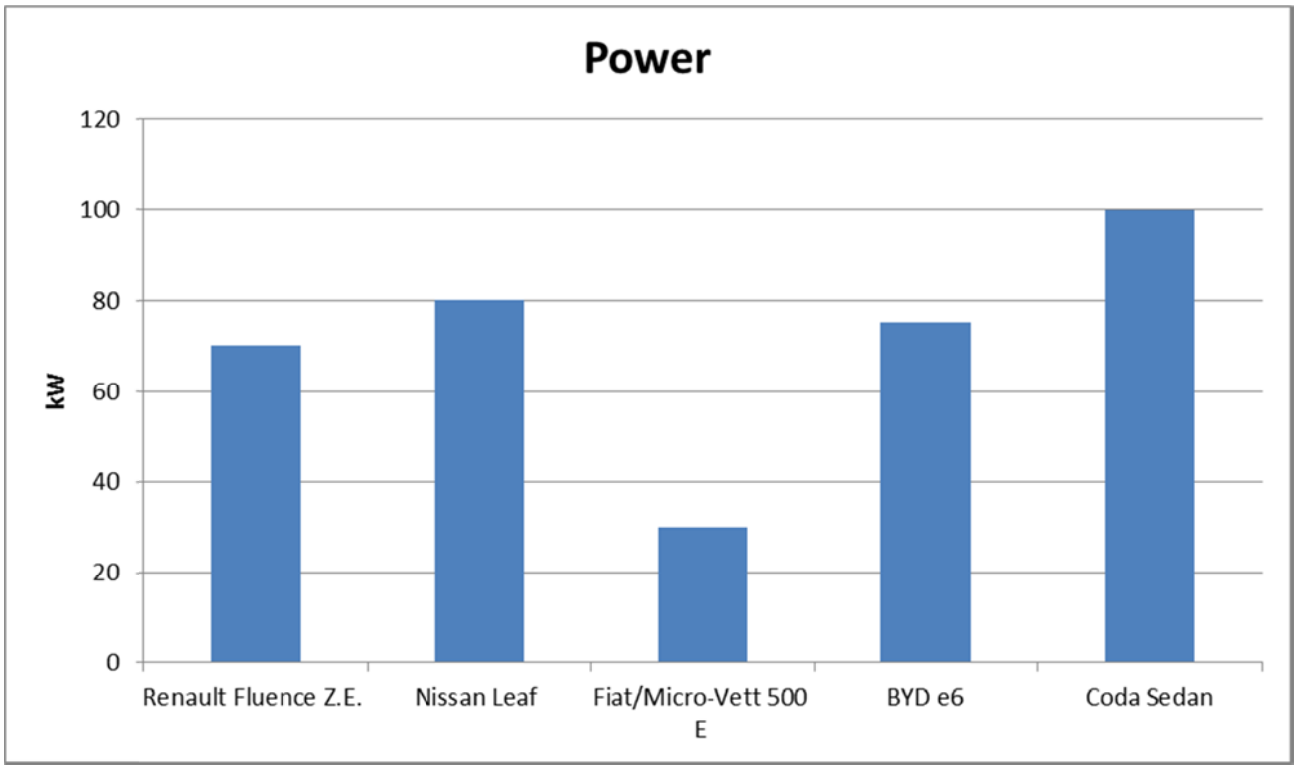

Figure 34: Power capabilities

When including the price the cost per kWh is around 2,400-3,700 DKK/kWh, except for the Fiat/Micro-Vett 500 E with a cost above 11,000 DKK/kWh.

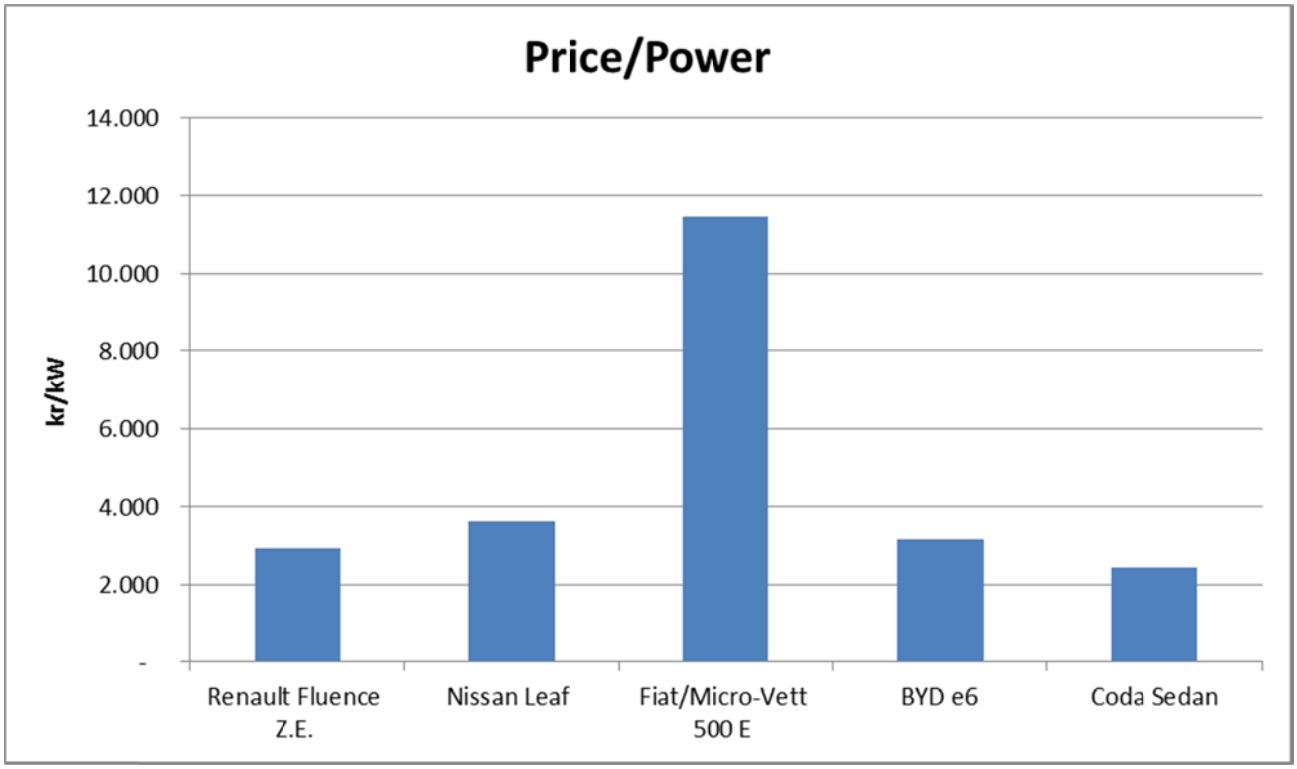

Figure 35: Comparison of price and power capabilities

Figure 36: Price and power capabilities

The top speed for the EVs >2012 varies between 100 and 200 km/h.

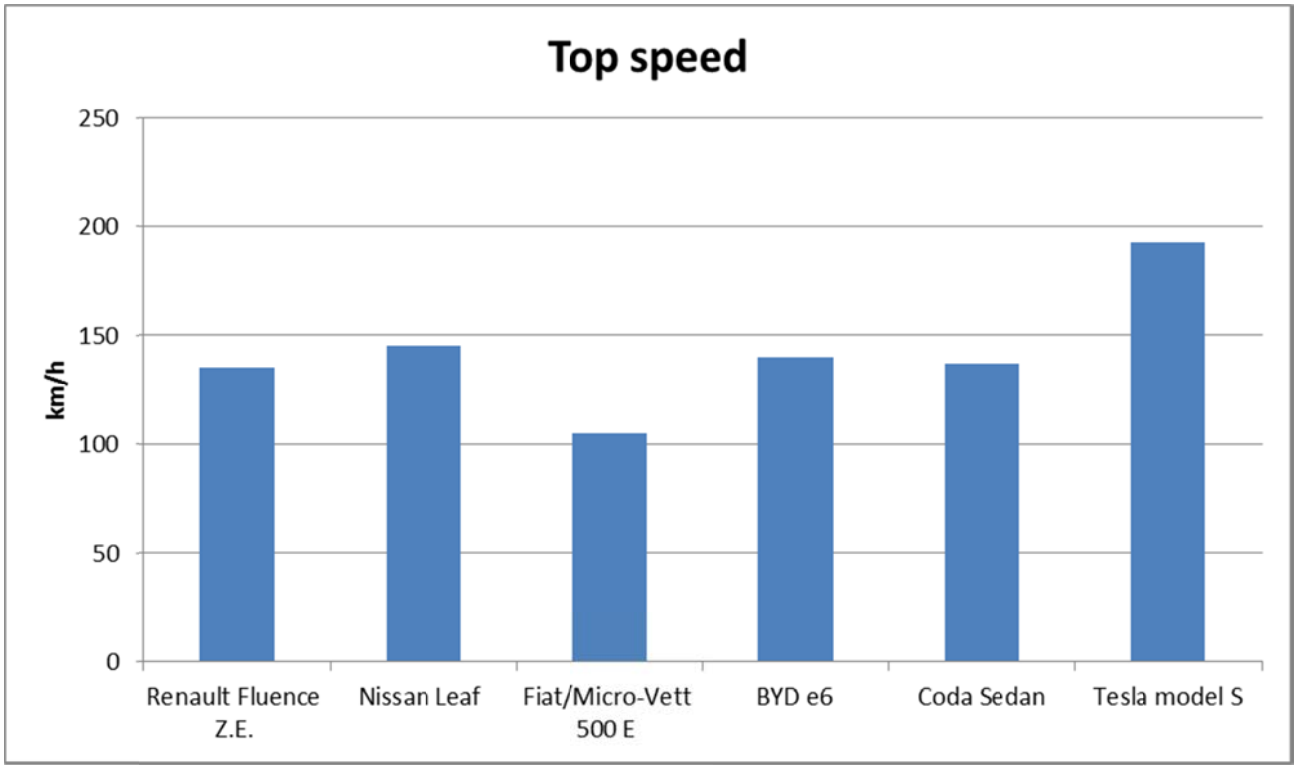

Figure 37: Top speed for EVs >2012

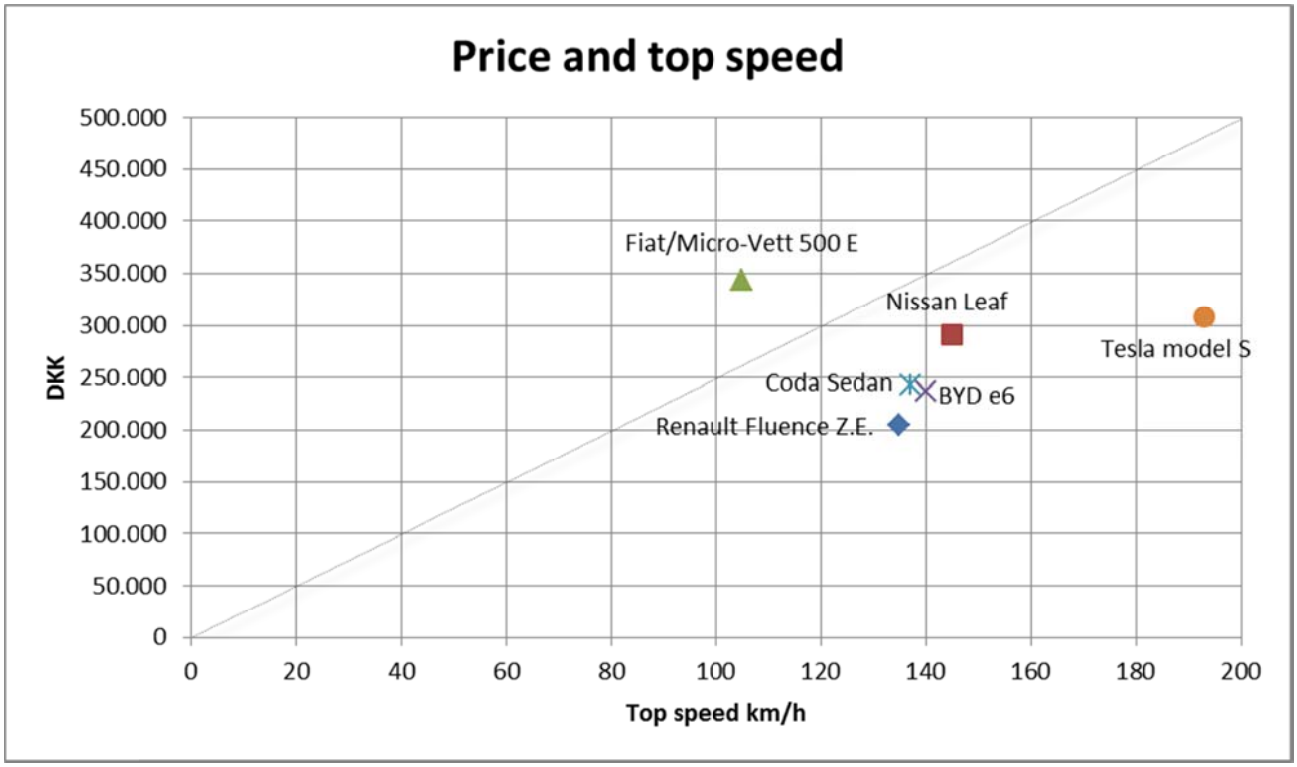

Figure 38: Price and top speed

11.2.4. Energy consumption

The energy consumption for the near term technology has an energy consumption between 150-200 Wh/km and may be a little higher than the current technology due to larger cars and thereby larger weight which reduces the energy efficiency.

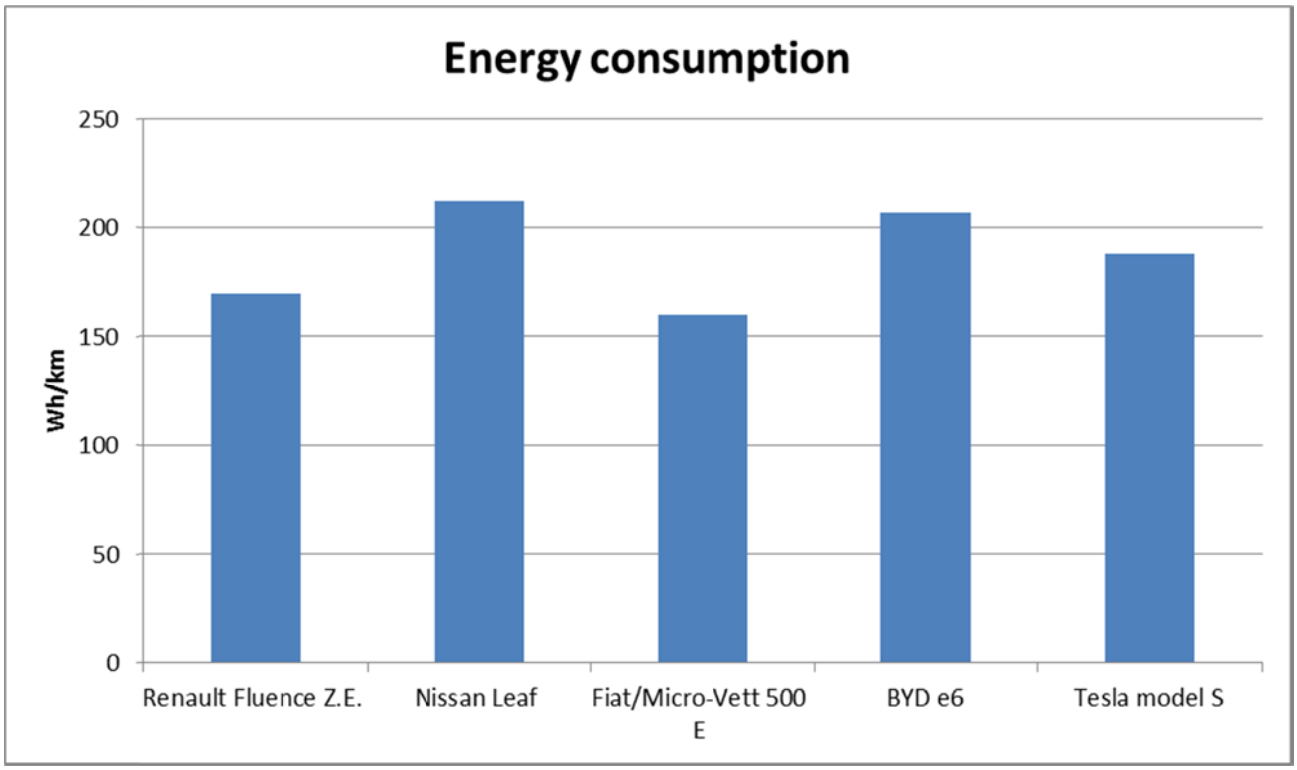

Figure 39: Energy consumption for near term EVs

11.3. Comparison of Electric vehicles <2012 and Electric Vehicles >2012

Analyses comparing performances, prices etc. were carried out between existing and near term technologies to illustrate the expected development.

11.3.1. Price and range

In Figure 40 both current and near term EVs is illustrated according to their investment cost and range. It is apparent that the near term technology has longer ranges than current models, which is caused by higher energy storage capacities in the batteries. The price of the near term technology is a little higher, but is caused by the fact that more family cars are available instead of the cheaper urban cars.

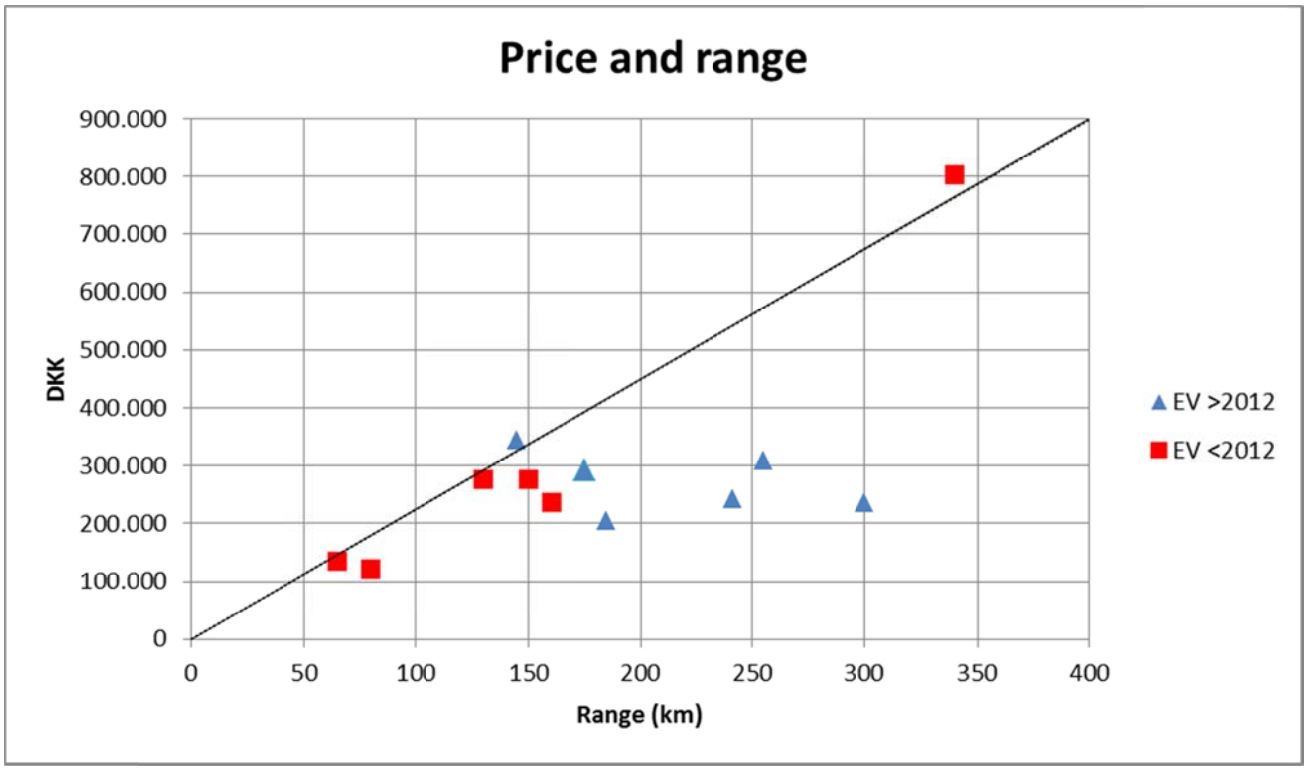

Figure 40: Current and near term technology by price and range

The range and the energy storage capacity for the near term technology is higher than the current technology, see Figure 42.

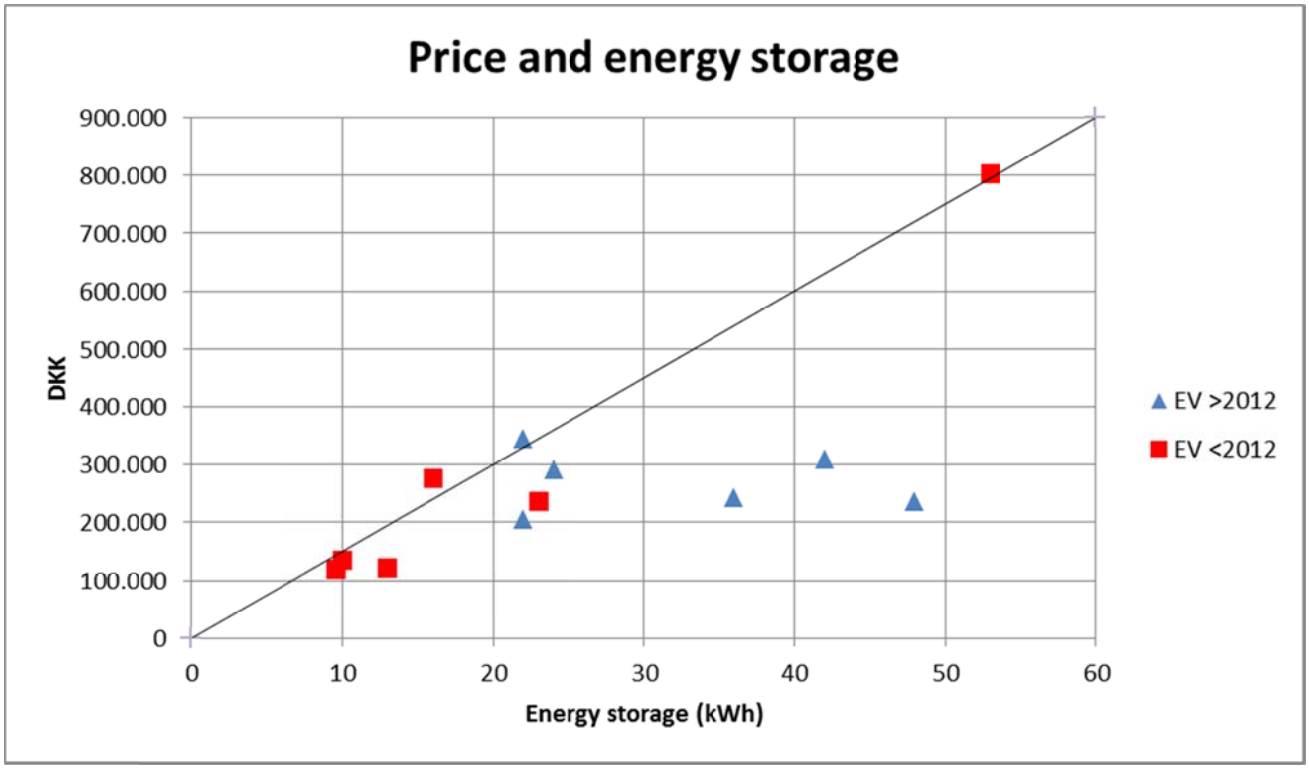

Figure 41: Price and energy storage for current and near term EVs

The range is prolonged due to new battery technology that also reduces the cost per kWh energy storage. In the near term technologies some of the family cars have even lower costs per kWh than the current urban cars. Prices may be reduced to a level around 4,000-6,000 DKK/kWh from the current 17,000 DKK/kWh for cars of the family car type.

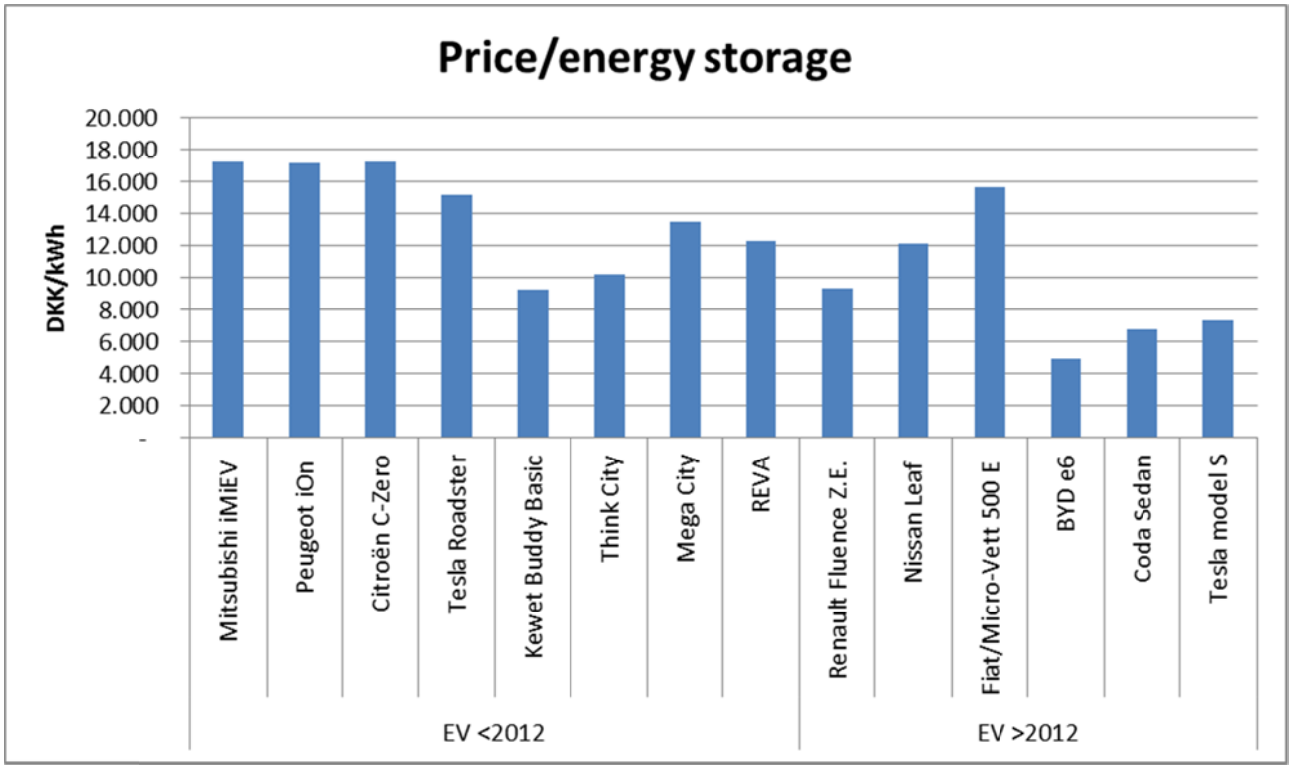

Figure 42: Cost per kWh energy storage capacity in current and near term technology

11.3.2. Power

Also when comparing the power performance improvements will occur for the near term technology. All of the near term models, except one, will have higher power performances than the current urban and family cars.

Figure 43: Comparison of existing and near term technology in terms of price and power capabilities

The new technology will, like with energy storage capacity, reduce the cost per kW for the vehicles. The model from Fiat has however the highest cost per kWh for all near term and current models.

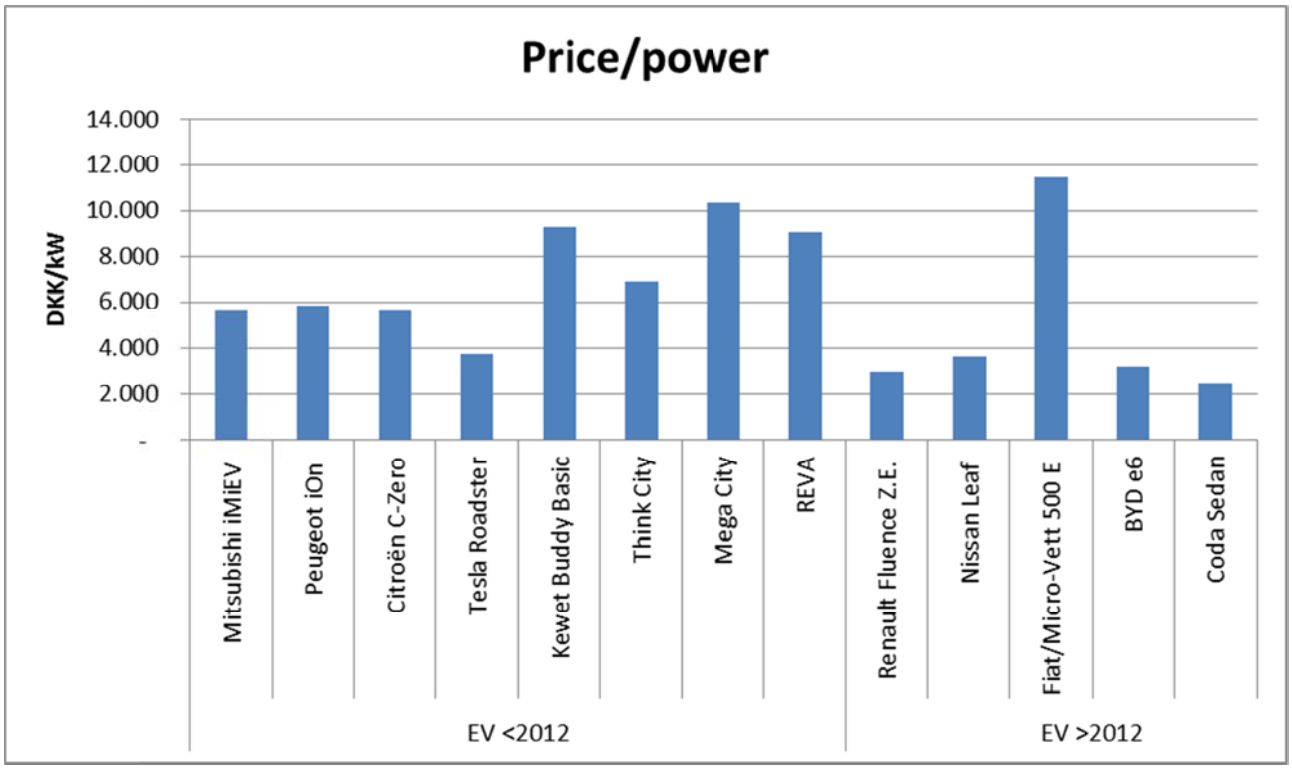

Figure 44: Cost per kWh for near term and current EV technology

The expected top speed for the coming EVs is increasing few km/h in average compared to the existing family cars.

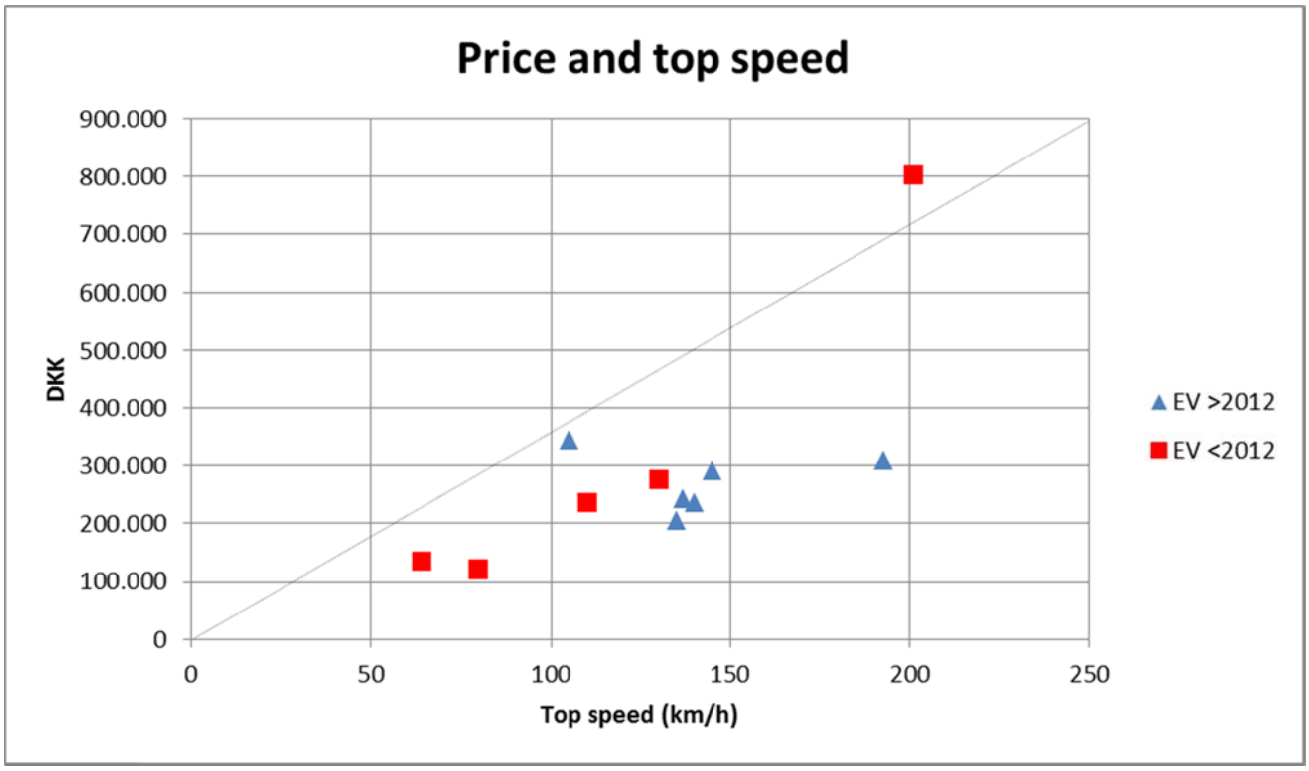

Figure 45: Price and top speed comparison

11.4. Plug-in hybrid electric vehicles

The PHEVs may run on electricity and be recharged from the electricity grid. The models included in the analysis are available on the market as of today and are some of the first and only models being launched. Few other PHEVs are expected to be launched on the market in the coming years. The Chevrolet Volt is categorized as a family car, while the Fisker Karma is a luxury sports car.

11.4.1. Price and range

PHEVs may be driven a certain distance from its electric engine and then switch to the fuel-driven engine when the electric driving range has been exhausted. Hence, a shorter electric range is expected than for EVs as the PHEVs needs to fit in two engines. The price and range of two different types of PHEVs are listed below with an electric driving range that does not exceed 80 km and investment prices of respectively DKK 200,000 and DKK 800,000. The Fisker Karma has however a driving range of more than 500 km when including the liquid fuel driven engine. The Fisker Karma is a so-called EVer – electric vehicle extended range meaning that the fuel in the combustion engine will produce electricity for the electric engine.

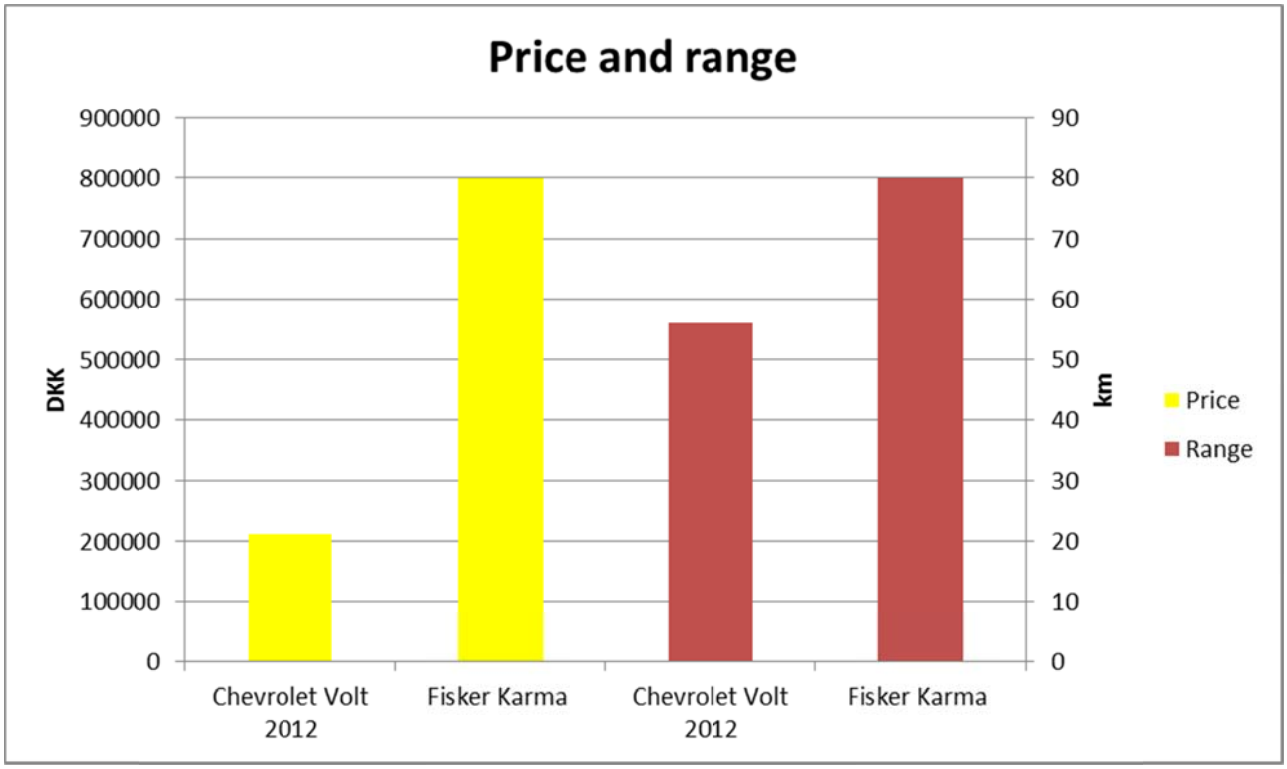

Figure 46: Price and electrical range for current PHEVs. Yellow price bar indicates low price data reliability.

11.4.2. Power, energy consumption, and energy storage

The power and energy storage performances for PHEVs are illustrated in Figure 47. The Fisker Karma model has a high power performance as expected from a sports car and achieves thereby a high acceleration and top speed. The energy consumption for the Fisker Karma is rather high with a consumption around 400 Wh/km. The energy storage capacities are rather low, ranging in the same level as the current urban EVs.

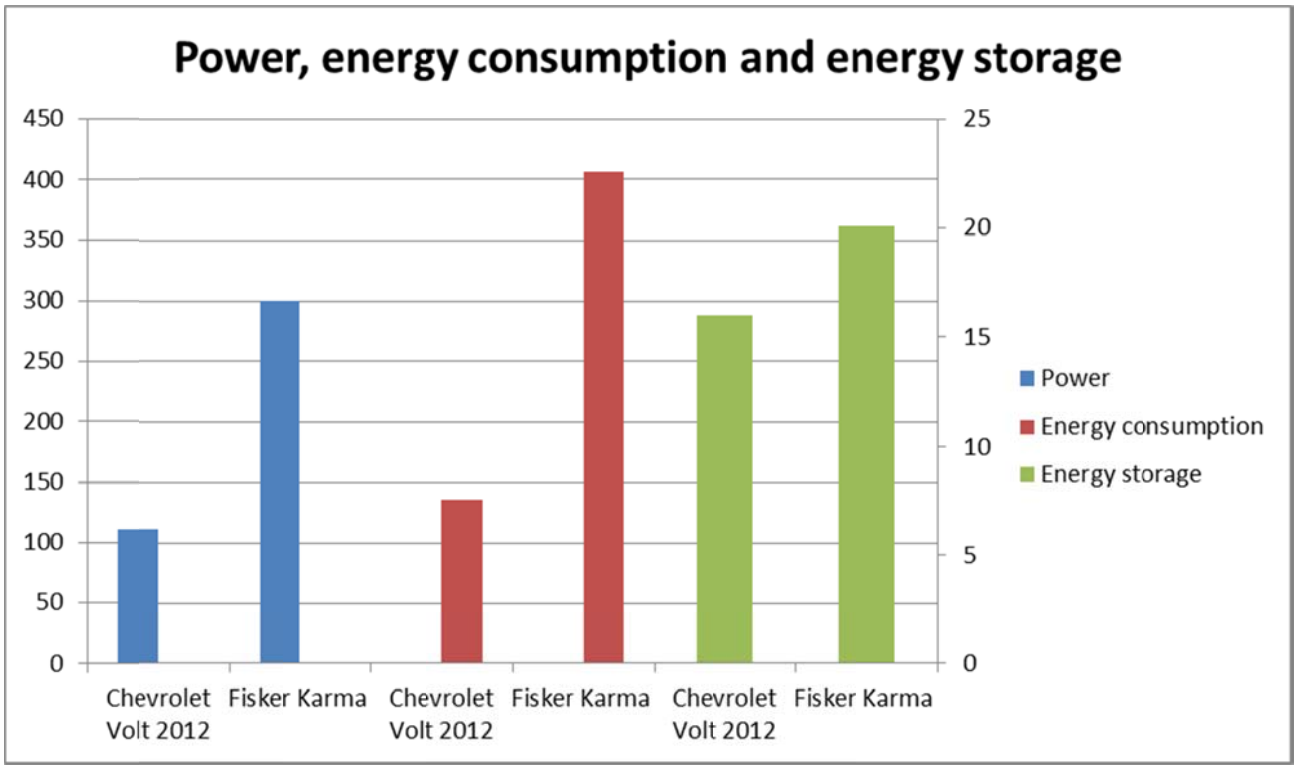

Figure 47: Power, energy consumption and energy storage specifications for current PHEVs. Power and energy consumption performances on primary vertical axis and energy storage on secondary vertical axis.

11.5. Comparison of EVs and PHEVs

To compare EVs and PHEVs following figures were developed with specifications of EVs <2012, EVs >2012 and PHEVs. First a comparison of the range, which depends on the energy storage capacity, was carried out showing that near term EVs >2012 have the longest ranges, in average of more than 200 km, while the EVs <2012 have an average electric range of around 150 km. The PHEVs cannot drive as far on electricity as EVs which is illustrated by the average PHEV electric driving range of 70 km.

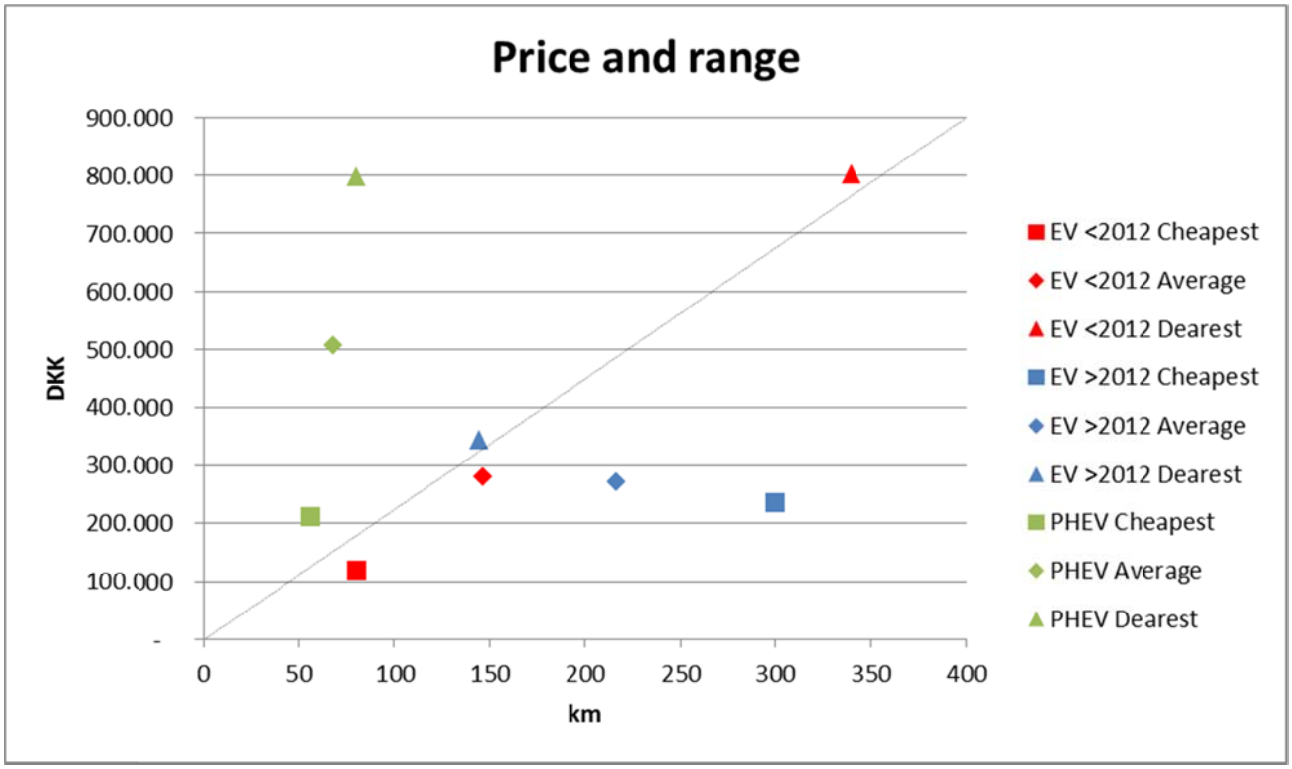

Figure 48: Comparison of price and range between EVs <2012, EVs >2012 and PHEVs

When comparing the top speed and the price between the current and future EVs and the PHEVs it is evident that the average top speed for EVs <2012 and EVs >2012 is not very different. This is however because a sports car was included in the category of EVs <2012, otherwise the EVs >2012 have higher maximum speeds. In same way is a sports car included in the PHEV category which affects the average top speed and makes it higher than for the other vehicle types. The top speed is also a good indicator for the power performance of a vehicle and the results regarding top speed may also apply for power capability.

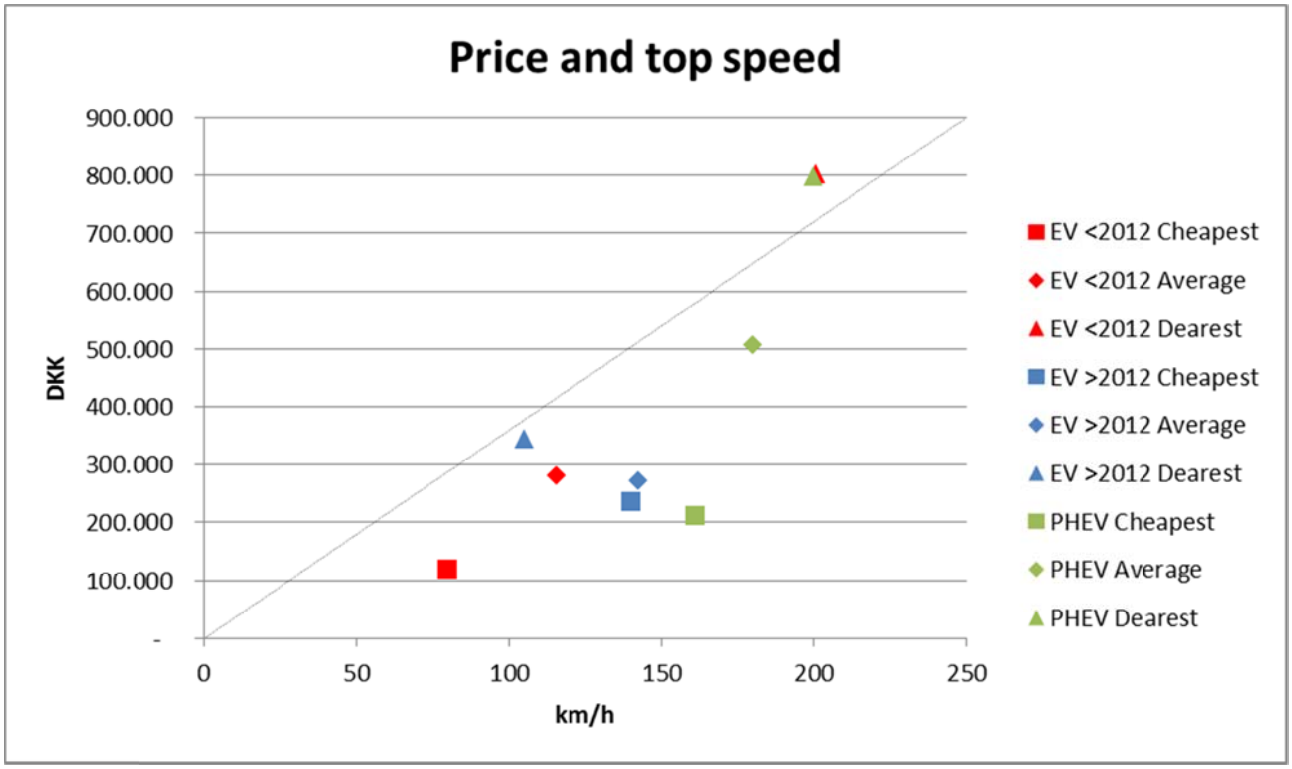

Figure 49: Comparison of price and top speed between EVs <2012, EVs >2012 and PHEVs

11.6. Hybrid electric vehicles

An example of a HEV was also selected for the analysis. The Toyota Prius 1.8 T2 is the most sold HEV on the market and is categorized as a family car.

The investment price and the power capability for a HEV are outlined in Figure 50.

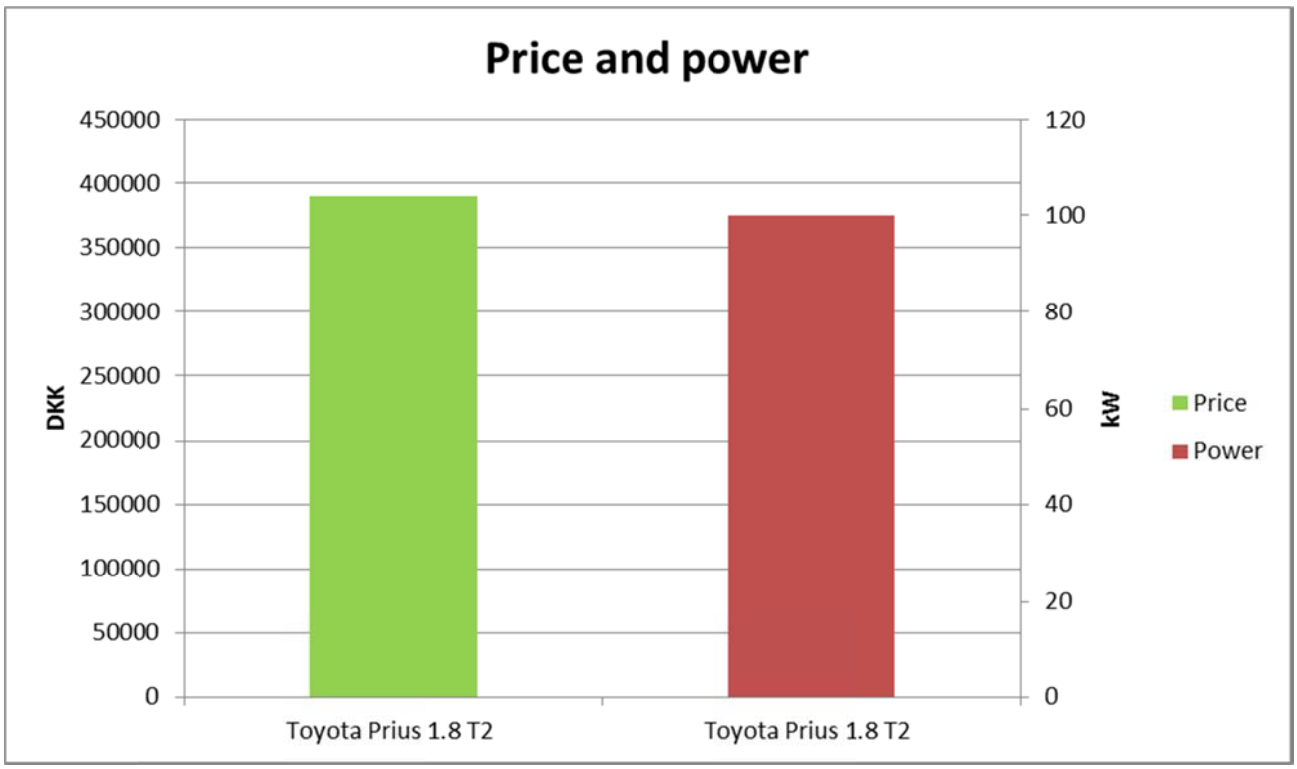

Figure 50: Price and power specifications for a HEV. Green price bar indicates strong price data reliability.

11.7. Electric vans

Two different vans are included in the analysis to demonstrate the current state of electric van technology.

The prices for the selected models vary between DKK 150,000 and DKK 250,000 and have a driving range of 120 km and 160 km respectively. The energy storage capacity is around 20 kWh.

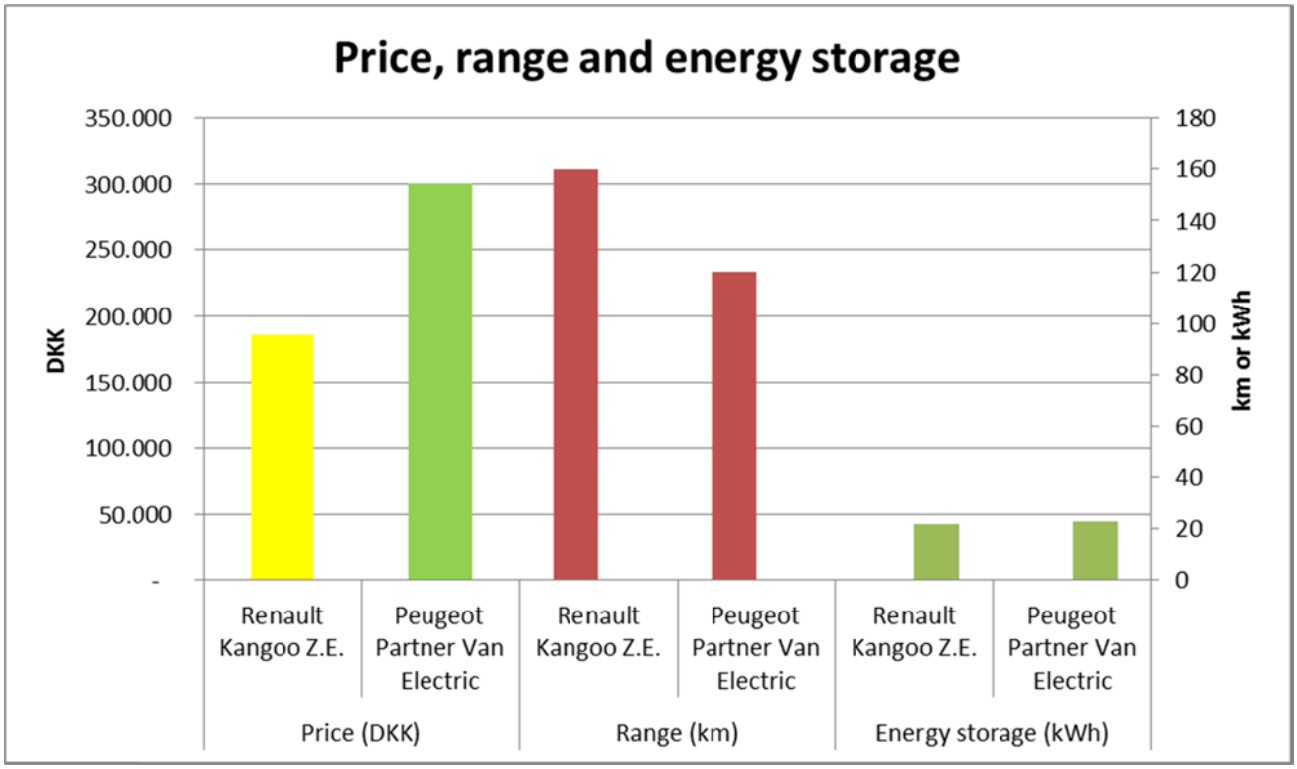

Figure 51: Price, range and energy storage for electric vans. Price reliability: yellow = low, green = strong. Price is on primary vertical axis, range and energy storage are on secondary vertical axis.

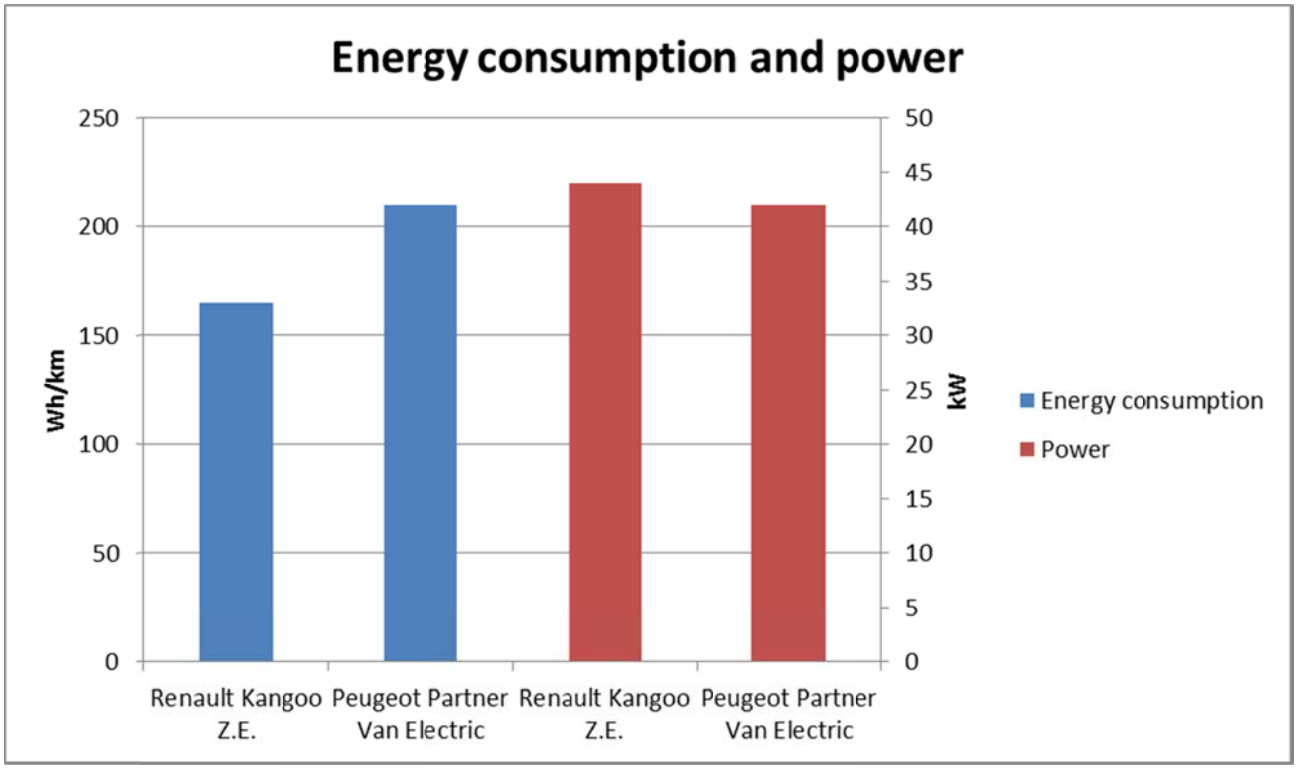

Figure 52: Energy consumption and power for electric vans

11.8. Electric trucks

Some electric trucks are also available on the market, but the electric trucks have a shorter range and lower top-speed than conventional ICE trucks and can hence primarily be used for urban driving.

The price for an electric truck is around DKK 800,000 with a power performance of respectively 70 and 120 kW.

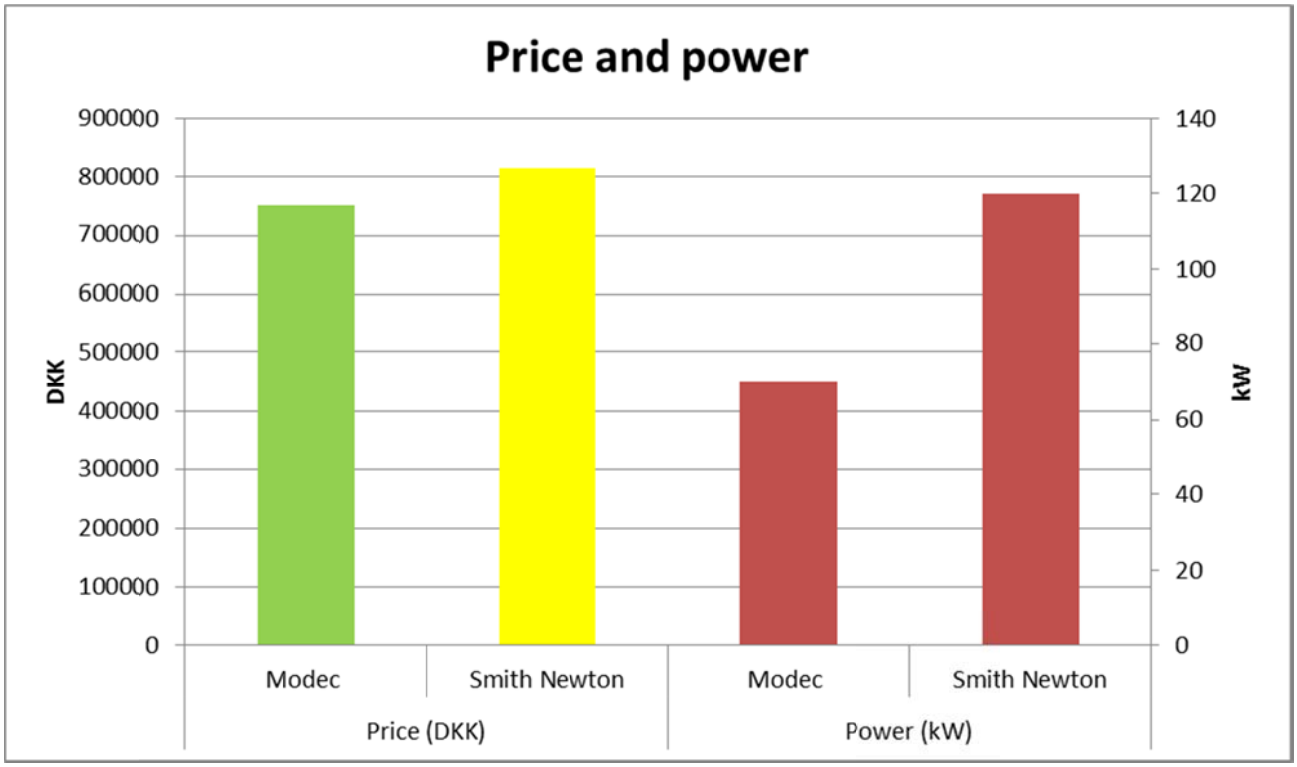

Figure 53: Price and power for current available electric trucks. Green bar color indicates strong price data reliability and yellow is low reliability.

The electric range is limited to around 160 km and as trucks often drive long distances frequent recharges might be necessary. The energy storage capacity is in the area of 100 kWh.

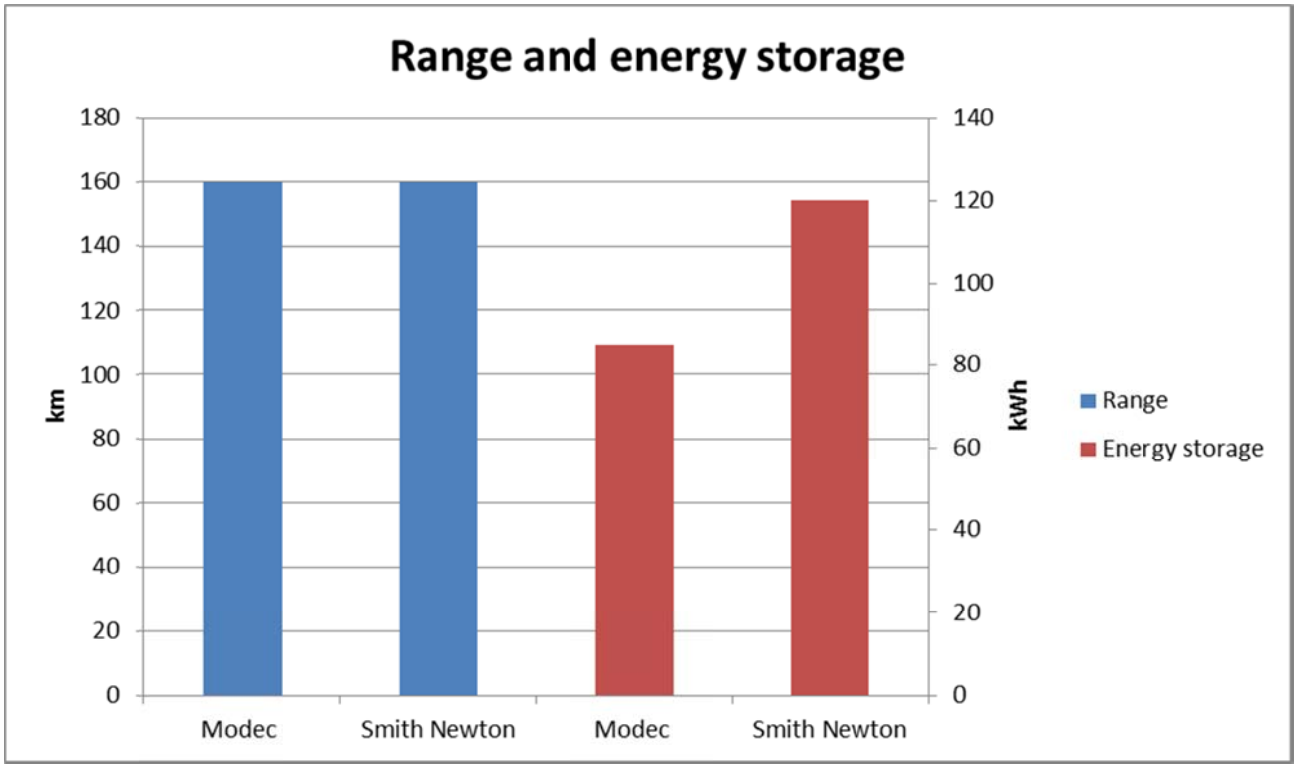

Figure 54: Range and energy storage for electric trucks

11.9. Summary of analysis

The following is a summary of the analysis for each vehicle type.

11.9.1. EVs < 2012

The current EV technology has investment prices varying from DKK 300,000 for family cars to DKK 800,000 for a sports car and to between DKK 100,000 to DKK 230,000 for the smaller urban cars. The range is typically not more than 150 km, not including the sports car, and the power performance does not exceed 50 kW. The price compared to energy storage capacity indicates that the urban cars have the lowest cost per capacity but also the highest cost per power performance. This is to give the urban cars as long driving range as possible and these cars does not need to perform as fast accelerations etc. The family cars have longer ranges and higher power capabilities and is thereby capable of meeting different types of driving patterns better. The energy consumption varies from around 120 Wh/km to 190 Wh/km with no general tendencies between the vehicle types.

11.9.2. EVs > 2012

The near term EVs are expected to have investment costs around DKK 200,000 to DKK 350,000, all categorized as family cars. The range is expected to be more than 150 km for all models and may top at 300 km while the energy storage capacity varies from around 20 kWh to 50 kWh. The price compared to energy storage capacity indicates that the cost per kWh may be as low as 4,000 DKK/kWh and as high as 15,000 DKK/kWh for some models. This is a huge difference for the same type of car. Also when comparing the power capabilities differences appear as most EV models is between 70-100 kW, but may be reduced to around 30 kW in another model. This gives some of the models the ability of driving longer ranges and achieves higher top speeds and accelerations. The energy consumption is fairly equal and is in the range of 150 Wh/km to around 200 Wh/km. Some differences in the performance measures is thus present between the different EV models in the near term technology.

11.9.3. Comparison of current and near term EVs

The price for the near term EV models is in general a little higher than the current models, but may be caused by the fact that more family cars are introduced instead of the smaller and cheaper urban cars. The range is however prolonged for most of the models and may be as high as 300 km. This is due to the fact that new battery technology is integrated in the vehicles and the energy storage capacities following increases. Also the cost per kWh energy storage capacity is reduced, especially when comparing the family cars. When looking at the power performances the near term technology will have higher features than the current. Comparing the family car types, a halving will occur for the cost per kW of power. The near term technology and especially the battery performances will increase which leads to a longer electric driving range and higher power performances. The energy consumption will not change dramatically within the near term while the top speed increases slightly from the current level due to higher power capabilities. The batteries will in the near term primarily be lithium-ion technology and the charge time will be 6-8 hours, not very different from the current time needed.

11.9.4. PHEVs

The price for two of the first PHEVs launched on the market is respectively around DKK 200,000 and DKK 800,000 with electric driving ranges below 80 km. The energy storage capacity is around 20 kWh, which is part of the reason for the rather low electric range. The power performance is 100 kW for the family car and 300 for the sports car, giving a high top speed and acceleration. The energy consumption is fairly high

for the sports car around 400 Wh/km and for the family car it is around 150 Wh/km, not very different from the EV family cars.

11.9.5. Comparison of EVs and PHEVs

The comparison of EVs <2012, EVs >2012 and PHEVs indicated that the models launched in 2012 or later have longer ranges than models with the current technology. The average range increased from around 150 km to more than 200 km. The PHEVs are not constructed for driving long ranges electrically, but rather a longer total range when including the ICE, and have thus the shortest electric ranges. In the comparison of top speed the difference was not as significant as for the range, but an overall guideline is that the future EV models have a little higher top speed than the existing, when excluding sports cars. The PHEVs have however the highest top speeds and the highest power capabilities.

11.9.6. HEVs

The investment cost for the selected HEV model is quite high and is for instance not included in the registration tax exemption in Denmark. The price is higher than EV family cars current and near term as well as the PHEV family car. It has a very low electric driving range and may not be recharged from the grid. The power performance is around 100 kW.

11.9.7. Electric vans

Two different electric vans were included in the analysis with prices of DKK 150,000 and DKK 250,000. Their driving range is 120-160 km and is thereby mostly for urban driving with relatively short distances. The energy storage capacity is around 20 kWh and the vans have a power performance just above 40 kW. The energy consumption is between 165-210 Wh/km.

11.9.8. Electric trucks

The price for an electric truck is around DKK 700-800,000 and may perform up to 120 kW. The high power capability is necessary because of the trucks' high weight. The range for the trucks is around 160 km with a top speed of 80 km and the trucks may therefore be excluded from driving on the high speed roads. Most of the current trucks are used in urban areas, driving goods between factories and suppliers.

11.9.9. Specifications

An overview of most of the specifications is outlined in Table 9.

Table 9: Specifications for EVs, PHEVs, HEVs, electric vans and trucks

Vehicle type	Price	Range (electric)	Energy storage	Power	Energy consumption	Top speed (electric)	Charge time
Unit	1,000 DKK	km	kWh	kW	Wh/km	Km/h	Hours
EV <2012	118 - 803	65-340	10-53	13-215	120-190	64-201	3.5-9.5
- Family car	275	150	16	47-49	135	130	6-8
- Sports car	800	340	53	215	188	201	3.5
- Urban car	118-235	65	10	13	120-190	64-110	7-9.5
EV >2012	205-344	145-300	22-48	30-100	160-212	105-193	6-8
PHEV	212-800	56-80	16-20	111-300	135-406	161-200	-
- Sports car	800	80	20	300	406	200	-
- Family car	212	56	16	111	135	161	4
HEV	389	2	-	100	-	45	-
EV van	186-300	120-160	22-23	42-44	165-210	112-130	7-8
EV truck	750-813	160	85-120	70-120	498	80	8

12. Key findings

The key findings are summarized below for each chapter.

Technology, advantages and challenges

- The battery is the key feature regarding improvements of cost, range, safety, life expectancy, etc.
- EVs have the largest potential for reducing CO_2 emissions, noise and air pollution.
- EVs can improve the energy efficiency in terms of energy consumption/km.
- EVs can reduce the operation and maintenance costs as well as the dependency on fossil fuels.
- EVs need to overcome a number of issues including: driving range, investment cost, standardizations, required infrastructure, safety, consumer knowledge, and battery technology

Status on diffusion

- The EV and PHEV market is evolving rapidly and new models are announced from many different companies with the first generation of mass-produced EVs being launched recently.
- The first generation of EVs includes many smaller models/urban cars because of their lower mass and thereby increased range.
- Most models in the large car segment (which includes sports cars) are marketed at high earners and early adopters of technologies and are well suited for early EVs.
- Few PHEVs are available, but may be seen as a key technology in the development from ICE technology to all electric vehicles.
- Several electric vans and trucks are available.
- Between 600-800 electric cars are driving on the Danish roads, and less than two per thousand new registered cars were EVs or PHEVs in the first nine months of 2011.
- Less than one per thousand new registered cars was EV or PHEV in the first nine months of 2011 in Sweden and the total amount of EVs is less than 500.
- Around 1 million vehicles with some sort of battery propulsion system globally exist globally.
- In 2011 it is expected that around 55,000 EVs have been sold worldwide with largest sales figures in Japan and China.

Development

- The market share of EVs and PHEVs in Denmark could increase in the coming years because of good local conditions for implementation.
- The market share of EVs and PHEVs in Sweden could increase in the coming years because of good conditions and a long tradition of auto production and development of innovative transport solutions.
- The market share of EDVs internationally could increase up to a share of 7-20% and may be very difficult to forecast as new technology, policies etc. could change.
- Batteries will experience large improvements within the coming years and the cost may be reduced to a price below USD 400 per kWh or lower. Also weight and expected lifetime will improve for EV batteries.

Business models

- Because of their high up front cost other business models than direct purchase may be necessary to encourage the uptake.

- Leasing of batteries or vehicles are possible alternatives to a direct purchase of an EV.
- Renting or sharing EVs are made possible through the establishment of car clubs.

Policies

- The Danish Government has developed a plan to promote initiatives regarding implementation of EVs and PHEVs. Electric vehicles are exempted from paying registration tax in Denmark until end of 2015.
- The Swedish Government has established a policy to promote green cars and set up an EV target for 2030. Cars can receive a tax exemption in Sweden from the motor vehicle tax (fordonsskat) if reaching certain specifications for different vehicle types.
- An international roadmap has been developed by IEA to describe the required actions to promote the diffusion of EVs and PHEVs.

Research, development and demonstration projects

- Research and demonstrations projects in Denmark have been launched to demonstrate the impact of EVs in a geographically limited transport system. Other projects focus on developing the infrastructure, gathering everyday experiences with electric vehicles and integrating fluctuating energy production.
- Research and demonstration projects in Sweden have been launched to demonstrate EVs in a transport system and to promote the growth of the Swedish auto industry. Other projects focus on the integration of EVs and the social impacts of car ownership.
- A lot of research, demonstration and demonstration programs are being carried out internationally funded by many European countries, United States and China, etc. The projects focus on research about electric and hybrid cars and Logistic and intelligent transport systems and the development and diffusion of EVs.

Current and near term technology

- EVs <2012: Investment cost for family cars are around DKK 300,000 and between DKK 100,000-230,000 for urban cars. The range is below 150 km for family cars and urban cars and they have a top speed just below 100 km/h for urban cars and just above 100 km/h for family cars.
- EVs >2012: The investment cost is expected to be DKK 200,000-350,000 for family cars for the coming models. The range is between 150-300 km while the top speed varies between 100 and 200 km/h.
- Comparison of EVs <2012 and EVs >2012: The price is unchanged for family cars while the range increases from around 150 km to more than 200 km in average. The top speed increases few km/h for the EVs >2012.
- PHEVs: The price for a PHEV is respectively around DKK 200,000 and DKK 800,000 with electric driving ranges of 60 and 80 km. The total driving range when including the liquid fuel driven engine is more than 500 km. The energy storage is just around 20 kWh.
- Comparison of EVs and PHEVs: The EVs >2012 have the longest ranges with an average of more than 200 km, EVs <2012 have a range around 150 km while the PHEVs have an electric range around 70 km. The top speed between the different vehicle types is almost similar when excluding the sports cars.

- HEVs: This type of car has an electric range of a few kilometers and an investment price of almost DKK 400,000.
- Electric vans: The electric vans in the analysis have investment costs of DKK 150,000-250,000 and a driving range of 120-160 km.
- Electric trucks: The electric trucks in the analysis have investment costs of around DKK 800,000 and an electric driving range of 160 km. The trucks could hence primarily be used for urban driving.

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