MSc Program
Renewable Energy Systems

The impact of EU and Netherlands policies to instal Public Charging Infrastructure (Levels 2 and 3) in the Netherlands: A case study of its financial viability

A Master's Thesis submitted for the degree of
"Master of Science"

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Affidavit

I, **JAIDEV DHAVLE**, hereby declare

1. that I am the sole author of the present Master’s Thesis, "THE IMPACT OF EU AND NETHERLANDS POLICIES TO INSTAL PUBLIC CHARGING INFRASTRUCTURE (LEVELS 2 AND 3) IN THE NETHERLANDS: A CASE STUDY OF ITS FINANCIAL VIABILITY", 106 pages, bound,and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master’s Thesisas an examination paper in any formin Austria or abroad.

Vienna, 13.10.2017

Signature

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Last, but, by no means the least (rather the most important) I would like to express the deepest of gratitude's to my parents and brother for encouraging and enabling me to pursue this course!

I dedicate this Thesis to my grandparents who have been a continuous source of inspiration as well as my uncle who guided me patiently through the preparation of this Thesis.

“The time is right for electric cars - in fact the time is critical.”

- *Carlos Ghosn*

Abstract

There has been a tremendous increase in the level of human activity on Earth since the start Industrial Revolution which has promoted great development within societies. However, recent scientific studies have shown that our actions have caused detrimental damage to our environment resulting in the observable phenomenon known as climate change. Some of the adverse effects of climate change include the destruction of habitats, changes in weather patterns and propagation of diseases – to name a few. This trend impacts all systems inhabiting our planet and has very grievous implications for the future if no action is taken. A major contributor to climate change is the transport sector which causes significant CO_2 and green house gas pollution – due the heavy reliance on consuming fossil fuels. These harmful gases have been proven to facilitate global warming. The international community has recognised these undeniable facts and therefore is taking decisive steps to ensure that all sectors to become sustainable. There is a strong advocacy by the global community to promote 'sustainable transport' and ensure that the transport sector becomes emission free and less carbon intensive. An innovative solution to facilitate this transition to sustainable transport is the adoption of electric vehicles (EV's) which are environmentally friendly and very efficient. EV's are developing at a rapid pace and the EU is taking a lead in this revolution. Within the EU, the Netherlands has taken proactive steps to deploy as many EV within the country and has set ambitious goal to go all-electric by 2030. Given this bold target; this prompted the question that if the EV market share is forecasted to increase in the Netherlands, how much will it cost to install the appropriate infrastructure to accompany these vehicles? Hence the scope is to answer the following research question: "***To determine the financial viability of installing public electric vehicle charging infrastructure (Level 2 and 3) in the Netherlands***". It was concluded that public charging infrastructure is capital intensive and the associated costs cannot be borne by the government alone - effective financial co-operation between the public and private sectors is required. To get a holistic view to address this research question, global EV trends, the Dutch EV market and Dutch policies have been included.

Keywords: *Electric Vehicles, Charging Infrastructure, the Netherlands, Renewable Energy, Financial Viability*

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1. General Introduction

Climate change caused due to mankind's extensive exploitation of Earth's natural resources has been a global phenomenon that poses a threat to our ecosystem to this present day. The effects of this dangerous trend impacts all sectors of society and its adverse effects include global warming, degradation of natural habitats, human health risks and weather pattern changes; to mention a select few effects. *(NASA, 2017 October 10 and IPCC, 2014)* The origins for this observable fact are many but; a key sector that facilitates to this change is the Transport sector (i.e. the system responsible for all modes of transport); whose core fuel hasn't changed drastically since the industrial revolution namely, the consumption of fossil fuels to power the majority of the existing transport modes. Due to the consumption of this finite energy resource, the global ecosystem is impacted because of the associated GHG emissions – which have been proven to be disastrous for the environment. The international community has recognized this fact and in the landmark COP 21 Paris Agreement signed in 2015 there have been strong recommendations for actions to make the transport sector more sustainable. *(Huigenza, 2016 May 23)*

Transport has a crucial role in the development of societies and impacts individual lives. It also fosters economic prosperity as it enables individuals and communities connect rural to urban areas as well as goods/products to a variety of markets. Due to the importance of this sector it becomes important to make sure that going forward it becomes sustainable – *ergo* the services provided by transport must be achieved in a safe, accessible, efficient and resilient manner while simultaneously minimizing environmental impacts and carbon intensity. Sustainable transport will be a greater facilitator to achieving the SDG's because transport plays a crucial role in each of the SDG targets. While efforts are made to ensure this transition is achieved as soon as possible it is important to be aware of the rapid urbanization, demographic changes, development in global transport and trade routes, increased digital connectivity, technological advances and economic development, all of which will dictate the efficiency for this transition. *(Cordano et.al, 2016)*

One of the most popular forms of transport that the global community utilizes is fossil fuel powered passenger vehicles. However, within the transport sector it is one of the most GHG polluting modes, due to the sheer volume of existing vehicles. Thus, an innovative solution to mitigate the environmental impacts from these vehicles as well as catalyze the transition to a sustainable transport system; is the adoption and replacement of conventional cars with electric vehicles (EV's). As will be presented in this report EV's have great potential and many advantages. EV's have been gaining popularity and with the correct utilization of resources and policies it is set to become a dominant transport mode in the future. *(IEA 2017 and IEA 2016)*

Critical to the success for popularizing EV's is the availability of the necessary infrastructure. The creation of this infrastructure is a State policy initiative with considerable resources required. Therefore, the research question addressed is critical to evaluating whether and when the infrastructure plan can be deployed and at what cost to both the State and the consumer.

The research being studied in this context is:
"To determine the financial viability of installing public electric vehicle charging infrastructure (Level 2 and 3) in the Netherlands"

The Netherlands was chosen as the specific case study because it is a leader in the global EV market, the government is in great support of this transport mode and significant data on the EV market was available. Netherlands has ambitions to be an all EV nation by 2030-2035. The idea to focus on a developed country was based on the premise that the findings from such a study could also be utilized to promote policies and financial measures in countries where the EV market has yet to gain traction. The purpose of this research is to provide a reader with insights into the current status and policies EV in the Netherlands (Chapter's 2-4). A special emphasis is placed on the charging infrastructure components for EV as well as the associated costs and business viability for installing them (Chapter's 5-6).

2. Electric Vehicle's – an Introduction

An EV can be defined as any form of transportation which utilizes an electric motor to generate movement. *(Ajanovic, 2015)* For the scope of this Thesis, EV's will refer to passenger vehicles that operate using an electric motor. The two types of EV's that have accelerated the adoption rate and market share of EV's globally are Battery Electric Vehicles (BEV's) and Plug-in Hybrid Vehicles (PHEV's). A BEV can be defined as a vehicle which uses a large battery pack to power the electric motor. The BEV must be plugged into a charging station or wall-outlet to be charged. Since a BEV operates on electricity it doesn't contain typical car components such as a fuel pump, fuel tank and fuel line. The key components of a BEV are as follows:

1. **Battery (auxiliary):** This component provides electricity to start the car before the traction battery is engaged and also is the source of power for the vehicle accessories.
2. **Charge port:** This component allows the vehicle to connect to an external power supply to charge the battery.
3. **DC/DC converter:** This device converts higher-voltage DC power from the battery to the lower-voltage DC power needed to run vehicle accessories and recharge the battery.
4. **Electric traction motor:** Power is transferred from the battery to the motor which drives the vehicle's wheels. Some vehicles use motor generators that perform both the drive and regeneration functions.
5. **Onboard charger:** This device takes incoming AC electricity supplied via the charging port and converts it to DC power for charging the traction battery. It also regulates battery characteristics such as voltage, current, temperature, and state of charge during the charging process
6. **Power electronics controller:** This unit manages the flow of electrical energy from the battery and controls the speed of the electric traction motor and the torque it produces.
7. **Thermal system (cooling):** This system maintains a proper operating temperature range of the engine, electric motor, power electronics, and other components.

8. **Traction battery pack:** Stores electricity for use by the electric traction motor.
9. **Transmission:** This devices transfer's mechanical power from the engine and/or electric traction motor to drive the wheels. *(From points 1-9 source: US Department of Energy, 2017)*

A schematic for all these components can be seen in Figure 1

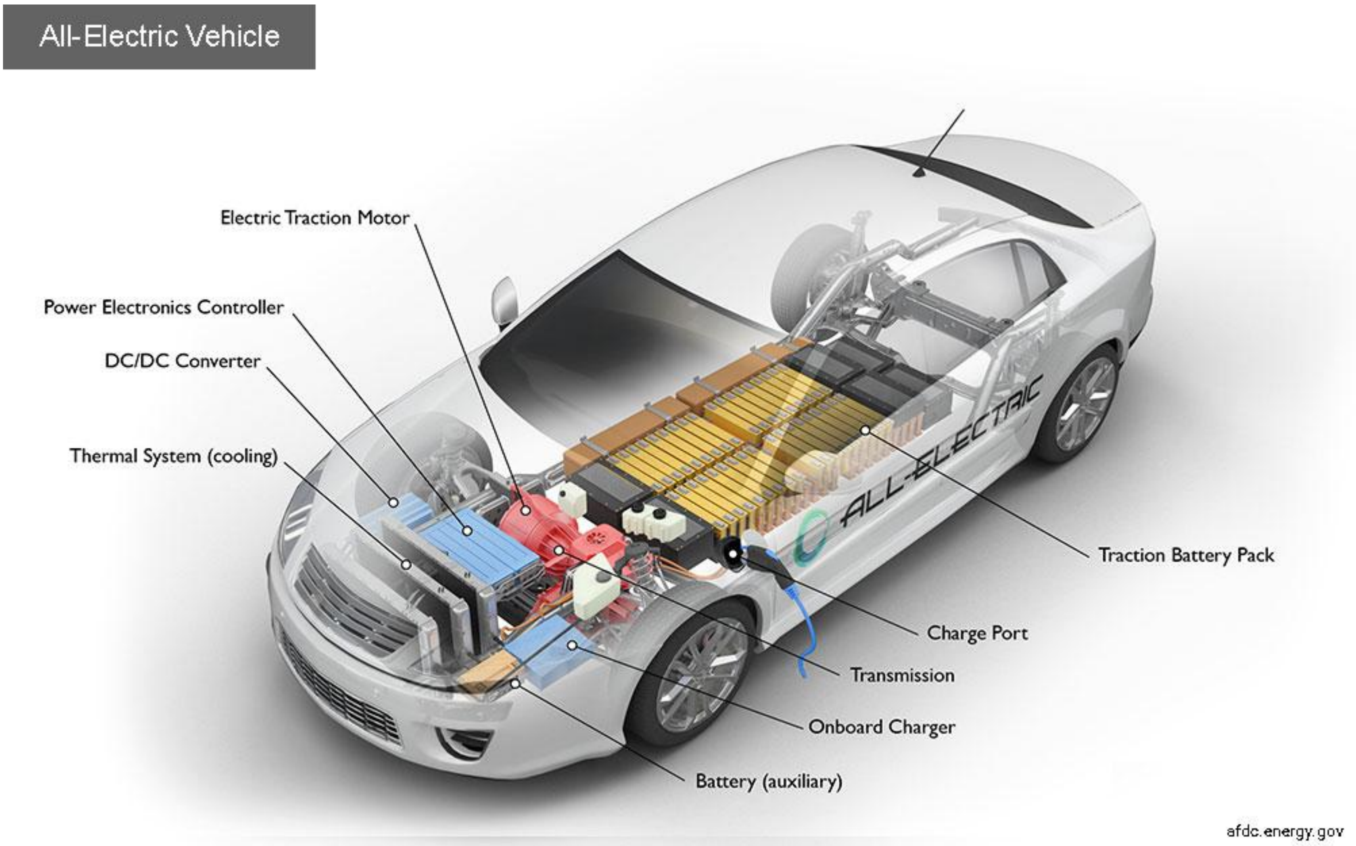


Figure 1: Components of a BEV ***(Source: US Department of Energy, 2017)***

Plug-in Hybrid Vehicles operate in a similar way to BEV but, they also utilize conventional fuel when the electric supply from the battery is exhausted. The battery can be recharged from an external socket but also can draw on the excess power when the vehicle brakes. It has the same components as a BEV with the following differences:

1. **Exhaust system:** Allows for the exhaust gases to be released from the engine through the tailpipe.
2. **Fuel filler:** Input for refuelling the tank.
3. **Fuel tank (gasoline):** Storage container for gasoline

4. **Internal combustion engine (spark-ignited):** This is the chamber where fuel is injected when combined with air, and the air/fuel mixture is ignited by the spark from a spark plug. *(From points 1-4 source: US Department of Energy, 2017)*

A schematic for all these components can be seen in Figure 2

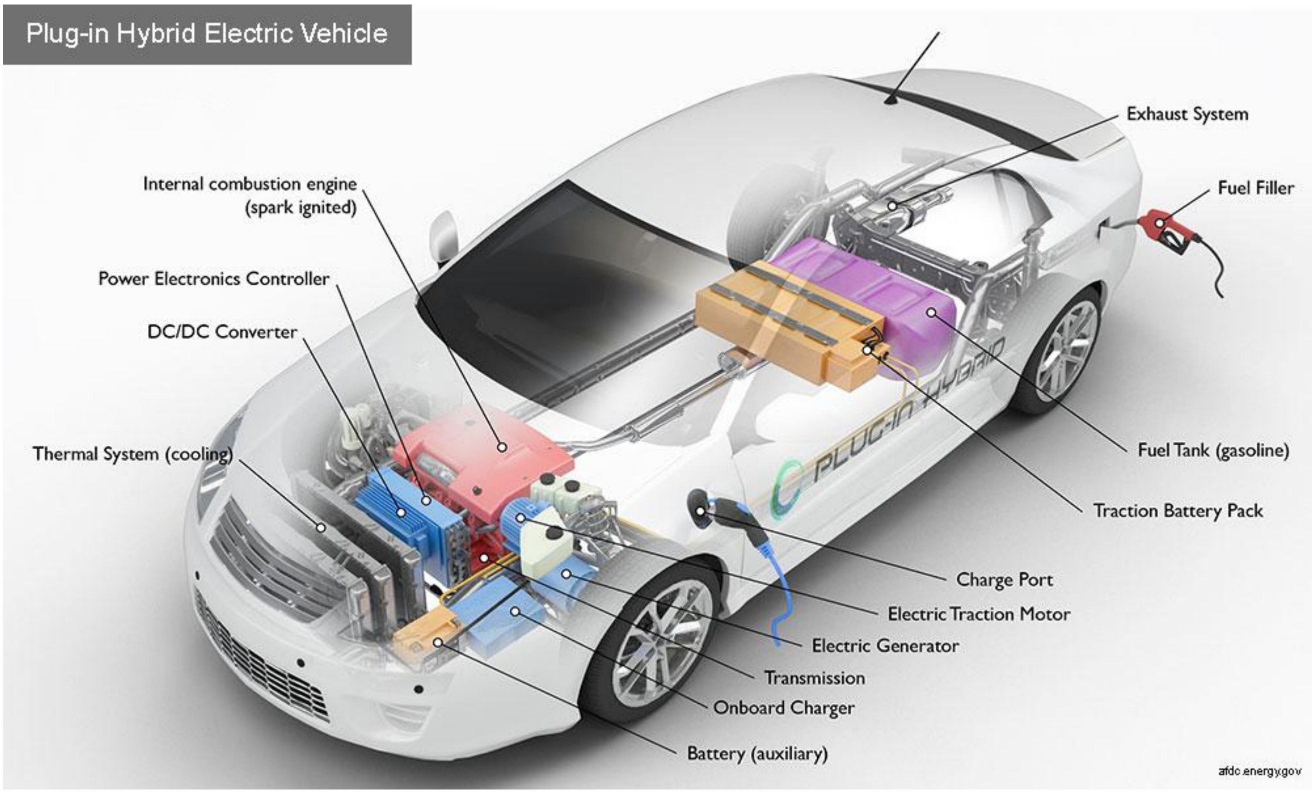


Figure 2: Components of a PHEV ***(Source: US Department of Energy, 2017)***

Since a PHEV has an electric and gasoline component which is inherent to its operation there are two ways in which these components can operate namely in parallel and series – they can also operate in a blended/mixed mode if required.

- **Parallel**: Operations will connect the engine and the electric motor to the wheels via mechanical coupling. Both the electric motor and the engine transmit power to the wheel directly.
- **Series**: In this mode PHEV's use only the electric motor to drive the wheels. The internal combustion engine (ICE) is used to generate electricity for the motor. This mode can be referred to extended-range electric vehicles

(EREVs) since the vehicle can get extra power from the ICE. *(From points 1-2 source: US Department of Energy, 2017)*

The main advantages of EV's are that they are energy efficient, very environmentally friendly, have increased performance benefits and reduced energy dependence. On the contrary some of the areas of improvements for EV's are the recharge time for batteries, increasing their range on a single charge, the cost of the batteries and reducing the bulk of the battery. These limitations have been getting better with the passage of time due to the high R&D efforts to enhance technical capabilities and performance of EV's. *(US DOE, 2017)*

2.1 Electric Vehicle Demand Factors – The Netherlands

Netherlands is a European and global leader for the development and propagation of EV's as the future of transport [more information on this statement will be provided and elaborated on in subsequent chapters] *(Pressman, 2017; Netherlands Enterprise Agency, 2017 and IEA, 2017)*. As with any product, there are factors which will impact the demand of EV's are as follows:

1. **Price:** This is a defining parameter for consumers when they decide to purchase an EV. The importance of this parameter is attributed to the cost of EV's being approximately 10.000-15.000 euro's more expensive than conventional fossil fuel cars. Further, there is uncertainty about an EV's trade-in value and residual value. This ambiguity arises due to the difficulty in accurately determining future performance of batteries - which is the main costing factor for an EV. Improvements in the tracking the behaviour of the batteries and drivers has led to better estimations for the residual value of EV's. *(Van der Kuip, 2011)*
2. **Range:** One of the biggest determinants for a consumer to purchase an EV is the range offered on a single charge. Currently fossil fuel cars have a better range than EV's due to the high energy content of the fuel as well as the established infrastructure. Conventional cars have a range of 750km on a single tank and a majority of the EV's in the current market have a range of 150km on a single battery charge. According to recent studies Dutch drivers cover 44km daily - which can be easily, achieved using an EV. However,

most consumers have not yet gotten over their range anxiety fear. This can only be abolished with the further development in battery capacity, efficiency and charging infrastructure *(Van der Kuip, 2011 and Liu et.al, 2015)* - all of which are being pursued relentlessly by the Dutch government.

3. **Charging Time:** Conventional cars require less than 5 minutes to re-fuel. The time for charging an EV is highly dependent on the method used. If the consumer uses a slow charger then it could take approximately 6-12 hours for the battery to recharge. If a fast charger (which has a significantly higher output) is utilized the EV can be charged in 15-30 minutes. To ensure that EV owners are able to charge their vehicles optimally it is necessary to develop and deploy charging infrastructure effectively *(Van der Kuip, 2011 and Gobczyński, 2011)* – an action the Dutch government has been working on constructively with positive results (refer to Electric Vehicle Infrastructure Section)
4. **Interoperability:** This term refers to the ability of the EV to be charged at any charging station. In the Netherlands, the government has ensured that most charging stations can cater to the majority of the EV's on the road. They have also implemented a single-card payment system which allows for electricity consumption payments to be as simple as possible. *(Van der Kuip, 2011)*
5. **Vehicle Life-time:** This criterion informs consumers how long an EV shall be in working condition after the vehicle is purchased. This is important to consider due to the significant individual investment into the vehicle. A BEV has an approximate life-time of 160.000 km and a PHEV of 402.000 km. This is mainly ascribed to the reduced maintenance that EV's have when compared to fossil fuel cars. *(Municipality of Alexandria, 2017)*
6. **Driving and Charging Habits:** The behaviour of driver, usage of the EV battery and frequency of charging will dictate how efficient and economical it is to convert from fossil fuel vehicles to EV's. *(Gobczyński, 2011 and Liu et.al, 2015)*

2.2 Electric Vehicle Supply Factors – The Netherlands

When focusing on the supply of EV’s, the main supply driver are the vehicle manufacturers. When EV purchasing and market incentives are in place then the supply for EV’s and charging infrastructure will also increase. As will be seen in the subsequent chapters the Netherlands has developed many forms on incentives to promote the purchase of EV’s and deployment of charging infrastructure. *(Van der Kuip, 2011)*

3. Transport Sector and Electric Vehicle Global Trends

The transport sector represented approximately 28% of the global energy consumption in 2013 and the energy demand of this sector was 107 exajoules (EJ) which was a significant increase from 66 EJ in 2010. 90% of the energy utilized in the transport sector was derived from fossil fuel products and renewable's only had a 2.5% penetration into the transport sector – which was the lowest among any of the major global sectors. This sector includes the energy consumption of all transport modes: road, rail, aviation and navigation. Road transportation has dominated the sector's total energy demand, accounting for three-quarters of its Total Final Energy Consumption (TFEC) in 2013 *(Gielen et.al, 2016)* – which can be seen in Figure 3

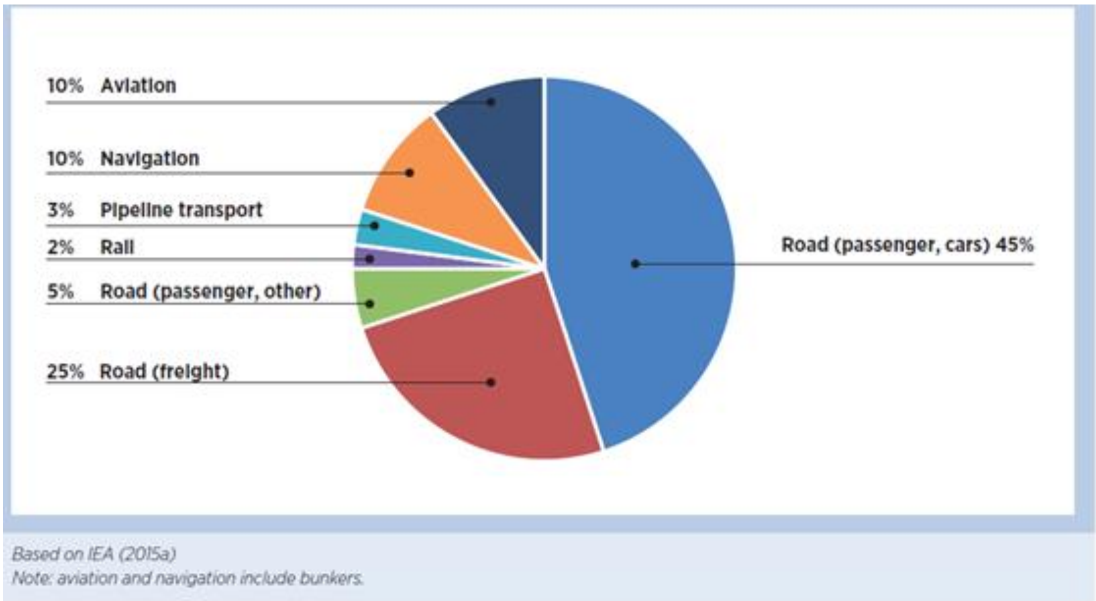


Figure 3: Global Energy Consumption as seen in the various components of the transport sector *(Source: Gielen et.al, 2016)*

The main reason for the resulting graphics in Figure 3 arises due to the number of passenger vehicles that are on the road globally which is approximately 1.1 billion as of 2015 – this is expected to increase further. Additionally the favourable economics conventional cars as well as the continuous population growth the main reasons for its popularity over other modes of transport *(M.N.Smith, 2016, April 22)*

When focusing on the energy intensity of transport modes, the rate at which fuel is combusted is highly dependent on the efficiency and mechanics of the vehicles. It has been found that the vehicles which allow passengers to commute are the most energy intensive and consume 2 MJ/passenger/km. The most energy efficient modes of transport are railways, pipelines and shipping however, these are limited by the number of networks available. *(Gielen et.al, 2016 and International Council on Clean Transportation, 2013, September 19)* - illustrated in Figure 4

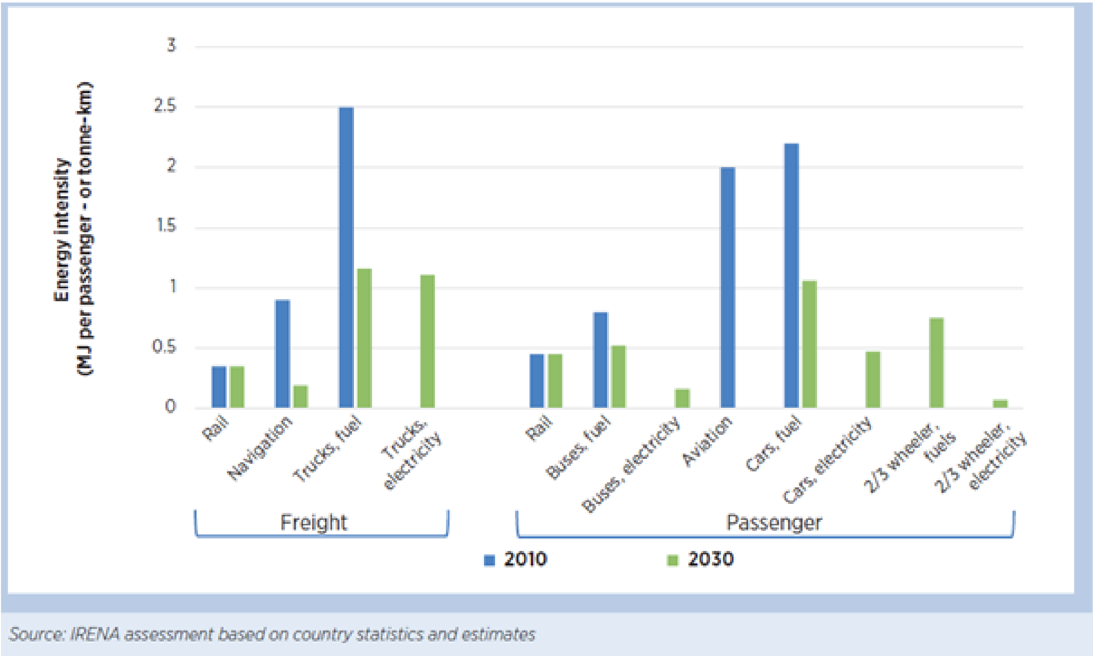


Figure 4: Energy Intensity of various transport modes *(Source: Gielen et.al, 2016)*

It has been well established that electricity is a very efficient energy source when coupled with the correct technology. Hence, electricity is currently being perceived as a new energy resource that will help make the transport sector greener and also increase the efficiency of vehicles. In terms of TFEC, it has been proven that electricity is far more efficient than fossil fuels. Electrical efficiency in terms of primary energy, it is highly dependent on the source of the electricity – coal has a lower efficiency than RE’s. Thus if electricity is sourced from RE’s, significant energy savings will be made. *(European Energy Agency, 2017)*

It has been accepted by the international community that RE’s have a crucial role to make the transport sector ‘green’. However, since different transport vehicles have various fuel requirements, it has been accepted that RE solutions will have to be tailored to each transport mode. Figure 5 shows the projected global fuel mix that is expected in various modes of transport by 2030. As can be seen from this figure passenger vehicles will consist of electricity, biodiesel and bio-gasoline – the latter two sources proven have very low GHG emissions compared to current fossil fuels. Rail transport will run mostly on electricity whereas the aviation, shipping and freights transport modes will utilize bio-fuels due their inherent greener nature. It is also interesting to note that passenger vehicles will maintain their status as the most energy demanding transport mode (TFEC = 56 EJ) which is in part is due to the forecasted increase in EV deployment. *(Dutch Ministry of Infrastructure and the Environment, 2014 and European Commission, 2016)*

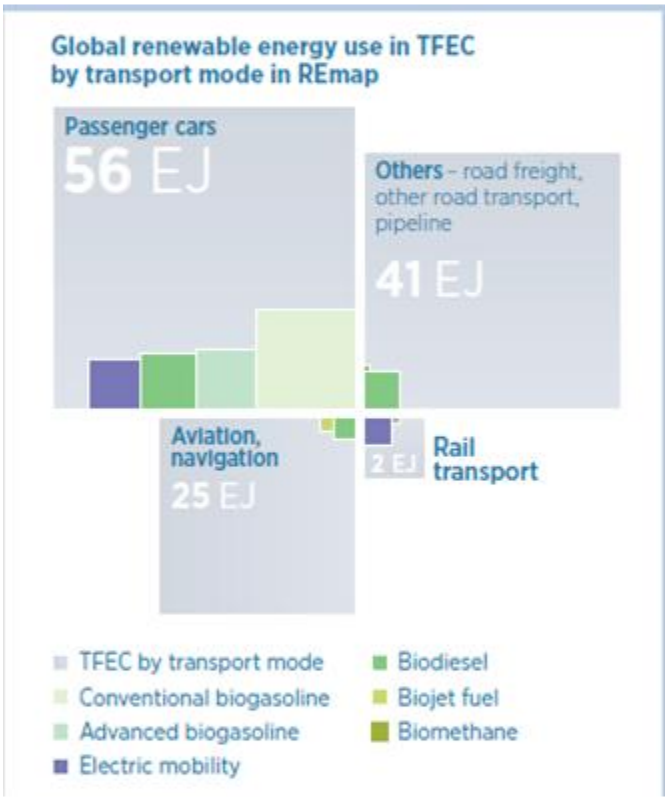
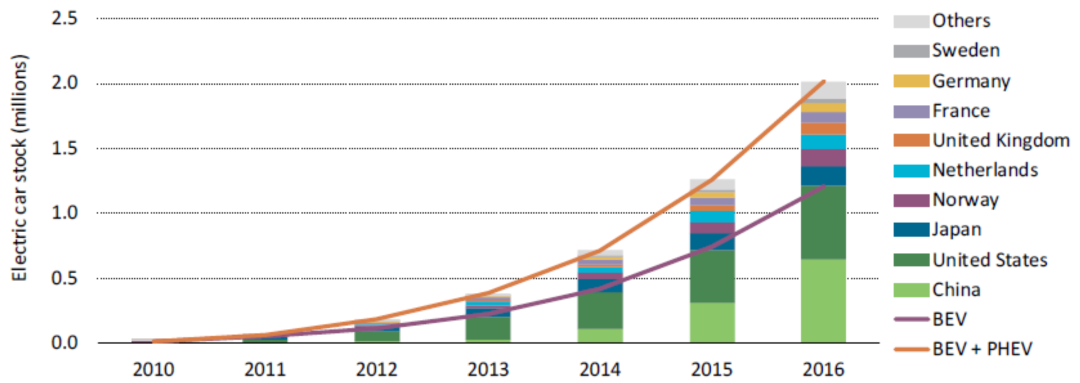


Figure 5: Projected Renewable Energy Fuel Mix for various transport modes in 2030 *(Source: Gielen et.al, 2016)*

For passenger vehicles – electric vehicles are perceived as the green solution for automobile transport. There are current estimates of a global car stock of approximately 800 million units and an estimate 70 million cars are sold per year. In 2015, 500.000 EV's were sold and at the end of the year 1.25 million electric vehicles were on the road. The current electricity demand for EV's is approximately 3 terawatt-hours (TWh) per year (this is 1% of the sector's total electricity demand of 300 TWh per year). If we assume 23% is sourced from renewable power, electric vehicles will consume 0.7 TWh per year of renewable electricity. EV's have also shown the possibility of providing an additional 630 TWh of electricity to the global energy system. *(Gielen et.al, 2016)* The global increase in sales of EV between the years 2010-2016 can be seen in Figure 6.



Notes: The electric car stock shown here is primarily estimated on the basis of cumulative sales since 2005. When available, stock numbers from official national statistics have been used, provided good consistency with sales evolutions.

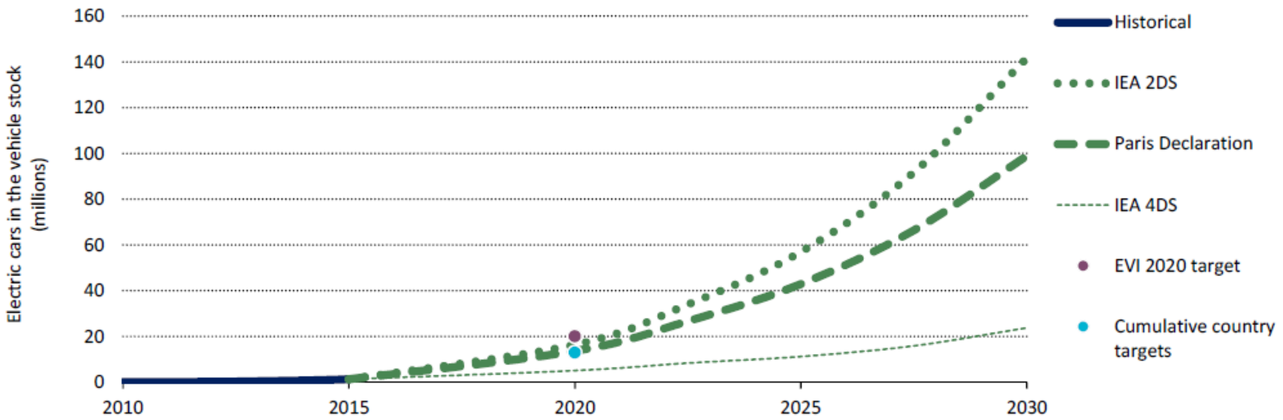
Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017).

Key point: The electric car stock has been growing since 2010 and surpassed the 2 million-vehicle threshold in 2016. So far, battery electric vehicle (BEV) uptake has been consistently ahead of the uptake of plug-in hybrid electric vehicles (PHEVs).

Figure 6: The growth rate of EV's between 2010-2015 ***(Source: IEA,2017)***

As can be seen from Figure 6, it is the developed nations which are leading the way when for EV deployment. This observation is mainly attributed to the increased EV incentives, rapid technological advancements and strong governmental support demonstrated for EV's. Within the EU Norway has the highest EV share, with 40% of the newly registered passenger vehicles being EV's. They have demonstrated to the international community that with the correct incentives and resources (such as bus-lane access for EV's, effective deployment of recharging stations, privileged parking, and toll-free travel for EV's) consumers are willing to convert from fossil fuel vehicles to EV's. *(Hockenos, 2017, February 7).*

At Paris Climate Convention it was agreed that the global target for EV's in the 2030 should be 100 million units for which significant efforts will be required as seen by the scenarios illustrate in Figure 7.



Note: 2DS = 2°C Scenario; 4DS = 4°C Scenario.

Sources: IEA analysis based on IEA (2016), UNFCCC (2015b), the EVI 2020 target and the country targets assessment made in Table 3.

Key point • **Reaching 2020 deployment targets for BEVs and PHEVs requires a sizeable growth of the electric car stock. Meeting 2030 decarbonisation and sustainability goals requires a major deployment of electric cars in the 2020s.**

Figure 7: EV growth projections for different scenarios until the year 2030 *(Source: IEA, 2016)*

To elaborate briefly on the projections further (refer to Figure 7), three scenarios have been outlined namely, IEA 2DS, Paris Declaration and IEA 4DS – listed in order of desired outcomes. In the IEA 2DS scenario which projects that if the international community is able to limit the global temperature to below 2°C it is predicted that 150 million EV's would be deployed globally. This massive figure is ascribed to the tremendous sustainable transformation of the transport sector – mainly through the inclusion of clean energy sources, strict environmental policies and technologies. *(IEA,2016)* The Paris Declaration has set a global deployment target of 100 million EV's and 400 million electric 2- and 3-wheelers by 2030. This second scenario can be realised if the global community can power 20% of the transport sector with electricity thus, complying with the climate change commitment of reducing the global temperature to 2.5°C *(UNFCCC,2015).* The IEA 4DS scenario is a projection that predicts that the global temperature will be limited to 4°C by 2050. It has been forecasted that if the global temperature were to be greater than 2°C, then there is a very high risk of irreversible damage to be done on our planet's ecosystem *(OECD, 2017).* Figure 7 clearly illustrates that if the international community takes the IEA 4DS path the rate of EV deployment would slow done due to the slow rate of transition from fossil fuels to electricity – which arises from continued use of fossil fuels for an extended period of time.

A global platform that is gaining attention is the Electric Vehicle Initiative (EVI) which is working to ensure that by 2020 there are 20 million EV's deployed globally. The EVI hopes to achieve this through:

1. Encouraging Participating countries to meet their national development objectives through effective policy and legislation.
2. Working with urban cities to ensure there is an increased adoption of EV's.
3. Sharing information of public investments for research, development and demonstration programs to address the specific gaps in EV technology.
4. Acting as a platform which allows private, government and industry stakeholders to communicate and allow for the rapid deployment of EV's and EV fleets. *(From points 1-4 source: Clean Energy Ministerial, 2017)*

The biggest advantage of implementing EV globally is the significant reduction in GHG emissions which is major pollutant that is a defining characteristic of the transport sector *(WWF Canada, 2012; E.Pike, 2012).* Figures 8 and 9 illustrate the scenarios and potential GHG emission reductions which can occur if sustainable development policy and actions are rigorously implemented by the international community.

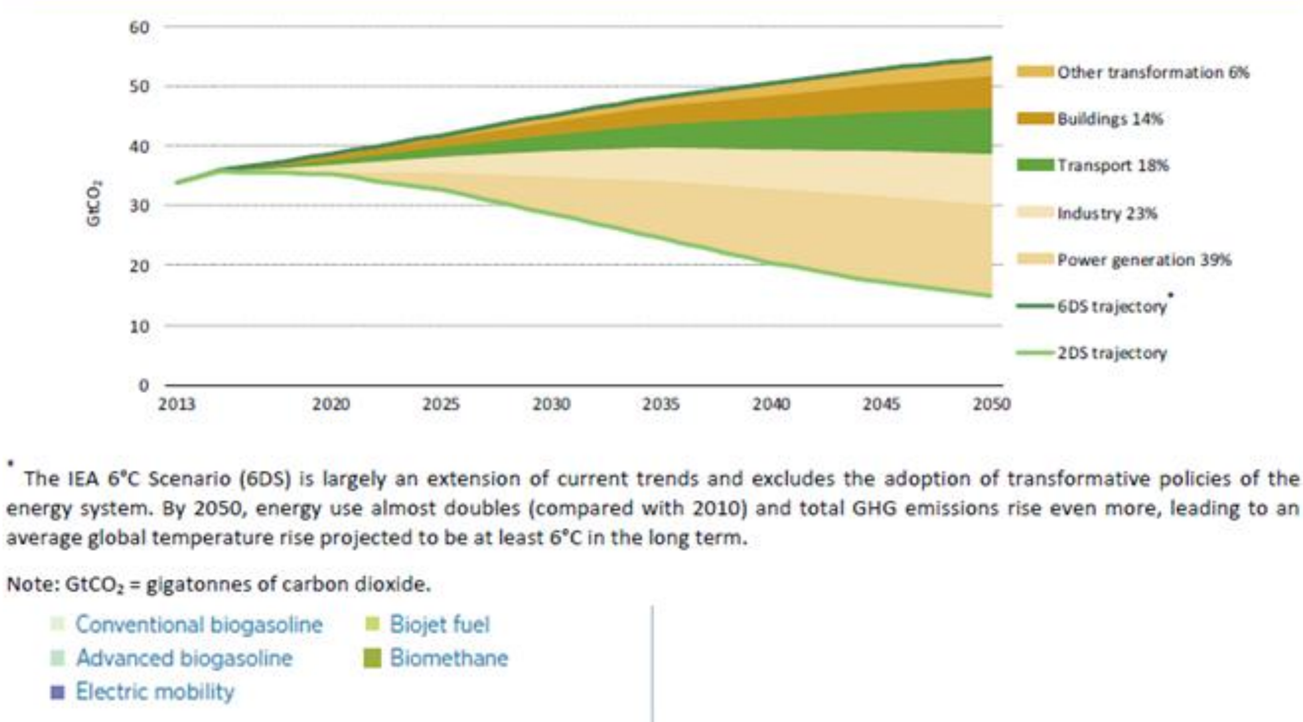
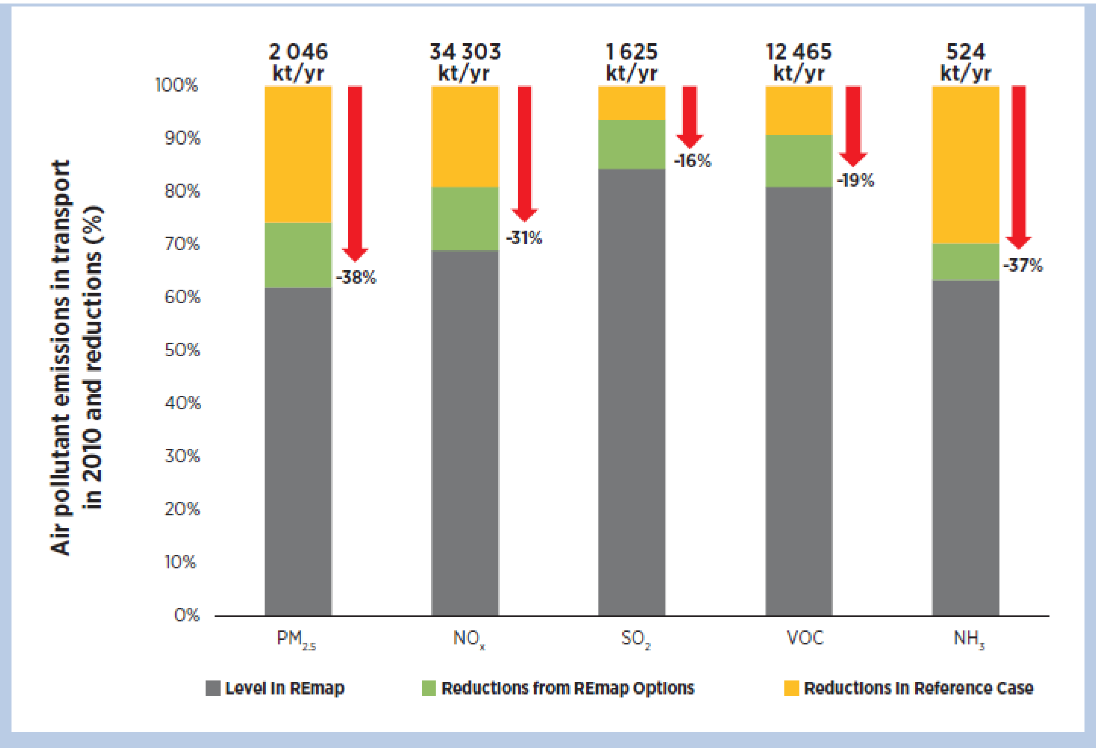


Figure 8: GHG Emission Reductions by sector to 2050 on a 2DS trajectory versus a 6DS trajectory *(Source: IEA ,2016)*

In Figure 8 (which is similar to Figure 7), it is noted that the transport sector accounts for 18% of the total GHG emissions when compared to power generation, industry and buildings. Hence, if GHG emissions were to reduce in this sector it would cause other sectors to significantly reduce their GHG emission. If the global community was to adopt a 2DS pathway as mentioned before then we could reduce the GHG emissions from 33GtCO_2 to 17GtCO_2, resulting in the overall temperature of the earth to be kept to the desired 2°C threshold. However, if the community was to head on 6DS pathway i.e. a pathway that is similar to the 4DS pathway described earlier but, the global temperature rises by 6°C, then it is expected that the GHG emissions rise from 33GtCO_2 to 52GtCO_2 – which would be detrimental to the environment. *(IEA,2016)*



Note: Abbreviations stand for – $PM_{2.5}$: fine particulate matter; NO_x: mono-nitrogen oxides; SO_2: sulphur dioxide; VOC: volatile organic compounds; NH_3: ammonia. The values at the top of the bars show the total transport sector emissions in 2010 of the pollutant in kilotonnes.

Figure 9: Reduction scenarios for the harmful emissions if EV's become mainstream by 2030 *(Source: Gielen et.al, 2016)*

The International Renewable Energy Agency (IRENA) has a programme called REmap which strives to suggest pathways to double the share of RE's in the global energy mix from 18% to 36% by 2030. The pathways are developed by performing in-depth country analysis on their policies, technology development and collaboration with other nations. Furthermore, cross-cutting technology roadmaps are developed to identify actionable task to increase the share of RE's. The REmap's pathways are always measured against a Reference case which in the case of the transport sector assumes that its current status remains relatively unchanged until 2030 – in other words, a business as usual scenario *(Gielen et.al, 2016).* In Figure 9, it is clearly seen that if the transport sector operates on a business as usual bases until 2030 (given existing plans and policies) there is a forecasted decrease in GHG emissions but, they will not be as significant if REmap options are implemented. This observation can be ascribed to the forecasted increase in RE, better energy efficiency and increased market share of EV's in the transport sector *(Politico, 2017 January 25)*

As has been explained in Professor Jungmeier's lecture, to really determine how green a particular technology is, it becomes necessary to analyze the life-cycle of the product *(Jungmeier, 2015).*

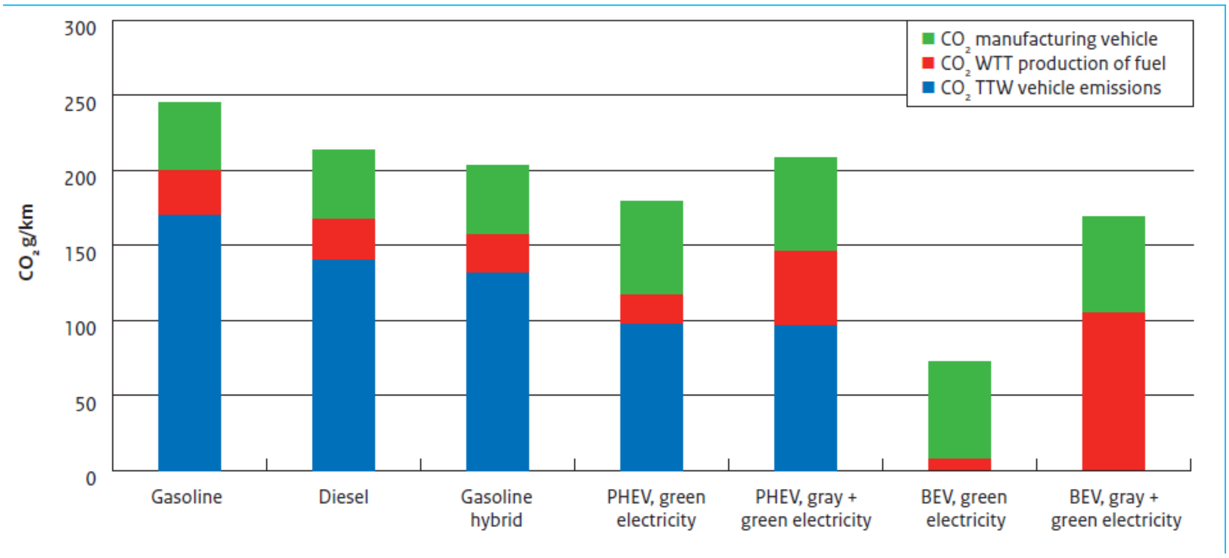


Figure 10: The CO2 emissions for different types of vehicles *(Source: Dutch Ministry of Economic Affairs, 2017)*

As seen in Figure 10 the life cycle of EV's have very CO_2 emissions overall when compared to fossil fuel cars. This can be ascribed to the fewer components that EV's possess when compared to conventional vehicles, higher efficiencies and less reliance on non-RE energy sources. A recent study has shown that if different grid portfolios, electric miles driven and non-electric miles driven are taken into consideration PHEV's are much more energy efficient and less GHG emitting vehicles when compared to BEV's *(Mclaren et.al, 2016)*

Technology is advancing at a rapid rate and the more established it becomes, the cheaper it gets (economies of scale concept). The biggest development in the field of EV's is the drop in battery cost, which is the biggest contributor in an EV's price structure. The drop in price can be attributed to technological learning, R&D (such as improvements in/ modifications of Li-ion chemistry[1], better membranes, increased charge transfer between battery electrodes, and mass production *(Dinger et.al, 2010).* Battery costs have fallen from $1000/kWh in 2008 to $268/kWh in 2015, which represents a 73% reduction over a seven year period. The goal is to reach $125/kWh by 2022 which would mean battery costs (and therefore EV costs) would be the same as those for fossil fuel cars. Meeting this target implies an additional 58% cost decrease in the next seven years, corresponding to a 10.3% cost decrease every year between 2016 and 2022. Additionally the energy density of batteries has increased from 60Wh/L in 2008 to 295Wh/L in 2015 which is significant improvement given the target for 2022 is 400Wh/L *(IEA, 2016 and Dinger et.al, 2010)* – refer to Figure 11 for illustration.

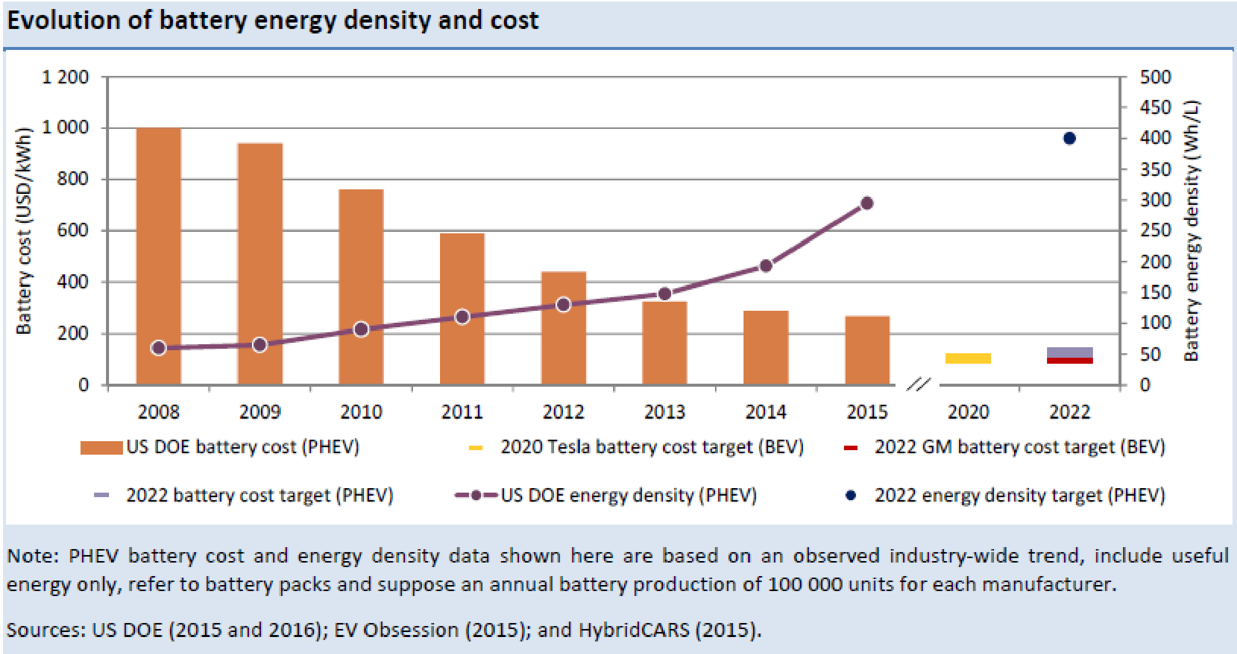


Figure 11: Battery Cost and Energy Density Projections *(Source: IEA, 2016)*

[1] Refer to reference 70 and 71 interesting research

In regards to EV Infrastructure, due to the increase in deployment of EV’s there is has been a corresponding increase in the deployment of charging infrastructure. In 2015 globally there were 1.45 million chargers deployed which has been a significant increase since the 20.000 that were available in 2010. When focusing on the publicly available chargers, in 2015 there were 190.000 units which increased from the 50.000 available in 2010. This growth rate represents a 71% increase in charging infrastructure since 2010. Publicly available chargers experienced a growth rate of 73% and fast chargers had a growth rate of 63% since 2010 *(IEA,2016)* – refer to Figure 12

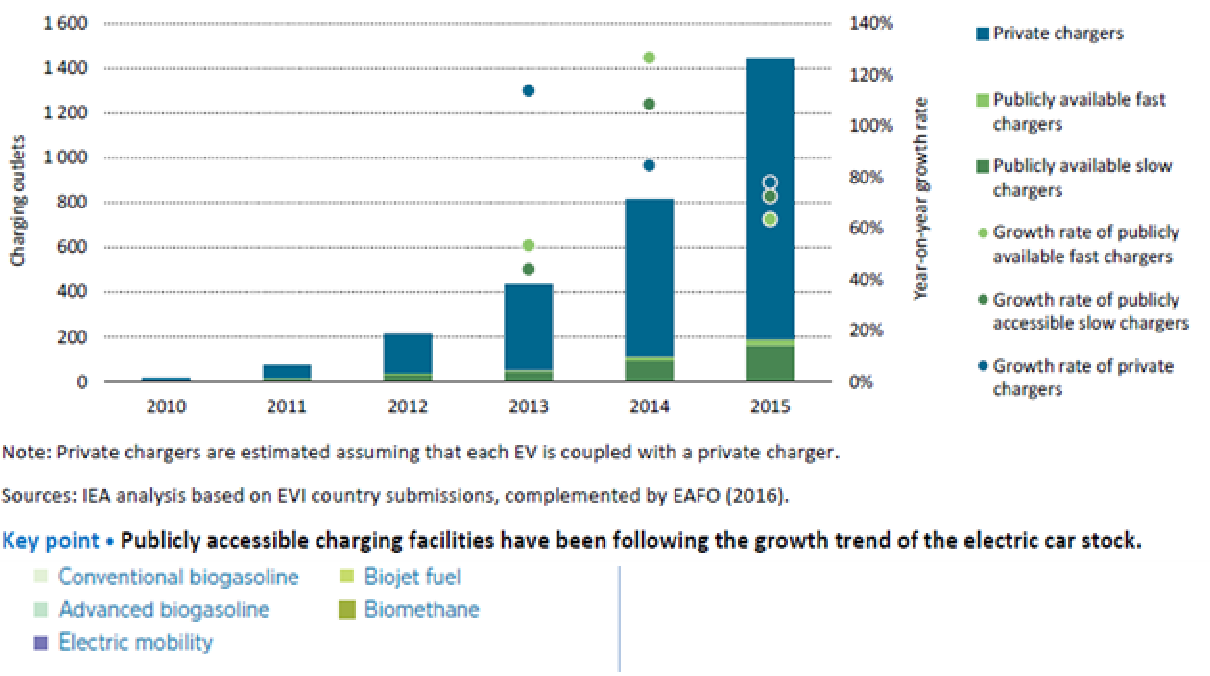
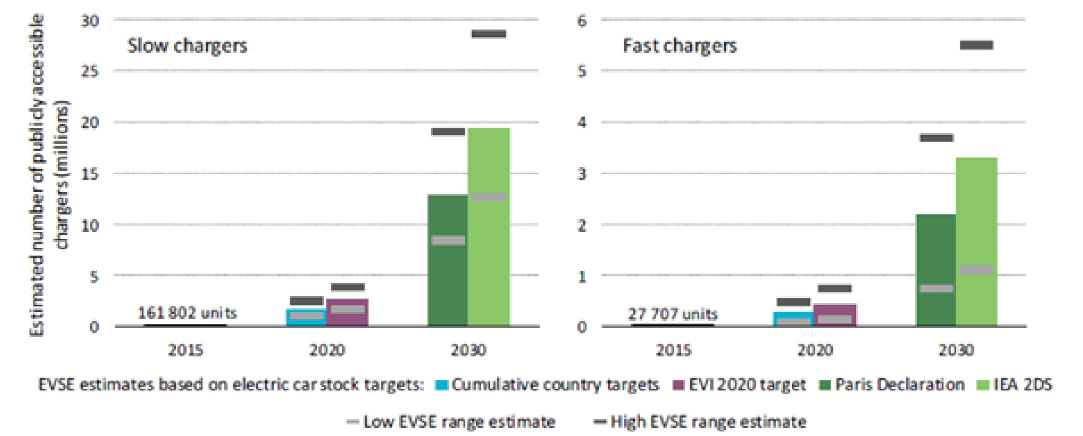


Figure 12: Growth rate of Electric chargers outlets globally between 2010-2015 *(Source: IEA,2016)*

Given the spurt in the growth for EV’s infrastructure, the IEA estimates that there will be an increase by more than a factor of 10 from 2015 to 2020, and by a factor of 100 by 2030. More specifically by 2020, publicly accessible slow chargers would need to reach between 1.1 million - 2.5 million units to meet the international targets agreed in various commitments and fast chargers would need to reach between 0.1 - 0.5 million units. By 2030, public chargers would need to range between 8.4 million - 19.1 million and fast chargers between 0.8 million - 3.7 million, to meet the targets of the Paris Declaration on Electro-Mobility and Climate Change and Call to Action *(IEA,2016)* – refer to Figure 13



Note: a lower and a higher range of EV/EVSE ratios were considered, based on the average of the observed three lowest and three highest EV/EVSE ratios, respectively, among the countries listed in Figure 13.

Key point • **Projections on EVSE outlets consistent with EV targets by 2020 and 2030 are more than a factor of 10 larger than 2015 estimates by 2020, and a factor of 80 to 120 by 2030.**

Figure 13: EV Charging Infrastructure Global Forecasts projected on the basis 2015 values *(Source: IEA,2016)*

The only foreseeable limitation with the advent of EV's is changes within the load profile that the grid will experience due to the increased electricity demand. The local nature of such an effect would impact lower penetration levels than those impacting the total energy demand. EV charging can be major flexibility source, but also major strain on system flexibility depending on consumer charging patterns. *(Mclaren et.al, 2016)* The precautionary actions that will need to be taken to prevent any serious incidents from occurring are as follows:

1. Slow charging in private spaces has the potential to offer flexibility, by modulating charging time and power. It has been found through analysis that 125.000 EV's is equivalent to 300 MW of flexibility i.e. is the same size as a medium capacity pump storage plant. Depending on the system and the deployment of other distributed energy resources, the ability of this flexibility to mitigate the impacts that EV's will have on low voltage grid levels is predicted to be moderate but, will have a greater effects at higher voltage levels.
2. The lack of adequate location and time signals in electricity pricing can be a problem for distribution networks when considering fast charging. Fast chargers usually range between 43 kW- 200 kW and requires substantial reinforcements of the electricity grid. The usage profile of fast chargers which

focuses on the need to minimize the charging times renders these chargers useless to serve demand side activities. Fast chargers cannot be utilized efficiently at night, since they cannot be integrated into low voltage household networks. Fast charging stations need to be sized and sited during the planning stages by distribution system planners to minimise their impacts. *(From points 1-2 source: IEA,2016)*

3.1 Netherlands EV Current Trends

Due to the presence of incentivising policy and tax returns, electric transport in the Netherlands has grown rapidly *(Morland, 2017 February 16).* The development of technology and the rapid fall of battery costs have caused consumers to buy EV's over conventional vehicles. The rise of EV's, the cause and effect relationship has also led to the increase of charging infrastructure in the country. These positive trends have made the Netherlands the 2nd most populous EV fleet (Battery Electric Vehicles and Plug-in Hybrid Vehicles) in the world and in absolute terms has the 4th highest numbers of EV's *(Dutch Ministry of Economic Affairs, 2017)* – refer to Figure 14

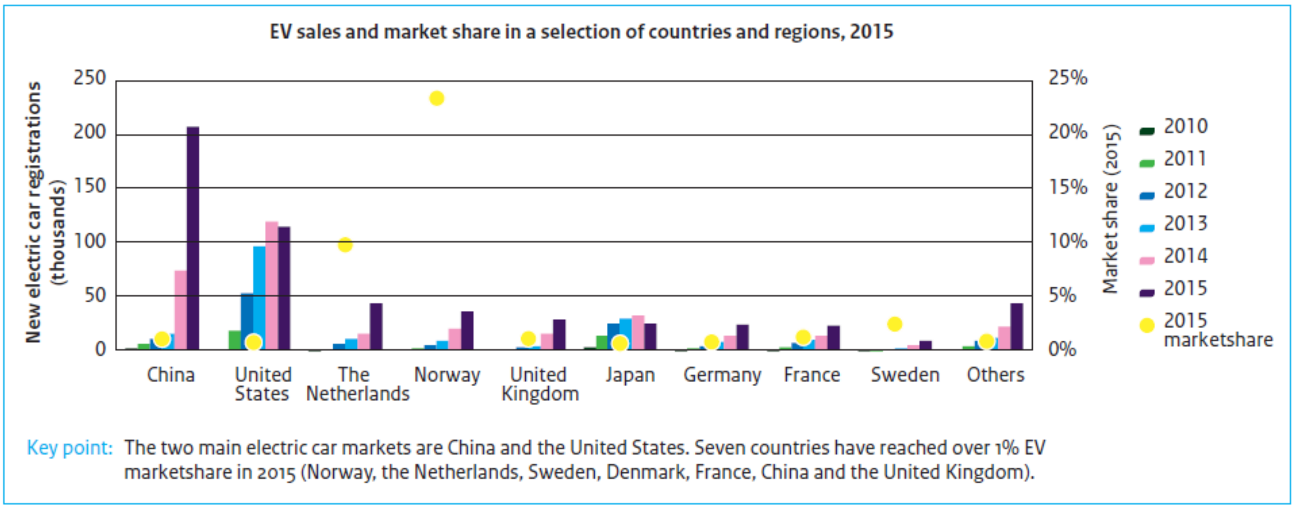


Figure 14: The market share of EV's in the Netherlands when compared to other global leaders *(Source: Dutch Ministry of Economic Affairs, 2017)*

As of November 2016, there have been more than 100.000 EV's which have graced Dutch roads. 95% this figure can be attributed to passenger cars. Of the passenger EV's approximately 12.000 are BEV's and 86.000 are PHEV's. The growth rate of the Dutch EV fleet over the period December 2011 to February 2017 can be seen in Figure 15

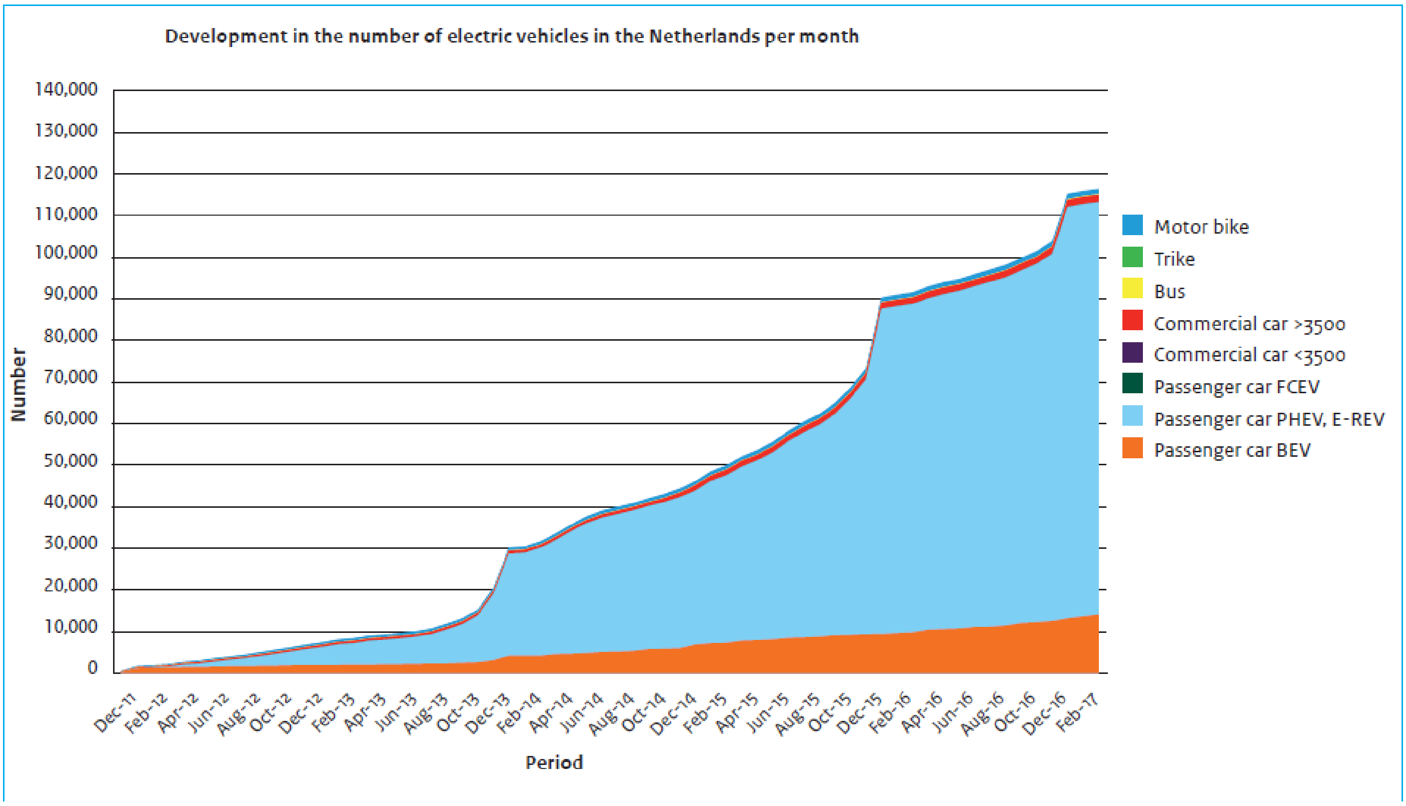


Figure 15: The development of the Netherlands EV fleet *(Source: Dutch Ministry of Economic Affairs, 2017)*

The government decided to focus their efforts on promoting charging infrastructure in the cities of Amsterdam, The Hague, Rotterdam, Utrecht, Breda, Tilburg and Eindhoven – which are major hubs in the Netherlands. The rationale for this was an intended domino effect that would cause adjacent municipalities to take actions and steps to increase their efforts to deploy charging infrastructure – which is proving to be a success. *(Netherlands Enterprise Agency, 2017)*

Another EV trend in the Netherlands are changes in the Total Cost of Ownership (TCO). On the basis of a 6-year period of ownership, the costs of an EV are 3.000 - 8.000 Euros higher than those of fossil fuel cars; for private individuals. This is mainly because of the high differences in depreciation charges. According to Bloomberg and Rabobank, the TCO's for EV's will be lower than fossil fuel cars in the year 2022-2023; which is consistent with the projection that battery costs will be cheaper than the ICE in the year 2022. *(Dutch Ministry of Economic Affairs, 2017)*

The Dutch government are also pioneers of technological developments for charging EV's – one such advent is the implementation of wireless charging through electromagnetic fields and induction. In Rotterdam, companies have developed charging plates which when driven over allows for the car to be charged. Efforts are being carried out on technologies that enable EV's to be charged whilst being driven. Electromagnetic fields which can be used to transfer the current to EV's while they are in motion will be installed in the road surface. This technology is still in its infancy but there is significant potential to revolutionize the charging infrastructure deployment. *(Oudshoorn, 2016)*

The deployment of EV's has the added benefit of creating jobs and added financial value in the Netherlands. In 2014, there were an estimated 3.200 jobs which were created and this represented a 25% employment growth when compared to 2013. The companies in the EV sector generated 820 million Euros and approximately 260 million Euros was attributed to added value for the Dutch economy in 2014 *(Dutch Ministry of Economic Affairs, 2017)* – refer to Figure 16

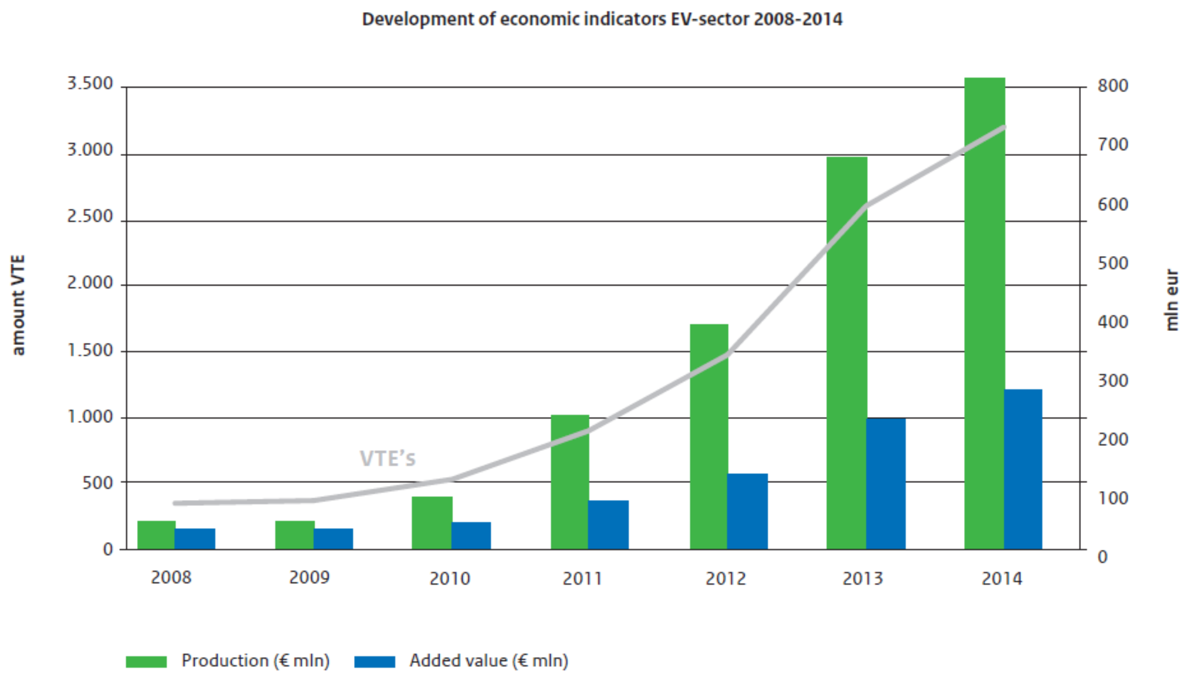


Figure 16: EV value added to the Dutch economy between 2008-2014 *(Source: Dutch Ministry of Economic Affairs, 2017)*

Other factors which are contributing to the added value of EV's to the Dutch economy are as follows:

1. The increase in number of pilots and projects and pilots to develop and implement smart-grid and smart-charging spaces.
2. Increasing finance, payment and mobility services are allowing private-lease and shared-car concepts to be more viable and sustainable.
3. Rapid R&D and scaling for vehicle propulsion technology, battery and information management systems are key areas that can be very valuable
4. Increasing educational interest in EV's and greater international co-operation are allowing the Netherlands to have access to external resources which will positively influence the Dutch economy. *(From points 1-4 source: Netherlands Enterprise Agency, 2015)*

The current trends presented favourably indicate that the Netherlands is on the path to optimally accommodate electric transport which has huge economic potential and environmental benefits. The government will continue to strive to ensure the Netherlands remains a leader for EV transport and become a role model for other countries to follow – hence aiding the global community to meet the international commitments for EV transport.

4. Electric Vehicle Policies – The Netherlands

4.1 General Thoughts on Policy

The international community is trying to ensure that the commitments which were made during the Paris Agreement of 2015 are realised by making as many sectors as sustainable as possible. The transport sector has gained much attention for reformative change due to this sector being the least changed since the advent of the fossil fuel cars. In the spirit of sustainability EV's have gained much attention and are considered a game changer to revolutionize the transport sector. The barriers to EV's can be overcome with governments using policy as a tool to facilitate the integration and deployment of EV's and their related infrastructure. There are many factors which can dictate how EV policy is formulated such as financial incentives, societal lifetimes and the latest research and developments. However, one key requirement of policy formulation is that the resulting tasks and responsibilities must be shared by relevant parties at varying levels – which allows for cohesive results to be produced. EV policy is a multi-faceted, where policy makers must take into consideration and operate from frameworks and actions that are interconnected *(Cordano et.al, 2016)* Governance is *nested*; if we take the EU as an example, the national level cannot viewed as separate from the EU, nor can the regional and local level actions be seen as detached from the national/federal or international actions in terms of investment, competition, standards (including for charging infrastructure). *(Van der Steen et.al, 2015)*

According to past and recent research, longer term policies and measures are considered to be highly effective to prohibit vehicles that do not adhere to specific fuel economy, emission standards and mandatory import targets. The argument for this type of policy is that policy-makers have multitude of options and can consider the following when formulating EV policies: (i) develop a transition strategy and engage with industry stakeholders; (ii) the identification of potential "lead adopters" and development of strategy for strategic-niche management; (iii) implementation of stakeholder partnerships with industry and consumer groups; (iv) promotion for the adoption of a new socio-technological regime through awareness campaigns and education programmes; (v) Tax negative externalities such as GHG emissions and creating positive incentives through excise relief and subsidies; and (vi) ensure a consistent mix of policy and regulatory signals, which offer long-term certainty. *(Gwilliam, 1997 and Van der Steen et.al, 2015)*

A new framework that is being utilized to promote sustainable transport is the ‘Avoid-Shift-Improve’ (ASI) concept which advises all transport mode passengers to do the following:

1. Avoid unnecessary and inefficient transport where possible. This can be achieved through improved transportation networks, development of compact cities, better demand management etc.
2. Shifting travel/transport when possible to ensure the whole travel journey is an environmentally friendly. Improving passengers travel behaviours plays a major role to inculcate this habit.
3. Improving the technological features of transportation modes to make them more energy efficient and less carbon intensive. *(From points 1-4 sources: GIZ, n.d.; Bos & Temme, 2014 and Dalkmann & Sakamoto, 2012)*

The advantages of having policies which promote an ASI concept can lead to many benefits to the transport sector namely:

1. Lower energy costs and imported fuel
2. Reduced traffic congestion
3. Creation of jobs
4. Lower health risks and noise pollution
5. Increased private investments
6. Better road safety *(From points 1-6 sources: GIZ, n.d.; Bos & Temme, 2014 and Dalkmann & Sakamoto, 2012)*

From a holistic stance it also becomes very important that transport policies focus on cross-sector integration and institutional co-operations. This is important because many of the global transport policies do not have complete synergy between the transport mode and resources available. If governments were to implement integrated policies then this greatly advances the progress to develop low carbon intensive cities, increased and better networks as well as promote development in rural areas.

Institutional and Sector co-operation is very important because the technological landscape is evolving continuously and thus, connections with other sectors will help with the development of effective policies. *(Cordano et.al, 2016)*

Another key requirement when devising transport policies are to ensure that they are intermodal i.e. these policies can cater to the needs to urban and rural passengers as well as ensure co-operation among different transport and service operators. A good example of inter-modality for EV's would be the development of policies which allow for a connection between private, public and shared modes of transport. The benefit of inter-modality in transport is to cultivate a people-centred approach – thus providing access to services to all types of passengers *(Prentice, 2003 and Cordano et.al, 2016).*

As mentioned earlier, long-policy actions can be effective to ensure goals are met but, it is equally important that policies also include short-term goals which are part of the bigger picture. An effective combination of short and long term goals is required in the transport sector due to its inherently multi-faceted and resource intensive characteristics (especially observed in infrastructure planning and system planning). Given the effects of climate change it also is important the policies account for resilience planning when deploying transport systems. It is important that systems are not only reliant on one mode of transport but the risk is diversified by insuring that many forms of transport exist. *(European Commission, 2014)* Policies must also include provisions that assist in the deployment of monitoring systems to evaluate transport services and collect data which can help operators and service providers to ensure the system(s) is (are) working as efficiently as possible as well as optimize their products. This data can also be used by other stakeholders in the transport sector to develop and deploy new products and infrastructure. *(Henning et.al, 2011 and Buggraf et.al, 2014)*

While formulating policies the utilization of an "evaluation framework" can be a useful template for the identifications of barriers and policy priorities. Such a framework can be used by policy makers to guide policy priorities and develop national policy strategies or local action plans for sustainable development. Another characteristic of this tool is that it should account for various jurisdictions, consumer choices/options, policy preferences and technological innovations. *(Pasanen & Shaxson, 2016 and Van der Steen et.al, 2015)*

The potential ‘elements’ which can be used for an EV policy evaluation framework are as follows:

1. **Purchase incentives:** The purpose of such incentives would be to help increase the markets share of EV’s by reducing/closing the gaps between very expensive EV’s and fossil fuel vehicles. Additionally, such an action would help strengthen the automotive industry. The main advantage of purchase incentives that it will reduce the upfront costs of EV’s but it also means that taxes will increase. *(ACEA, 2017)*
2. **Company car taxation:** Reduce the tax rate that are applied to company cars as they emit less GHG compared to privately used cars. This action will hopefully accelerate depreciation for EV (businesses) and private usage benefits include the compensation of EV battery cost from the tax base. The taxation can be set in such a manner that polluters pay more than eco-friendly vehicles. A current limitation (for this action) which is seen in OECD countries is that company cars are under-taxed and therefore promotion of EV’s would mean raising taxes on fossil fuel cars – which might not be acceptable to the public. *(Tausz, 2015)*
3. **CO_2 taxation:** Due to growing environmental concerns governments are applying CO_2 taxation (in some form) to conventional vehicles. Hence to create incentive to purchase EV’s, governments are not applying this taxation rate to EV’s. *(Tietge et.al, 2016)*
4. **VAT Exemption:** Certain governments are allowing EV’s to be exempt from VAT. The purpose of this action is to bring the TCO of EV’s and conventional cars to the same level – therefore increasing the uptake of EV’s. *(Tietge et.al, 2016)*
5. **Increase taxes of fossil fuels:** Such an action would make the public strongly consider converting to EV’s because it would means conventional vehicles would be more expensive to utilize. The risks of such an action include public backlash and detrimental effects to lower income households. *(Whitley, 2013)*

6. **Fostering Innovative and Green Procurements:** This process can help enlarge the EV market by slowly penetrating various sectors to promote the advantage and necessities of EV's. *(Tausz, 2015)*
7. **Access to bus lanes:** This will serve as an advantage should consumers purchase an EV's and as well as give EV drivers a perception of priority. *(Myklebust, 2013)*
8. **Access Restriction Schemes:** Governments are also advocating Low Emission Zone (LEZ) and Congestion charges in a bid to reduce environmental damage caused by heavy traffic and conventional cars. EV's are exempt from this scheme and therefore this is another advantage governments are willing to offer to current and future EV drivers. The risks of such an action are similar to those of increasing fossil fuel taxes. *(GIZ China, 2014)*
9. **Priority Parking:** Exclusive parking EV's are being implemented by governments to facilitate increased EV uptake. However, governments can lose a significant amount of parking spot revenue. *(EEA, 2016)*
10. **Building Regulations:** The EU has passed legislature that all member states must ensure that new and current buildings are revamped so that they can accommodate EV's into their system i.e. they must the capacity to have a charger installed should the need arise. However, this is difficult due to the high costs involved and the rapid technological advancements – for ex. wireless induction charging in the future may make these building changes needless. *(Reiner et.al, 2010)*
11. **Public Infrastructure Deployment:** To address the range anxiety fear that most people have regarding EV's – the deployment of public infrastructure will provide more charging options to EV drivers hence, eliminating the need to rely on home/working charging only. However, there is a risk of stranded investments occurring as there is no proven standard business model to effectively deploy this infrastructure. New technology developments for charging infrastructure will bring new set of barriers that need to be overcome before they become established. – refer to Chapter 5 for more details.

12. **Vehicle-2-Grid (V2G):** There have been studies which clearly show that EV's can be used to store/electricity when the energy demand from grids is forecasted to increase in the future as well as in smart grid systems. However, this concept has yet to be fully proven and excessive use of the EV battery may cause it to degenerate faster. *(Raustad, 2015)*

It is clear that governments have many policy options to consider for the promotion and uptake of EV's. All the aforementioned framework options will have impact on the EV *value chain* – refer to Figure 17; for example a purchase subsidy will target the vehicle value chain more specifically it will have an impact on the consumer's ability to purchase an EV.

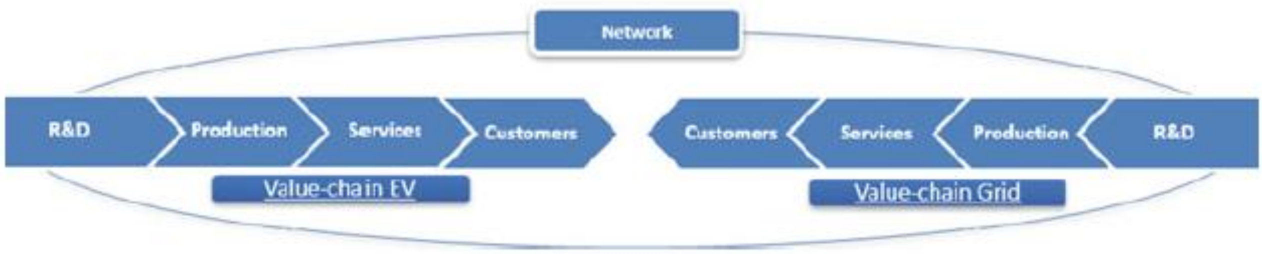


Figure 17: Value Chain of EV's *(Source: Van der Steen et.al, 2015)*

The value chain for EV's can be subdivided into three sections namely:

1. **Vehicle Value Chain:**
   1.1. Research and Development: In this phase significant efforts are placed into the design and efficiency of EV's and their related components.
   1.2. Production: The dominant stakeholders in this phase are the original equipment manufacturers (OEM's) such as auto-manufacturers. Activities in this phase focus on the assembly of the EV including batteries, hardware and software.
   1.3. Services: In this phase activities are focused on providing services such as car dealerships, insurances, training mechanics etc.
   1.4. Customers: This is the final phase of the value chain – i.e. activities are focused on creating incentives and promotions to ensure EV's are sold to potential/interested customers. (Note: customer refers to the end user of EV/fleet operators). *(From points 1.1-4 sources :Van der Steen et.al, 2015)*

2. **Charging Infrastructure Value Chain:**
    2.1. Research and Development: In this phase significant efforts are placed into the design EV charging infrastructure.
    2.2. Production: Charging infrastructure producers will utilize their resources and expertise to manufacturer charging stations as well as provide inputs on how their technology can be integrated with electricity networks and energy production sites.
    2.3. Services: Energy supplier, grid, monitoring & evaluating systems operators will ensure that the charging stations are accessible to the target customers.
    2.4. Customers: In this phase activities will focus on encouraging the customer to try different charging method (depending on their needs) namely: slow charging, fast charging, private charging and public charging (Note: customer refers to the end user of EV/fleet operators). *(From points 2.1-2.4 sources: Van der Steen et.al, 2015)*

3. **Network Value Chain:** This value chain is comprised of all stakeholders that inhabit the EV eco-system. The purpose of this chain is to ensure that the international community as well as the transport sector head towards an all electric future and therefore, meeting our international commitments that have been laid out in the past as well as recent years. *(Source: Van der Steen et.al, 2015)*

Policies as mentioned earlier are a tool to be used by governments to steer and dictate actions to promote sustainable development. The types of tools that governments have access to are as follows:

1. **Legal:** Governments have the authority to develop and implement rules, directives designed to a mandate, enable and incentivize measures and direct stakeholders to ensure policy goals are met. *(Tolson, 2008)*
2. **Financial:** Governments can either distribute or collect material resources such as cash to incentivize/de-incentivize particular behaviour and trends. The main difference between financial and legal measures is that the former is not binding; stakeholders have a choice to utilize the offers/incentive provided by

government. Examples of financial instruments are purchase grants, tax benefits, research funding and subsidies for various sections of the EV-value chain. *(Akitoby et.al, 2015)*

3. **Communication:** Governments have major influence on the communication channels which can help persuade the public to accept/disregard an idea/concept. In the case of EV's governments could use various channels such as schools, media outlets and campaigns to promote the advantages and necessity of an all electric future for the transport sector. *(Howlett, 2009)*
4. **Organisation:** A government apart from being a governing body is also an organization and therefore it has the ability to use its own resources and capacity to achieve the goals it has set out, rather than relying on other stakeholders. For example a government can act as a launching customer and buy new EV's that it released or it can also be responsible to create an environment which enables EV charging infrastructure to be deployed rapidly. *(Van der Steen et.al, 2015)*

4.2 Netherlands EV Policy

The Netherlands is a nation which is leading the EV revolution within the EU and global community. The Netherlands is a very small country but has a very high density of economic output, urban areas and passenger cars. *(Tietge et.al, 2016)* The Netherlands is not a major car manufacturer however, EV manufacturer giant – Tesla has been considering the Netherlands as a potential location to open a Giga-factory in Europe; thus further establishing the Netherlands as a principal nation to propagate EV's in the region. *(NL Times, 2017 June 19)* The EU had called for member states to submit national action plans with the goal of increasing the share of RE's by 2020. The action plan submitted by the Netherlands had clearly stated the nation desire to increase the deployment of EV's. The action plan set the following targets 15.000-20.000 EV's in 2015, 200.000 by 2020, and 1 million EV's by 2025. The government had set aside 65 million Euros for direct EV incentives and 500 million Euros for indirect stakeholders in the EV market. *(Dutch Government, 2009)* The action plan was extended in 2011 and covered the period 2011-2015. The target of 20.000 EV's in 2015 was met 2 years earlier when there were 44.000 EV's by the end of 2014. This huge spike was due to the significant direct incentives that were being provided to EV owners (the peak market share was 5.4% in 2013). In 2015 the market share of EV's dropped to 3.9% due to the reduction in EV incentives. *(Tietge et.al, 2016)*. Currently the direct incentives which are provided to EV owners are as follows:

1. **Registration Tax:** BEV's are completely exempt from the registration tax. This taxation increase the higher the CO_2 emissions hence, diesel cars which have a very high emission rate when compared to gasoline cars will pay a higher registration tax. PHEV's which have an electric and conventional compoent are taxed based on the amount of CO_2 emitted. *(Fier Automotive, 2015 and ANWB [BPM], 2017)*
2. **Ownership Tax:** This tax is dependent on the curb weight and type of vehicle. An average gasoline vehicle has an annual tax of 588 Euros and a diesel vehicle of 1.208 Euros. *(Tietge et.al 2016)* BEV's will be exempt from these taxes. PHEV's which have an emission rate between 1 g/km and 50 g/km will get a 50% discount on this tax. However, very old cars (>12 years) will pay the complete tax and will also incur an additional 15% - due to these machine not being environmentally friendly when compared to modern cars. (*ANWB [MRB], 2017)*
3. **Company car tax:** There is tax that is applied to company cars when utilized for private use. At the end of 2014, 92% of the EV's registered belonged to Dutch companies – thus this tax needed to be applied to create incentives to buy EV's privately. If a company EV has been driven more than 500km/year – a percentage of the vehicles list price (i.e taxable-benefit) is added to the employee's annual income for the first five years after registration. The taxable benefit is determined by the amount of CO_2 emitted from the EV (BEV/PHEV). *(Tietge et.al, 2016)* From 2017 a 4% tax will be applied to BEV's and 22% will be applied to PHEV and fossil fuel cars. *(ANWB [Bijtelling], 2017)*

An interesting observation to be made for the company tax between the periods of 2013-2016 is that if a vehicle had a CO_2 emission of 50g/km it was exempt from this tax but in 2016 this same vehicle would have a 15% tax applied on it. *(Tietge et.al, 2016)* – refer to Figure 18. This is a good example of how the Dutch government is trying to promote EV adoption among the public by exempting BEV's from the taxes that would be paid by conventional vehicle owners.

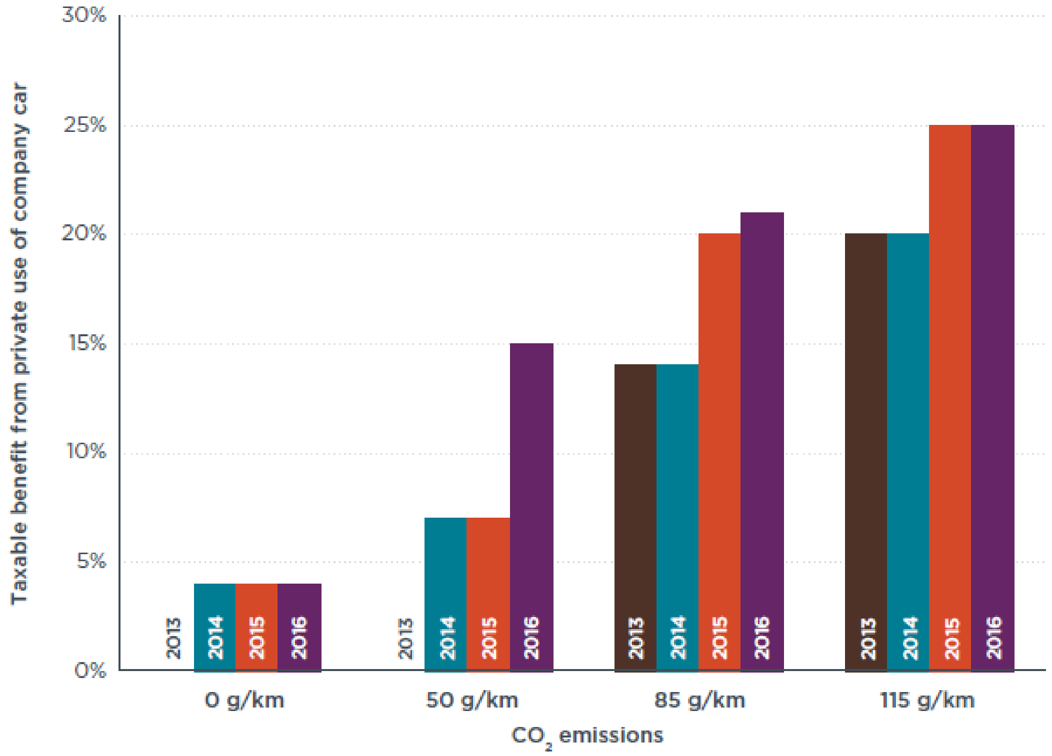


Figure 19. Taxable benefit arising from the private use of company cars for different CO_2 emission levels in 2013-2016.

Figure 18: The taxable benefit for private use of company cars which have different CO2 emission in 2013-2016 ***(Source: Tietge et.al, 2016)***

A graphical summary of the direct incentives that are provided by the Dutch government can be seen in Figure 19.

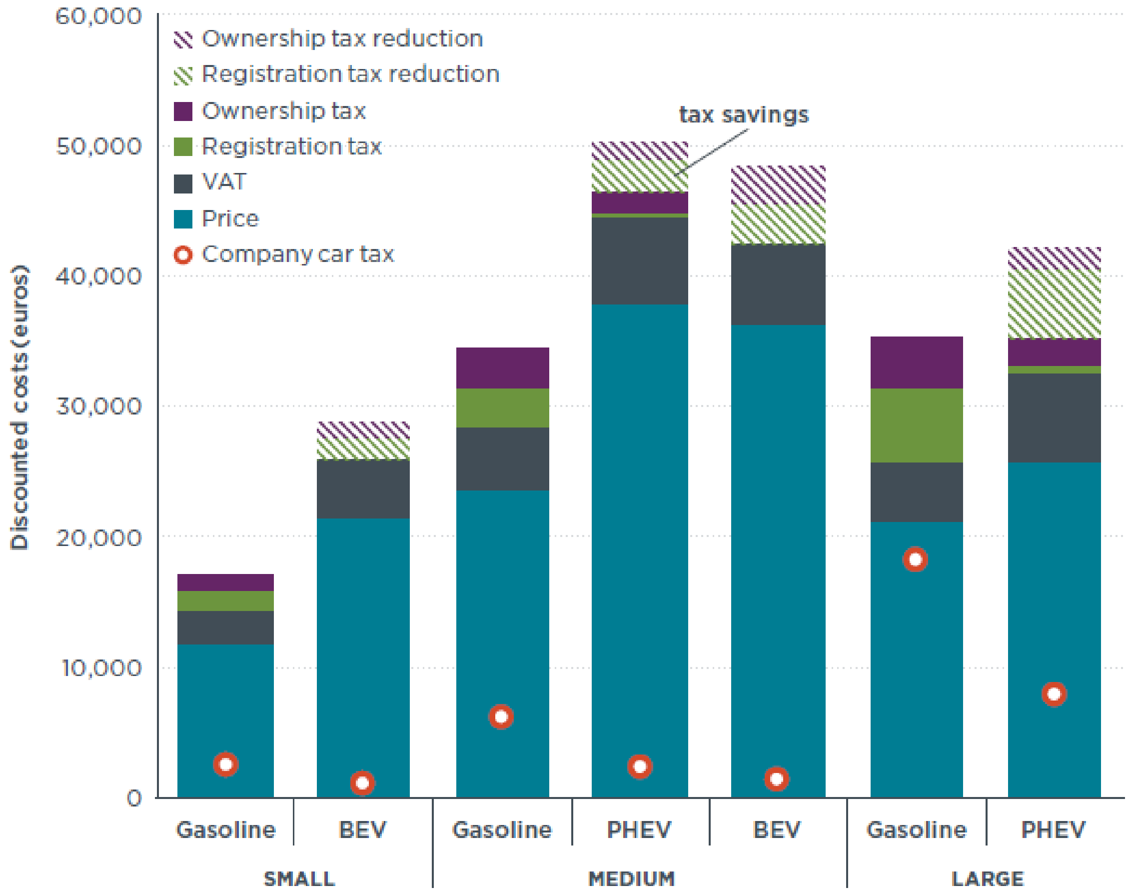


Figure 19: A summary of the tax benefits EV's (of different sizes) in the Netherlands (*Source: Tietge et.al, 2016)*

Figure 19 clearly demonstrates that in all types of vehicles gasoline vehicles are currently much cheaper than EV's – which is mainly attributed to its established technology as well as fossil fuel subsidies from various stakeholders. *(Whitley, 2013)* However, conventional vehicles are not spared from the taxes levied on them by the government. EV's despite being more expensive than conventional vehicles are exempt/have reductions on taxes in an attempt to make them cost effective. The difference in price between large gasoline vehicles and PHEV's is very small and therefore this demonstrates how tax exemptions can make EV's attractive options. BEV's are still more expensive than gasoline vehicles despite tax exemptions. However, as mentioned earlier there is an observable trend of battery costs falling further and therefore the the price of the BEV's can be expected to drop even further. *(IEA, 2016)*

The indirect incentives that EV owners are entitled to include a parking place with guaranteed charging station and priority access to parking permits in major cities such as Amsterdam and Utrecht. *(Tietge et.al, 2016)*

4.3 Netherlands EV Charging Infrastructure Policy

When focusing on the Netherlands there are specific policies and actions the government has taken to promote the implementation of EV and its infrastructure. The first major policy to serve this purpose was the 'Electric Transport Green Deal for 2016-2020'. It was agreed with a vision that the charging infrastructure in the Netherlands would be developed. This vision hopes to address new technological developments, regulations, interoperability and making the business case sound. To realise this vision, the government hopes to incentivise market stimuli, legislation and regulations, develop knowledge and innovation and undertake international efforts and organised collaboration. *(Dutch Government, 2016)* The Green Deal has the following goals for EV charging infrastructure in the Netherlands:

1. **Improving and expanding the charging infrastructure for EVs.** This requires the realisation of a sound business case. Cooperation with the National Knowledge Platform for Public Charging Infrastructure (NKL) and efficient use of the Publicly Accessible Electric Charging Infrastructure Green Deal will help formulate a shared vision on the future of the smart charging infrastructure: through management of the balancing and/or congestion of the grid and using EV's for energy storage. *(Dutch Government 2016 and NKL Nederland, 2017)*
2. **Improving the storage capacity of electric vehicles** when taking into account the variable use of renewable energy and grid stability. This can be achieved through scaling up experimentation and research through the Smart Charging Living Lab Initiative. *(Dutch Ministry of Economic Affairs, 2017 and Hamelink, 2015)*

As mentioned earlier a second tool that is being used by the Netherlands government is to promote charging infrastructure is the ‘Publicly Accessible Electric Charging Infrastructure’ Green Deal. In this deal, the government has pledged a contribution of 5.7 million Euros which will be made available to local and regional authorities for the implementation of charging infrastructure for the period 2016-2018. With this funding it is expected that 10.000 public charging points will be implemented. The central government’s contribution is available to all local and regional authorities (municipality, province or region) in the Netherlands that promote the deployment of publicly accessible charging infrastructure and that they meet the preconditions set. Local and regional authorities have to prove that they themselves are making an equal financial contribution to the rollout through invitations to tender (for a contract or concession) or other channels. The local/regional authorities must show that they are guaranteed contributions by private parties. *(Dutch Ministry of Economic Affairs, 2017)*

The Ministry of Infrastructure and Environment is also offering incentives to business to invest in charging infrastructure by allowing them to participate in the Environmental Investment Tax Scheme (MIA). The two ways this scheme is allowing private charging points on a business site are covered by the MIA is as follows:

1. If the car and charging station are located on the company’s own site, and the total investment is less than €50,000, the entire amount qualifies for the MIA for the lease company.
2. If the car and charging point are provided by a private leasing company and the total investment is less than €50,000, the entire amount can be covered by the MIA potentially.
3. Businesses may also apply for the MIA to install a charging point. If the investment is between €2.500 - €50.000, the amount will be covered by the MIA. (*From points 1-3 sources:* Dutch *Ministry of Economic Affairs, 2017; RVO, 2017; European Commission, 2006 and IEA [EIA], 2017)*

The government also has plans to reduce the energy tax it imposes on charging stations. This means that charging operators will be able to charge consumers less for every kWh supplied to the electric charging station. There is also ongoing discussion on applying an energy tax on parties that store energy (apart from the parties which generate the energy). *(Dutch Ministry of Economic Affairs, 2017)*

The Formule E-Team (FET) is a public private partnership between business, knowledge institutions and the government to promote developments concerning electric transport. The FET ensures that development of electric driving in the Netherlands continues and that it is line with international development and opportunities for green growth. The FET's performs its activities through recommendations, networks, knowledge transfer and the provision of support for projects or creation of temporary working groups. The FET signed the Green Deal and one of its working groups the 'Electric Charging Infrastructure Group' will be working alongside the Association of Dutch Municipalities to reduce the bottlenecks that prevent charging infrastructure from being deployed. The FET will also assist in observing market trend for infrastructure and aid the government to find pathways to reduce the cost of such infrastructure. *(Nedeland Elektrisch, 2017 and Ministry of Economic Affairs, 2017)*

Furthermore, in 2010, a PPP – ElaadNL; a group of electricity grid operators had collaborated with each to install public charging infrastructure. They had a budget of 25 million Euros and were able to install 3.000 charging station between 2010 and 2014. *(ElaadNL, 2015)* ElaadNL dissolved in 2014 and currently the Dutch government has decided to provide support (financial and legal) to upcoming PPP's which wish to install public charging infrastructure. The government has initiated 33 million Euros to fund infrastructure projects, of which 5.7 million Euros has been contributed by the government and the remainder has been funded by regions, municipalities and private sector. *(Tietge et.al 2016 and Dutch Government, 2016)*

In regards to financing options, which is usually a major block for charging infrastructure, the Netherlands Investment Agency (NIA) attempts to optimally align Dutch projects with the funding options provided by the European Fund for Strategic

Investments (EFSI). The NIA is therefore trying to act as a mediator in linking parties so that the funding required can be obtained. *(Dutch Ministry of Economic Affairs, 2017)*

Parties that participate in the 'Zero-Emission City Logistics Green Deal' have agreed to work with the municipalities to ensure they strive towards zero emission city logistics by 2020. Such an initiative will help the propagation of EV's as they are considered zero-emission vehicles. Additionally the national government through the National Knowledge Platform for Public Charging Infrastructure (NKL) is attempting to increasing knowledge-exchange, research and support for charging infrastructure – the Netherlands prides itself in being a leader in this area. (*Green Deal ZES, 2017)*

Finally, the basic philosophy the Dutch government follows when dealing with policy initiatives for charging infrastructure is *'paal volgt auto'* i.e policy follows the car. The charging tree for infrastructure (i.e. priority) followed by government is:
1. EV drivers who park and charge on their own premises (work and home).
2. Emphasis is then placed on semi-public charging facilities (i.e. private facilities in parking areas near stations, shopping centres and on business premises).
3. Lastly, public charging facilities must satisfy the requirements for charging services. *(Dutch Ministry of Economic Affairs, 2017)*

The underlying rationale for this charging tree is the priority for infrastructure on the basis of the cost. Hence, the costs of charging for EV drivers to recharge on their own premises is the least expensive and therefore the government would like to deploy as many of these charging units as possible. Public charging stations are more expensive because the installation costs, investment and variable costs of the charging point are greater. *(Dutch Ministry of Economic Affairs, 2017)*

However, if the Netherlands is to become all EV by 2035 public charging stations will need to be installed in sufficient numbers to ensure drivers who don't have access to a residential charger will be able to charge their EV for use. The market will dictate the mix of charger station options in the Dutch EV ecosystem. The market model will standardise two issues when dealing with payments for usage of EV charging infrastructure:

1. To charge all EV's at any type of charging station using a single card i.e. interoperability
2. The ability to charge a user for the consumption of electricity (*Ministry of Economic Affairs, 2017)*

The market model has three roles:

1. **The charging point customer** – EV vehicle user that wishes recharge his/her vehicle. The user is provided with access to a charging point by means of a card or an app – which also acts as the user's ID when utilizing the charging facilities.
2. **A service provider –** the supplier of the card. This party keeps a record of the quantity of electricity purchased by the user and charges the user for it. The service provider will liaise with **the charging point operator** during the process of EV recharging to ensure that the facilities are in working condition and are able to supply electricity to the EV.
3. **An infrastructure provider –** keeps records on the quantity of electricity purchased by consumers at specific charging point. *(From points 1-3 source: Dutch Ministry of Economic Affairs, 2017)*

The key features of the market model are:

1. Freedom of choice in respect with competitors (simple to switch providers)
2. Competition: dynamic and competitive market with transparency
3. Convenience: simplicity and uniformity
4. Cost effectiveness: optimised for SME admission
5. Future-proof i.e. to adapt flexibly to new technological developments
6. Self-regulating and requiring no amendment to existing legislation and regulations
7. The government will serve as a facilitator, regulate and help start the process *(From points 1-7 source: Dutch Ministry of Economic Affairs, 2017)*

4.4 Netherlands Local EV and Infrastructure Policies - Examples

When focusing on local studies, Amsterdam, which is the Netherlands most populous city as well as most EV dense city, has placed a strong emphasis on EV adoption and charging infrastructure. In Amsterdam, EV owners can receive a subsidy of 5.000 Euros for EV's with a minimum of 60km. *(City of Amsterdam, 2017)*.On the topic of infrastructure, The city's "Sustainable Amsterdam Agenda" has set a target of 4.000 charging points to be installed by 2018 in an efforts to improve air quality, reduce pollution and increase share of RE in the city's energy mix. *(City of Amsterdam, 2015)* To achieve this goal the municipality of Amsterdam along with energy supplier Nuon have decided to work together to install public infrastructure. Amsterdam EV owners who don't have access to private parking spaces can request the municipality to install a public charging point – which comes at no cost to the EV owner. *(Bagner, 2016)*

The City of Utrecht which is the Netherlands second most EV populous city and has the highest number of BEV's is also emulating Amsterdam's efforts to further popularize EV's. Utrecht aims to be climate neutral by 2030 and in its action plan for sustainable transportation a target of 10.000 EV's in 2020 has been set. The city will subsidize the installation of private charging points with a maximum of 500 Euros; if the private charging point is accessible to the public, the subsidy is increased to 1.500 Euros *(Tietge et.al, 2016)*

An example of co-operation between stakeholders in national and provincial level to install public charging infrastructure is the Metropoolregio Amsterdam Elektrisch (MRA-E) partnership. The goal of this partnership is to install 1.200 charging stations in the regions of North Holland, Utrecht, and Flevoland, and more than 80 local governments. *(MRA-Elektrisch, 2017)*

4.5 Netherlands EV and Infrastructure Policies – Summary

Table 1: Summary of EV policies in Netherlands *(Source Tietge et.al 2016)*

Type	Netherlands	Amsterdam	Utrecht
Regulatory incentives	• 200,000 EVs by 2020 • 1 million EVs by 2025	• 10,000 EVs by 2015	• 10,000 EVs by 2020
Direct consumer incentives	• Comparatively low registration tax for EVs • Ownership tax exemption • Reduced company car tax		
Indirect consumer incentives		• Parking spaces attached to charging stations are reserved for EVs • Priority access to parking permits	• Parking spaces attached to charging stations are reserved and free for EVs
Charging infrastructure	• E-laad foundation: 3,000 charging stations with 25 million euros • Green Deal: 33 million euros • MRA-E: 1,200 charging stations	• Up to 500 euro subsidy for private chargers • Up to 1,000 euro subsidy for semi-public chargers	• Up to 500 euros for private chargers • Up to 1,500 euros for semi-public chargers
Complementary policies	• 3,000/5,000 euro subsidy for electric vans and taxis • Environmental Investment Rebate tax deductible • Favorable asset depreciation rates for EVs • Education and promotional events • Innovation incentives for SMEs • Web portal "Netherlands electric" • Research of EV technologies	• Additional 5,000 euro subsidy for electric vans and taxis • Web portal "Amsterdam electric" • Preference for EVs in municipal fleet	• 35 EVs in municipal fleet • Web portal "Utrecht electric" • Preference for EVs in municipal fleet

5. Electric Vehicle Infrastructure

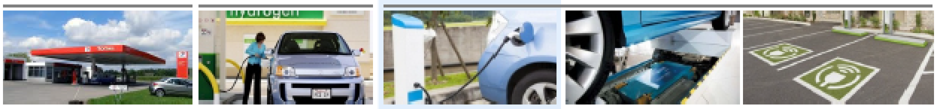
5.1 General and Basic Overview

In the previous sections of this report, it has be mentioned and described that EV's are a disruptive technology which will revolutionize the transport sector by making it more sustainable and environmentally friendly. *(IEA, 2017)* However, to ensure that EV's gain faster adoption and are able to replace fossil fuel vehicles, it becomes imperative that charging infrastructure be deployed rapidly and as effectively as possible. Without the appropriate infrastructure it becomes very difficult to utilize EV's for daily activities. Each transport vehicles require different infrastructure to allow it to function efficiently. The global infrastructure market is set to have a market value of $49.95 billion in 2025 *(Grand View Research, 2017 April).* Figure 20 shows the different types of infrastructure required for different types of vehicles.

Electric powertrains: Charging infrastructure archetypes

Focus of Chapter 3

Energy source



	GASOLINE/DIESEL	HYDROGEN	BATTERY		
	Fueling gasoline or diesel at a petrol station	**Fueling hydrogen at a hydrogen refueling station**	**"Wired" charging using a plug**	**Battery swapping**	**Induction charging**
Description	Conventional gasoline or diesel refueling	Hydrogen refueling (similar to natural gas refueling)	Plugging in to a charging station using a cable and plug	Replacing a battery for a fully charged one at a special swapping station	Battery in the car is charged by wireless induction charging
Time needed[1]	5 min	5 min	4-8 hrs (slow) 20-30 min (fast)	5 min	~2-8 hrs[2]
Suitable for which power-trains	▪ ICE ▪ HEV ▪ PHEV ▪ REEV (gasoline)	▪ FCEV ▪ REEV (hydrogen)	▪ PHEV ▪ BEV suitable for plug-in charging	▪ Special BEVs suitable for battery swapping	▪ Special BEVs suitable for induction charging
Example car	▪ All ICEs	▪ Hyundai ix35 (FCEV)	▪ Renault Zoe (BEV)	▪ Special model of Renault Fluence	▪ N/A (few pilot cars)
Current availability in Europe	Widely available: ~131,000 stations	Very limited: ~80 stations	Limited availability: >20,000 (slow) >1,000 (fast)	Very limited ~50 stations	Not available (few pilots in progress)

1 Time need for full refueling or recharge. For fast-charging of battery, time to reach 80% of battery capacity is commonly used
2 Since induction charging is still in pilot stage, common duration and power level are not yet established; power levels of 22 kW have been achieved
SOURCE: Europia, Fuel Cell Today, Public sources, McKinsey

Figure 20: The different types of Infrastructure required for vehicles powered by fossil fuels, hydrogen and batteries (electricity) ***(Source: McKinsey & Company, 2014)***

In reference to Figure 20 it can be seen that fossil fuel vehicles only require a fuelling station, it takes approximately 5 minutes for refuelling and the corresponding infrastructure is well established globally due to the long history of fossil fuels and the huge amounts of government subsidies for this energy source. *(Whitley, 2013)*.

When focusing on hydrogen fuel cell vehicles (HFCV), they are powered by hydrogen fuel cells and the main benefits imparted by utilizing a hydrogen powered vehicle are reduced carbon footprint of consumers, reduced air pollution in cities, and faster fuelling time with longer range than current battery electric vehicles. The main hurdles which are hampering deployment of HFCV the low margins and return on investment in infrastructure, which makes it difficult to attract private investment, particularly from traditional fuel distributors and the intense resources required to compress the H_2 gas. *(Kwasie et.al, 2015)*

Figure 20 shows that there are 3 types of infrastructures/charging options that can be used to charge EV's namely: wired charging (a.k.a plug in charging) using plugs, swapping batteries and induction charging. Wired charging is the most popular and most common form of charging infrastructure being utilized by many nations globally. The core component of the wired charging method is the installation of various charging stations which have different characteristics. *(IEA, 2016 and IEA, 2017)* The time needed to charge an EV through this method depends on the power output of the charger – it can take between 4-12 hours on a slow charger and between 15-30 minutes on a fast charger. *(US DOE, 2017)* Currently in Europe the availability of this infrastructure is limited and more deployment and investment in this infrastructure is required. *(EURELECTRIC, 2016)*

Battery swapping is another charging mode that has explored – due to the range anxiety fear that many EV sceptics consistently advocate. The main advantage of this method is a drastic reduction in the "charging" time required for EV; since all that needs to be performed is removal of the current battery and replaced with a fully charged battery. *(Sarker et.al, 2011)* To ensure that this mode of charging becomes popular it becomes very important that the swapping station is built at a strategic location because if this parameter is not chosen properly, EV drivers can be stranded if their vehicle runs out of power. A major hurdle which needs to be overcome is the standardization of batteries - this arises because different vehicles do not have the same battery. To ensure the swapping process is as efficient as possible standardization is a key requirement. Additionally, if the batteries are overcharged in the swapping station then it could lead to them degenerating and discharging faster and therefore can impact the efficiency of the EV. Most importantly, this whole process revolves around the battery and therefore, it is imperative that battery costs decline. If batteries aren't cheap then EV drivers will need to find more economical options to charge their EV's. *(Kerns, 2016 July 19)* There has been an observable trend that battery prices are getting cheaper and are expected to be on par will fossil fuel prices by 2022 *(IEA, 2016 and IEA, 2017)* – which makes this charging option viable. EV giant Tesla was a pioneer for this method but, they have come to the conclusion that fast-charging is the way forward for EV charging. *(Lambert, 2016 May 10)*

The most innovate charging method for EV's is wireless induction charging. This type of charging utilizes magnetic resonance coupling i.e. the use of magnetic fields to transfer electrons from a wireless plate to the vehicle's battery – resulting in charging (Note the EV will need to be slightly modified with additional parts to be compatible with this technology) This novel technology is currently in the research phase and shall take time to become established and viable. *(Assawaworrarit et.al, 2017)*

Battery Swapping and Wireless charging are ideas which have yet to gain full traction therefore this Thesis will elaborate more on the plug-in charging method – as it is the most mature charging mode and therefore it is imperative that investments are made to improve the technology and accelerate installation of charging infrastructure.

The variables in wired EV charging are: the power level of the charging station (in terms of kW), the type of electrical current it uses, the plug and type of battery factors. These parameters will determine how the EVs can be charged, where it can be charged and the duration to charge them. *(McKinsey & Company, 2014)*

1. **Power level:** The power level of the charging source, expressed in kW, is defined by both the voltage (V) and the current (A) of the power supply. This parameter determines how quickly a battery can be charged. This parameter usually ranges from 3kW (slow) – 120kW (fast). The lower power levels are used for residential chargers and it can take several hours to fully charge a battery. Residential power chargers can be upgraded through a connection with the local grid which enables access to faster charging levels. High power levels are typically found in public charging places which allow for fast charging; cutting the charging time from several hours to 15-30 minutes. *(ZAP MAP, 2017)*

2. **Electrical current:** Electricity sourced from the grid is usually AC. Batteries in EV's can only store DC therefore, the electricity provided by the grid to the EV needs to be converted into the appropriate from. Most modern day EV's are equipped with an on-board AC-to- DC converter. With DC fast-charging stations the converter is integrated within the unit itself converts AC electricity from the grid into DC electricity for the EV. *(BEAMA, 2015)*

3. **Plugs:** This component is the interface that connects the EV to the charging unit. From an international perspective there is currently no global standard for EV charging plugs. Multiple plugs and sockets exist to connect vehicles to charging stations.

   For slow charging which is often the charging option that is utilized by EV owners who wish to charge their vehicle at home and/or work the following connection plugs are available – refer to Figure 21

Figure 21: A generic schematic of the slow charger connectors for EV's *(Source: ZAP MAP, 2017)*

Slow charging units have the option to be tethered or un-tethered. The latter utilizes a Type 2 whereas the former has a Type 1 connector which is supplied by the EV manufacturer *(ZAP MAP, 2017).* In Europe a majority of the grids are three-phase and any foreign Type 1 connector is not compatible with the electricity network, therefore most European nations have adopted a standard plug called the Mennekes Type 2 connector – refer to Figure 22. The reason this is popular is because it offers additional protection to the electrical equipment (including water and dust), offers very secure attachment and has one hand operation capabilities. *(MENNEKES, 2017)*

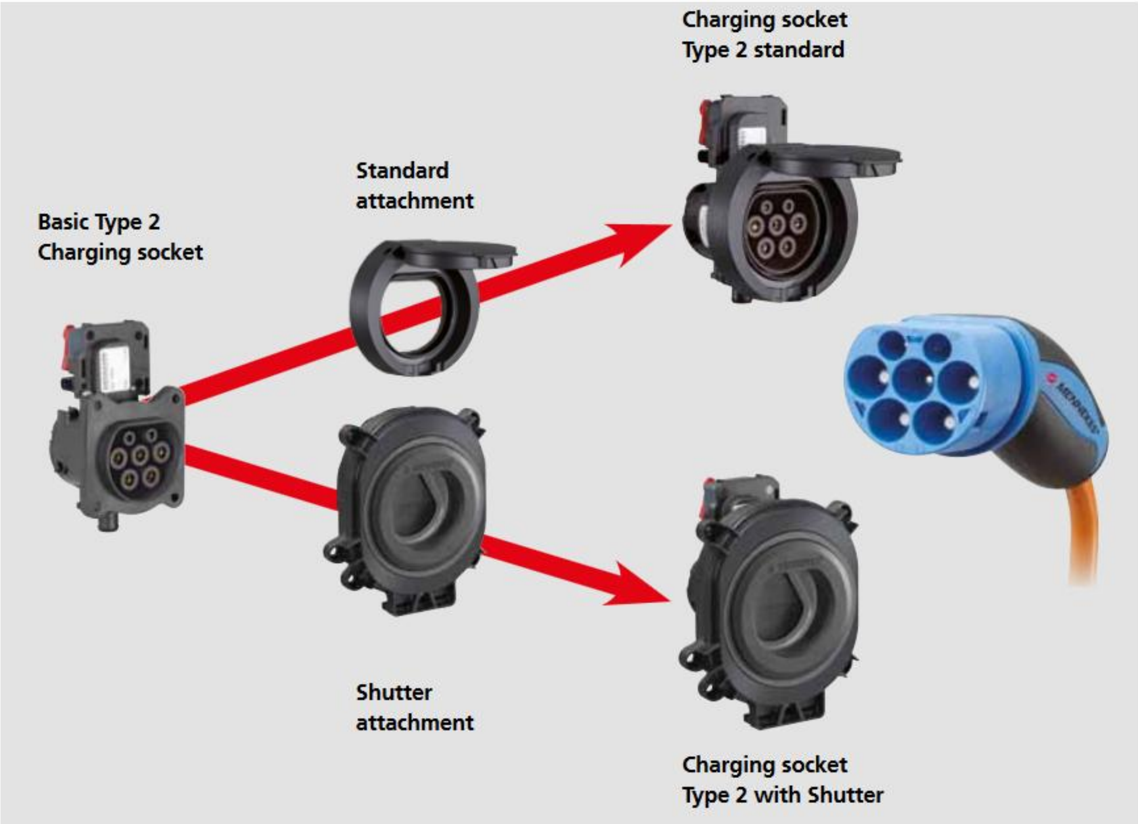


Figure 22: Mennekes Type 2 connector *(Sources: MENNEKES, 2017)*

Fast charging which has higher power outputs and current levels have the following connector designed for such an environment:

a) **Combined Charging System (Combo):** Figure 23 shows the standard Combo charging plug and socket which is a part of this system. When this plug is in it's station holster it is completely de-energized. When the plug is inserted into the socket the station transfers the maximum current to the EV and the vehicle will send a return signal which indicates that it the system is ready for charging. After the connection has been established the vehicle's on-board charger handles the subsequent operations. For the fast charger CCS plug and socket it is very similar to the Combo charger but there are two extra pins which connect the vehicle to the stations DC charging circuit. The operation of this plug is the same as that of the Combo charger (*Hydro Quebec, 2015)* – refer to Figure 24.

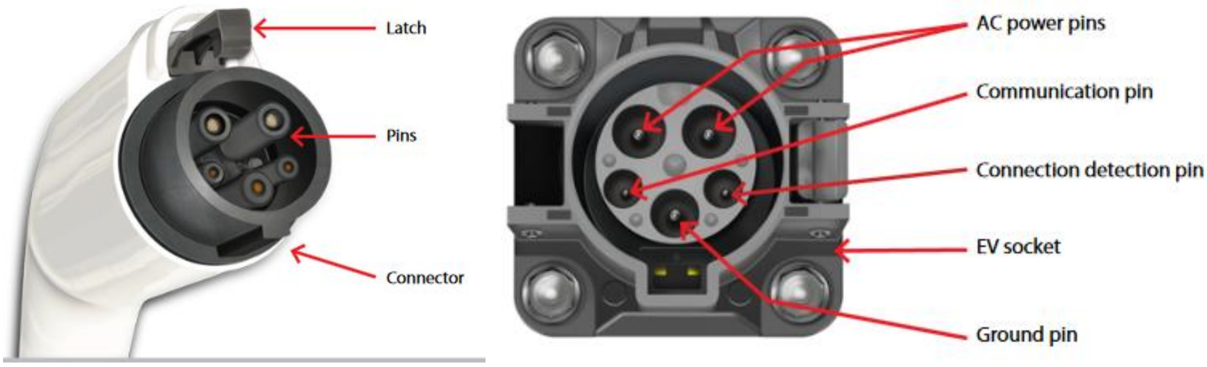


Figure 23: Combo Charger Plug [left] and socket [right] ***(Source: Hydro Quebec, 2015)***

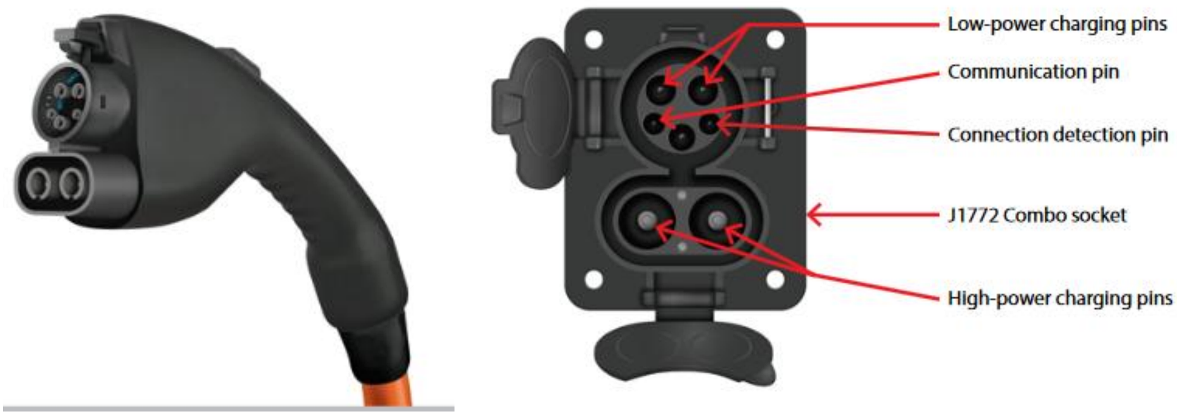


Figure 24: Fast Charging CCS Plug [left] and Socket [right] ***(Source: Hydro Quebec, 2015)***

b) **CHAdeMO:** The Japanese CHAdeMO association developed a specific plug that was meant for DC Fast charging purposes. The operation is similar to that of the Combo charger but instead of transferring maximum power to the EV, it regulates the amperage and voltage based on a two way communication (analog and CAN-bus protocol) between the EV and charging unit. The latching mechanism is very rigid while the system is energized and will de-energize all components once disconnected. This connector is also enabling vehicles in Japan and Europe to act as energy storage medium thus, offering flexibility to the grid and regulating energy demand. *(CHAdeMO, 2017)* – refer to Figure 25

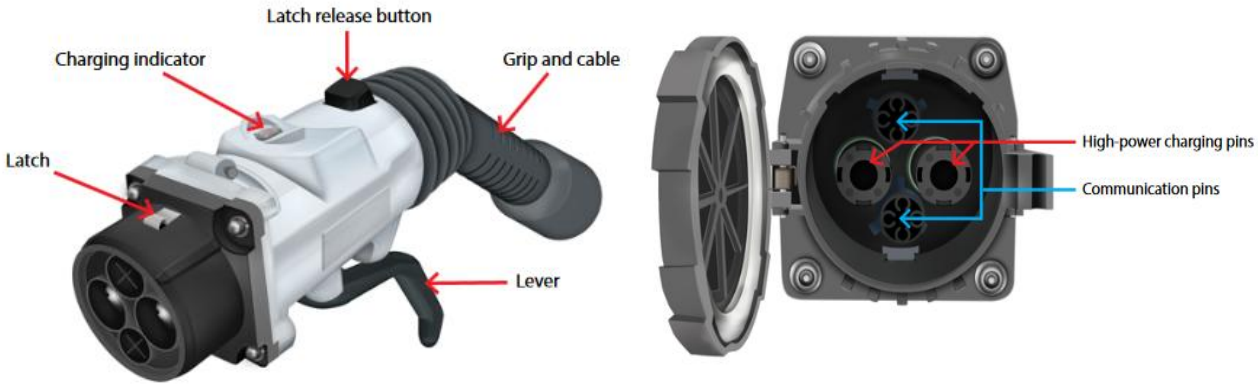
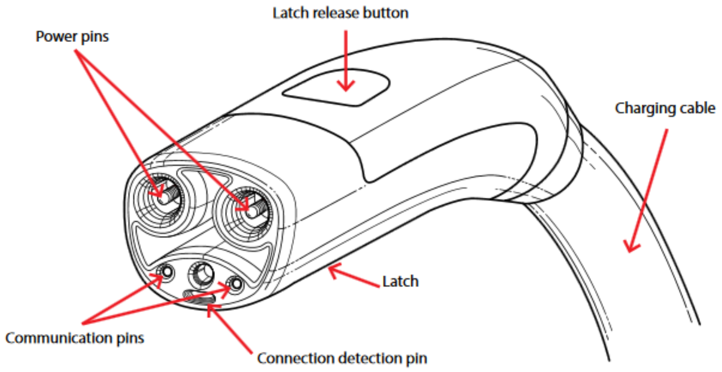


Figure 25: Fast Charging CHAdeMO Plug [left] and Socket [right] ***(Source: Hydro Quebec, 2015)***

c) **Tesla Supercharger:** Tesla has designed their own charging station as well as plug for their vehicles. The unique aspect of this plug is that in the same framework it can support AC and DC charging. The recharging process only starts once there is an established connection between the vehicle and charging station. (*Hydro Quebec, 2015)* – refer to Figure 26



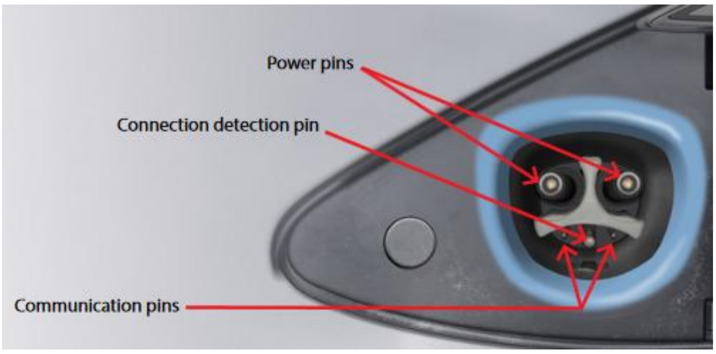


Figure 26: Fast Charging Tesla Supercharger Plug [top] and Socket [bottom]
(Source: Hydro Quebec, 2015)

4. **Battery size:** Different EV's have different power levels and current types that they can accommodate. These parameters are determined by battery size (expressed in kWh). Most EV batteries which have small capacities usually charge at 3.7 kW power output. Popular EV models with this battery capacity include Mitsubishi Outlander, Volvo V60 Plug-in Hybrid, Opel Ampera, Toyota Prius Plug-in Hybrid version. Full BEV's rely on their battery capacity for their driving range and these batteries are larger which can cope with higher power levels for charging. Examples include the Nissan LEAF which has a 24 kWh battery capacity and can charge at 7 kW using AC or 50 kW utilizing DC, the Renault Zoe which has a smaller capacity 22 kWh battery size and charges 43 kW using AC and the Tesla Model S which can have a 60 kWh or 85 kWh battery which will charge using 10 or 22 kW AC, or using the Tesla Supercharger which has an output of 120 kW DC. *(McKinsey & Company, 2014)*

Furthermore, slow-charging vs. fast-charging – is an important consideration when discussing and understanding the level of charging network coverage. The type of charging utilized will dictate how long an EV will take to be completely refuelled and therefore also determine a driver's driving behaviour. The current ratio for slow: fast charger stations are approximately 20:1. Countries which are dedicating resources to increase the network of fast chargers to make intercity travel with EV's more practical include Estonia, Norway, Denmark, and the Netherlands. *(FastNed, 2017)* The deployment of fast chargers is heavily reliant on national government support as well the involvement of the private sector through public-private partnerships. *(McKinsey & Company, 2014)*

5.2 Plug-in EV Infrastructure Components and Levels

The Plug-in charging is the most established way of charging EV's. The main infrastructure required for this charging method is the electric vehicle supply equipment – EVSE. This is defined as "equipment that sits between the fixed electrical wiring of a building or street and the electric vehicle itself. EVSE includes all cables, connectors, protective devices, communication equipment or accessories installed specifically for the purpose of delivering energy to the EV" *(BEAMA, 2015)*

The batteries in EV's require a DC current to be charged however, the electricity from the grid is AC. Therefore to ensure compatibility between the EV and EVSE, the vehicles have an onboard converter which can convert the AC into DC. It is also possible to charge the vehicle directly with DC if the current output from the EVSE is of this form. AC has lower power (utilized for slow charging options) and DC higher power potential (utilized for fast charging options) *(BEAMA, 2015)* A general overview of the type of charging options available can be seen in Figure 27.

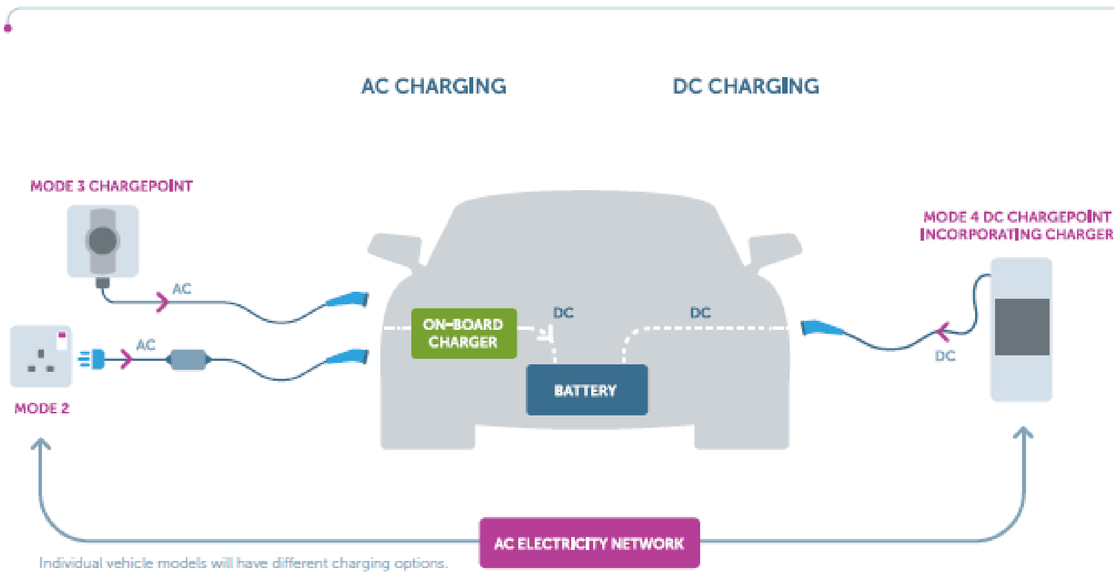


Figure 27: Overview of Charging Options for EV's *(Source: BEAMA, 2015)*

EV infrastructure is dependent on the 'level/type' of charging utilized and these levels are defined on three parameters namely: voltage (V), current (A) and time (minutes/hours). There are 3 levels of charging and they are as follows:

Level 1: Level 1 charging is a method that utilizes between 110-120V and AC current (15-20A) to charge the EV via the on-board converter. The main advantage of this charging method is the cord cable which is provided by the EV manufacturer can be directly inserted into the electrical sockets that exist in private/residential work places and therefore economically viable. However, plugging the EV cord directly into a wall socket is not recommended because there is no shock protection offered. Hence it is recommended that an In-Cable Control and Protective Device (ICCPD) is attached the EV cord to ensure safety as well as offering greater control over the charging power. *(BEAMA, 2015)* An alternate option to increase safety during the charging process is the installation of a dedicated charging pedestal or wall mount. Level 1 is the simplest method to charge a vehicle; they are not networked and do not have tracking and payment session features – but, these can be added with additional costs. *(Forward et.al, 2013 and Smith, 2016)* Figures 28 and 29 show a standard Level 1 cord and a car using this charging method in a parking lot.

Figure 28: An EV cord with a standard socket (USA) and ICCPD *(Source: Herron, 2016)*

Figure 29: Example of level 1 charging at a workplace parking lot *(Source: Smith, 2016)*

Level 2: Level 2 charging is very similar to level 1 but, instead of utilizing 120V it uses 240V and 40-60A, therefore has a faster charging time when compared to level 1. A separate circuit boards and equipment needs to be installed in either homes or public places to convert the 120V to 240V. *(Forward et.al, 2013 and EV Town, 2015)*. Figures 30 and 31 show the various possibilities EV owners have for Level 2 charging.

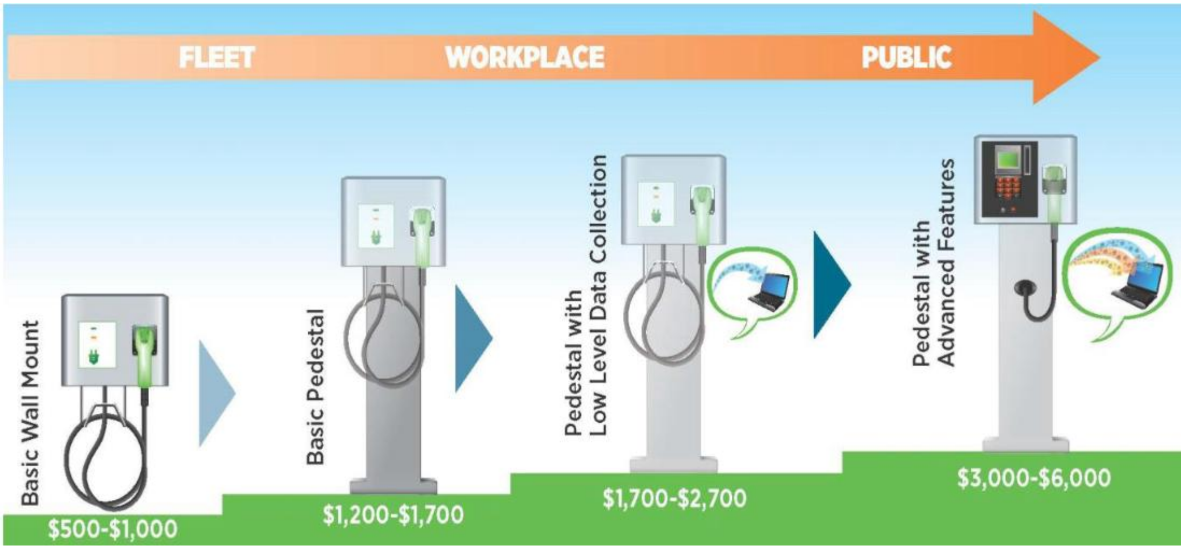


Figure 30: The various options for Level 2 charging a station ranging from wall mounts to pedestals *(Source: Smith, 2015)*

Figure 31: An example of level 2 charging at home using a wall mount *(Source: Voelcker, 2017 April 27)*

Level 3: Level 3 charging also known as DC-fast charging will charge the EV directly through a DC i.e. no conversion is required. The average voltage of this charging is 450V and it can charge the vehicle to full capacity in minutes rather than hours. The power output from these chargers ranges from 20kW – 120kW; the average output is 50kW. As mentioned earlier the most popular charging systems for this method are CHAdeMO, CCS and Tesla's Supercharger. This charging is very important EV's are used for long journeys as drivers want to recharge as fast as possible to continue the trip. Furthermore, if these stations are installed in urban locations then it can replicate (to-an extent) the refuelling process performed when using conventional cars. *(Chargepoint, 2017 and BEAMA, 2015)*

Figure 32: An example of DC charging stations offered by ABB and the compatible cars listed below *(Source: Hudson, 2017)*

Figure 33: A Tesla Model S utilizing the Tesla Supercharger *(Source: Tesla, 2017)*

Figures 32 shows an illustration of the DC charging stations that are developed by ABB namely a CCS station (left), a CCS/CHAdeMO station (middle) and a multi-standard station (right) – the compatible cars for each station are listed below. Figure 33 shows the setup a Tesla Model S has when it utilizes the Supercharger.

To ensure that we are able to reap the benefits of EV chargers it becomes very important that governments invest time and effort to ensure this technology is made easily accessible to mitigate driver fears especially 'range – anxiety'. Therefore, the four categories of charging infrastructure which need to be installed to guarantee efficient operability of the EV system are as follows:

1. Public charging station on public domain (e.g. roadside/sidewalk); these charging points are available 24 hours a day, seven days a week. They are the standard charging point in a public space.

2. Semi Public accessible charging station; these are charging points located in public spots such as parking lots, shopping malls, workplace etc. hence their availability will be dependent on the opening hours of these places.

3. Fast Charging points; these charging stations will provide more power to an EV very quickly and therefore reduce the charging times significantly. They are located in strategic locations such as motorways and are considered one of the most suitable solutions to allow EV's to cover long distances.

4. Privately accessible charging station (e.g. home or office locations). These are charging points that are located on private spaces with private electric supply. When consumers purchase an EV, the car manufacturer will often include a home charger kit *(From points 1-4 source: Eurelectric, 2016 and Dutch Ministry of Economic Affairs, 2017)*

As will be shown in the next sub-section, the Netherlands has made great progress when dealing with the deployment of EV charging infrastructure.

In addition to all the charging equipment that is required to charge the electric vehicles, other requirements that need to be taken into consideration when expanding EV infrastructure are wiring, connection to the grid, land costs, smart metering costs, labour and planning & permits. *(Markel, 2010)*

To summarize the EV charging infrastructure please refer to the Table 2 below:

Table 2: Summary of EV charging requirements *(Source: De Jong, 2016 and Porsche, 2017)*

	Slow Charging		**Fast Charging**	
	Level 1	**Level 2**	**Level 3**	**Future**
Voltage	120 V	120-240V	300-450V	450-800V
Current Type	AC	AC	DC	DC
Charging Time	8-12 hours	3 hours	20 min (80%)	15 min (80%)
Plug Connector Type	CCS	CCS	CHAdeMO,CCS, Tesla Supercharger	To be defined
Where can it be used	Private/Public Locations	Private/Public Locations	Public Locations	Public Locations

5.3 Netherlands EV Infrastructure Current Status:

In many reports which focus on EV's and the corresponding infrastructure; the Netherlands has always been considered an EU and global leader in this sector. According to McKinsey & Company there are 1.1 charging station per vehicle in the Netherlands; which the highest ratio for charging station:EV in the world. *(McKinsey & Company, 2014, Tietge et.al, 2016 and Dutch Ministry of Economic Affairs, 2017)* There is also a very good distribution of fast charging stations throughout the country as seen in Figure 34. Additionally, many of the public charging ports that are installed are "Smart-Charge" ready and have a very good distribution– refer to Figure 35

Figure 34: Distribution of FastNed Station in Netherlands *(Source: FastNed, 2017)*

Figure 35: Distribution of Smart Charging Ready Station in Netherlands (Source: Hamelink, 2017)

The main reasons for the popularity and increasing deployment of charging infrastructure in the Netherlands can be attributed to the following:

1. University and Research Institutes are investing time to develop new technologies to increase EV efficiency. They are also part-taking in social events to popularize the uptake of EV's
2. The Dutch Organisation for Electric Transport is an industry association that has been connecting various stakeholders to help deployment of EV and infrastructure
3. Government and Business are working together to help transition to an EV future by sharing the associated costs for ex. charging point station costs
4. There are financial incentives to fund EV related projects
5. Collaboration with other nations such as the USA, Germany and India have given Netherlands access to ideas and other resources to help accelerate the deployment of EV and infrastructure.
6. Tax Breaks and Energy Incentives that are provided to EV owners *(From points 1-6 source: RVO, 2016)*

According to the Dutch Ministry of Economic Affairs most recent statistics, there are 98.700 charging station in the Netherlands as of 2016, the breakdown of this value can be seen in Figure 36.

Charging points[4]	31-12 2014	31-12 2015	31-12 2016
Public (publicly accessible 24/7)	5,421	7,395	11,768
Semi-public (with restricted public access)	6,439	10,391	14,320
Fast charging points	254	465	612
Private charging points	28,000	55,000	72,000
Total			98,700

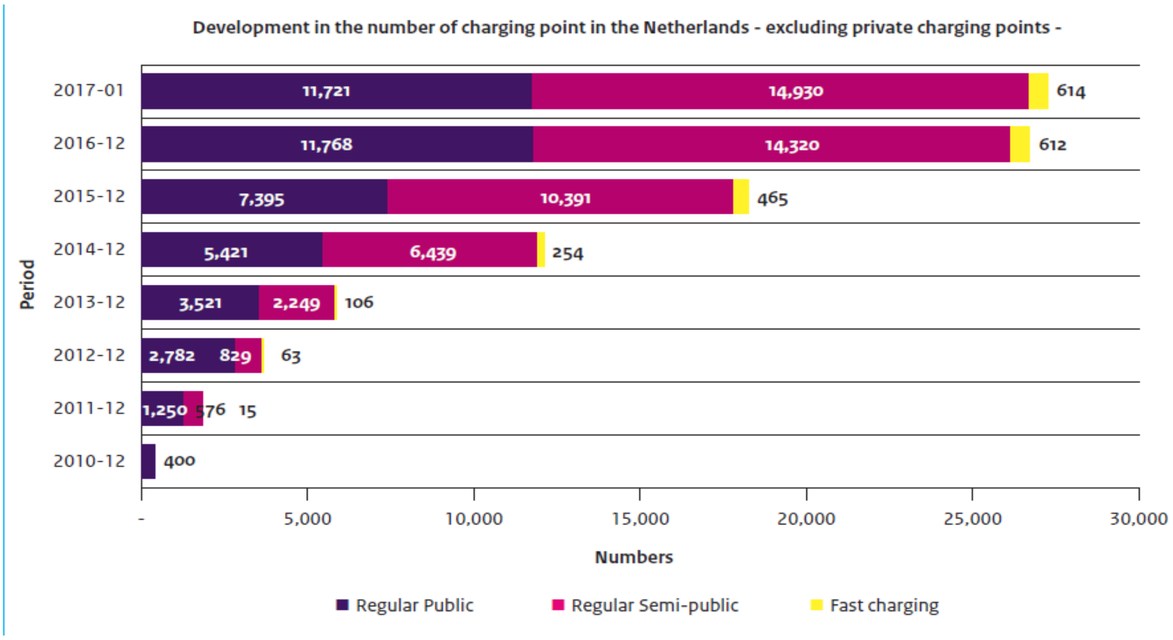


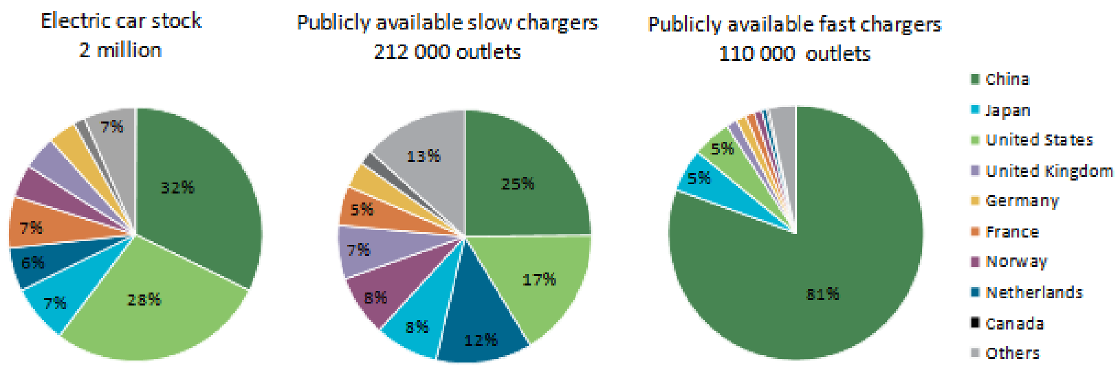
Figure 36: Statistics for Charging Infrastructure in Netherlands *(Source: Dutch Ministry of Economic Affairs, 2017)*

As seen in Figure 36, there has been a huge leap in the deployment of EV infrastructure in the Netherlands since 2012 when only 400 charging stations existed. However, if the Netherlands is aspiring to go all electric by 2035, it becomes very important that more infrastructures be installed to cope with the increased demands for EV which is expected to reach 140.000 EV by 2020 alone. *(Dutch Ministry of Economic Affairs, 2017)*

In the Netherlands there is an increased incentive to ensure that in the future more public charging hubs to be installed in locations such as parking lots. This will help reduce costs and make deployment of charging infrastructure more efficient – as seen in locations such as Arnhem. *(Swart & van Beek, 2014)*

The Netherlands has also begun to experiment with the integration of wireless conduction charging on roads *(Pieters, 2016)* and vehicle-to-grid supply to help ease the increase in pressure and demand on the grid with the advent of increased usage of EV's. *(Stuij, 2015)*

As seen in Figure 37, there are 2 million EV's globally and the Netherlands has a 6.4% share and when in EV infrastructure it has a 12% share in public slow chargers and a negligible percentage for fast chargers. *(IEA, 2017)* Despite the positive trends that the Netherlands has demonstrated; when its progress is compared with international competitors such as Norway, USA and China – much more development is desired if the Netherlands has aspirations to be a global leader in the EV ecosystem.



Sources: IEA analysis based on EVI country submissions, complemented by EAFO (2017a).

Key point: Electric cars still outnumber public charging stations by more than six to one, indicating that most drivers rely primarily on private charging stations. Publicly available EVSE shares are not evenly distributed across markets. This is consistent with the early stage of electric car deployment.

Figure 37: Global Statistics for EV Infrastructure *(Source: IEA, 2017)*

6. Financial for Electric Vehicle Infrastructure – The Netherlands

As mentioned in previous sections, the cost for EV's are being driven down due to the technological development in batteries and the reduced costs for charging. The battery accounts for 30% of an EV's overall cost. This decrease also attracts new market players and therefore increases competition; which will help reduce the costs even further. The development of battery factories by companies such as Tesla and Volkswagen will help decrease the battery costs due to the economy of scales concept. In the Netherlands the cost for batteries is approximately €200-€250/kWh and this is expected to drop to €100/kWh by 2020 and should reach parity with ICE's in 2022. The reduction of cost in EV's also has the added benefit for the reduction in charging infrastructure costs. The energy costs are expected to decline with the inclusion of RE's in the energy mix. In the Netherlands there are approximately 25 providers which offer installation of slow charging units. The cheapest way to charge an EV in the Netherlands cost approximately €0.25/kWh with an initial investment for the private charging infrastructure being €250 for level 1 and €1250 for level 2. These costs are significantly lower than the public charging infrastructure which has additional requirements such as charging poles and separate metering. If charged publicly, level 2 charging would increase to €0.30/kWh and fast charging would cost €0.60/kWh. *(de Jong, 2016 and Netherlands Enterprise Agency, 2016)*

When focusing on the financial landscape of the EV charging infrastructure, in the Netherlands it has been privatized with 20 Charge Point Operators (CPO) and approximately 10 Mobility Service Providers (MSP) responsible for the deployment and maintenance of this infrastructure. The CPO is responsible for operational aspects of the charging stations i.e. electricity supply, installation and repair service, while the MSP handles the sales i.e. they are responsible for the charging subscriptions, the charging cards, apps, and payment transactions. *(de Jong, 2016)*

On analysis of the cost structures for public charging stations (both slow and fast) it has been found that the connection costs play a major role in determining the total cost of installation. Additionally for the fast charging stations the charging poles will be more expensive due to the need for larger grid connections for these chargers. The benefits of public charging infrastructure will rely on the consumer charging behaviour and charging pole utilisation which is inclusive of the connection time/parking time, charging time and distance travelled. The technical aspects of the chargers i.e. the capacity, charging power, vehicle efficiency, GHG reduction and economic factors such as EV adoption rate and charging price also determine the benefits on deploying public charging infrastructure. *(de Jong, 2016)*

According to the Master Thesis written by De Jong, the majority of the charging poles used in EV charging stations were 3x25A charging poles while a minority utilized 3x35A charging pole. The average connection cost for the charging pole was €1.807, 47 and in the cases analyzed it was found that the connection costs fell between €1.704,96 and €1.909,98. When the connection costs were analyzed further it was found by De Jong that within the connection cost, the highest costs arose from the services, internal and external labour – which was 70% of the connection costs. The activities which are involved when setting up a new charging connection were 3 to 3 phase changes, extra lengths for cables, changing electric patterns, obtaining permits for digging, municipality permits and notices to inform public that a new charging station is going to be installed. The main costs for installing a level 2 public charger as researched by De Jong can be found in Table 3.

Table 3: Infrastructure Costs for Level 2 Public Charging Station ***(Source: De Jong, 2016)***

Infrastructure	Sub – Total Cost	Total Cost (Average)
Hardware: Level 2 Public Charger	N/A	€ 2.300
Co-ordination: Location Decision, Planning and Co-ordination	N/A	€ 300
Installation: Materials	€ 180	€ 470
Installation: Outsourced Labour	€ 229,30	
Installation: Supplements	€ 60,78	
Connection: Charger Point Operator Costs	€ 1299,49	€ 2.800
Connection: 3 x 25A, 17 kVA including 25m cable + permits	€ 1807,47	
Connection: Grid upgrade	€ 969,31	
Connection: Grid Operator Revenue	€ -1299,49	
Bricklaying: ±10m² walkway per (€40/m²)	N/A	€ 350
Signage and road markings	N/A	€ 250
Total Investment Cost		**€ 6.470,00**

The lifetime of charging poles is 7-8 years. Hence, two regular charging poles will be required in a 15-year period, which is equivalent life time for a fast charging station. Thus, the initial investment will need to be doubled when compared to a fast charging station.

The yearly operation costs as calculated by De Jong can be seen in Table 4 below:

Table 4: Operational Costs for Level 2 Public Charging Station ***(Source: De Jong, 2016)***

O&M	Sub – Total Cost	Total Cost (Average)
CPO: Maintenance	€ 200	€ 220
CPO: Cleaning Station	€20	
CPO: Connection Grid Connection	€ 168,66	€ 268,66
CPO: Communication wifi and cellular connection	€ 100	
CPO Miscellaneous: User Services	€ 20	€ 77
CPO Miscellaneous: Overhead	€ 20	
CPO Miscellaneous: Insurance	€ 12	
CPO Miscellaneous: Unforeseen	€ 25	
CPO Miscellaneous: Hard/Soft Upgrades	€ 25	
Total Fixed OPEX Cost		**€ 565,66**

The OPEX costs for a public level 2 station is **€ 565,66** with a majority of the costs originating from the maintenance and connection installation costs.

The costs for installing a level 3 fast charger station are as follows:

Table 5: Infrastructure Costs for Level 3 Public Fast Charging Station *(Source: De Jong, 2016)*

Infrastructure	Sub – Total Cost	Total Cost (Average)
Hardware: Level 3 Public Fast Charger	N/A	€ 25.000
Co-ordination: Location Decision, Planning and Co-ordination	N/A	€ 2.500
Installation: Charger	€ 180	€ 2.500
CPO Connection: CPO: 3 x 160A t/m 3 x 250A, max 175 kVA incl 25m cable	€ 14.230,14	€ 44.394,86
Grid Operator: Materials	€ 9330,26	
Grid Operator: Outsourced Labour	€ 30.298,58	
Grid Operator: Supplements	€ 4.765,76	
Grid operator Revenue	€ -14.230,14	
Curbside Location	N/A	€ 3.500
Signage Curbside	N/A	€ 1.000
Station: Civic Works	N/A	€ 50.000
Station: Structure	N/A	€ 35.000
Station: Solar Roof	N/A	€ 40.000

Station: Signage	N/A	€ 20.000
Safety		€ 5.000
Total Investment Costs for a Fast Charger		1 Fast Charger on the Curbside: **€ 79.894,86** 1 Fast Charger Station: **€ 224.394.86** 2 Fast Charger Stations: **€ 249.394.86**

The costs of the connection and charging hardware have the highest impact on the total costs for a fast charging station. Additionally, the high investment costs occurring for grid operators contribute a significant part of the total costs along with the high costs for the structural building of a complete station.

The operating costs for installing a level 3 fast charger station are as follows:

Table 6: Operational Costs for Level 3 Public Fast Charging Station ***(Source: De Jong, 2016)***

O&M	Sub – Total Cost	Total Cost (Average)
CPO: Maintenance	€ 1.800	€ 4.300
CPO: Maintenance Labour	€ 1.000	
CPO: Cleaning Station	€ 1.500	
CPO: Connection Grid Connection	€ 2.400	€ 3.100
CPO: Communication wifi and cellular connection	€ 700	
CPO Miscellaneous: User Services	€ 20	€ 4.675
CPO Miscellaneous: Overhead	€ 150	
CPO Miscellaneous: Insurance	€ 250	
CPO Miscellaneous: Unforeseen	€ 4.000	
CPO Miscellaneous: Hard/Soft Upgrades	€ 250	
Total Fixed OPEX Cost		**€ 12.075**

The OPEX costs for a public level 3 station is **€ 12.075,** and similar to the level 2 station, a majority of the costs can be traced to the maintenance and connection costs – but, at higher amounts due to the advanced technology and high power output.

For the purpose of completeness, in Table's 7-9 the CAPEX and OPEX costs for a public level 1 charging station have been provided. The data for these costs were sourced from Margret Smith's paper entitled *"Level 1 Electric Vehicle Charging Stations at the Workplace".* The costs presented in this report are US-based costs but, the literature review paper for this Thesis clearly shows the US-costs and EU-cost are comparable. This paper was used due to lack of literature on public level 1 infrastructure costs in the Netherlands.

The fixed costs for installing a level 1 public charging unit in a parking spot are as follows:

Table 7: Infrastructure Costs for Level 1 Public Charging Station in a Parking lot *(Source: Smith, 2016)*

Infrastructure	Total Cost (Average)
Upgrade of electrical outlet	$ 350
Level 1 Public charging station	$ 650
Total Fixed CAPEX	**$ 1000**

The operations costs for installing a level 1 public charging station (parking spot) are as follows:

Table 8: Operational Costs for Level 1 Public Charging Station in a Parking lot (Source: Smith, 2016)

O&M	Total Cost (Average)
New outlet	$ 30
Electrician Working Hours	$ 65/hour
Total Fixed CAPEX	**$ 95/hour**

The fixed costs for installing a level 1 public charging unit in a workplace are:

Table 9: Infrastructure Costs for Level 1 Public Charging Station (wall mounted + pedestal) at workplace *(Source: Smith, 2016)*

Infrastructure	Total Cost (Average)	Total Costs
Upgrade of electrical outlet (wall mounted)	$ 350	**$ 1.450**
Level 1 Public charging station (wall mounted)	$ 450	
Level 1 Public charging station (wall mounted) connection	$ 650	
Upgrade of electrical outlet (pedestal)	$ 350	**$ 3.550**
Level 1 Public charging station (pedastal)	$ 1200	
Level 1 Public charging station trenching	$ 2000	
Total Fixed CAPEX		**$ 5000**

There were no OPEX costs available for level 1 public charging unit in a workplace due the lack of information available / little requirement for maintenance. *(Smith, 2016)* As can be seen from Table's 7-9 the costs for a level 1 charger in a public space such as a parking spot ($1000 + 95/hour) and workplace ($5000) are significantly cheaper than public level 2 and 3 chargers. However, the trade-off which is being for the cheaper costs is the longer charging times due to the lower outputs.

The summary of the CAPEX and OPEX for level 1, 2 and 3 stations can be found in Table 10

Table 10: Summary of Costs for Level 1, 2 and 3 charging infrastructure (self-prepared)

Charging Infrastructure	CAPEX Costs	OPEX costs	Project NPV[2] (over 15 years)
Level 1 Charging Station Parking Lot	$ 1000	$ 95 / hour	Not calculated
Level 1 Charging Station Workplace (wall mounted)	$ 1450	N/A	Not calculated
Level 1 Charging Station Workplace (pedestal)	$ 3550	N/A	Not calculated
Level 2 Public Charging Station	€ 6470	€ 565,66	€ 6913
Level 3 Public Charging Station (curbside)	€ 79.894,86	€ 12.075	€ - 20.302,17
Level 3 Public Charging Station (solar roof station)	€ 224.394.86	€ 12.075	€ - 165.802,17

Table 10 clearly shows that level 1 charging has the cheapest economics and level 3 the highest but, the level 2 (with positive NPV) and level 3 (with negative NPV's) charging infrastructure projects are very capital intensive – these results are elaborated in the next sections.

[2] Refer to next section and excel sheets for further information

6.1 EV Infrastructure Financial Assumptions, Methodology for NPV Calculations

An NPV calculation for the public level 1 charging infrastructure was not conducted due to a report which states that the EU EV market aims to deploy level 2 and level 3 chargers publicly due to faster charging times as well as better adaptability to existing grid network. *(MENNEKES, 2016)* The NPV calculations for the level 2 and level 3 public charging infrastructures can be found in the supplementary Excel sheets that have been submitted along this Thesis. The investment horizon for these projects was defined as 15 years on the basis of the life time of a level 3 charging station. The level 2 charging station has a life time of 7 years but, for the comparable calculations and analysis, this parameter was also extended to the 15 years by including the maintenance and repair costs in the 7^{th} year. The fixed capital, operating costs and grid operator revenues were sourced from De Jong's paper because it was one of the few papers which focused on infrastructure related costs in detail within the Netherlands. (*De Jong, 2016)* These costs were compared to other reports which provided costs in North American market *(Agenroad & Holland, 2014; Francfort, 2015 and Government of Newfoundland and Labrador, 2015).* Results of the comparison showed that the data was very similar however, since the focus of this study was on the Netherlands – De Jong's data was chosen. When determining the WACC rate of 5% and the O&M inflation rate of 2% - this was based on the first homework assignment that was presented to us in this course. *(Weißensteiner, 2015)* The average energy consumed per day was 8.71kWh/day and the cost of electricity was taken as 0.15€/kWh. Thus the electricity sale from a level 2 charger was calculated as follows:

$$8.71\,\frac{kWh}{day} \times 0.15\,\frac{€}{kWh} \approx 1{,}3065\,\frac{€}{day} \times 365 \approx 477\,\frac{€}{\text{year}}$$

Level 3 chargers in the Netherlands had an annual income/day of 11,985€/day and therefore the annual electricity sale for fast chargers are:

$$11{,}985\,\frac{€}{day} \times 365 \approx 4400\,\frac{€}{\text{year}}$$

Lastly, when doing the NPV calculations it was assumed that the revenue stream from the project would increase by 10% every five years. This was done because it is expected that the infrastructure would become more established within this period and thus increased revenue would be expected.

6.2 EV Infrastructure Financial Results and Implications

The Net Present Values (NPV) for the public level 2 is € 6913 and for the public level 3 fast charger the curb-side and station settings had NPV's of charging infrastructure (refer to supplementary excel sheets) the resulting values are € -20.302,17 and €-165.802,17 respectively. On the basis of these calculations it can be concluded that a level 2 charging infrastructure is an investable project when compared to level 3 fast chargers. From these calculations it can also be concluded that fast charging stations can be considered as a capital intensive assets and investment. Curb-side fast charging connected to the grid will demand fewer infrastructures due to the absence of significant infrastructure requirements and is the cheapest fast charging option. The level 2 charging poles are perceived as cheap technology which contributes to increased charging capacity, but due to their technical specifications the charging time required is much longer when compared to the fast charging alternative. A fast charger is a higher capacity machine and the higher efficiency of this technology is a major factor that contributes to the significantly higher investment costs. According to De Jong's study, there is a small co-relation between the level of urbanization and the requirement for fast charging solutions. He found that in very urban places there is a high requirement for fast charging solutions when compared to rural areas. The equivalence of fast charges (level 3): regular chargers (level 2) in rural areas are approximately 1:200 and for urbanized areas it is 1:100. These ratios are high due to the high density and the forecasted increased EV users per square kilometre. Using the cost data it has been estimated by De Jong that for level 2 charging infrastructure to break even there would need to be 1200 charging sessions/year which is equivalent to 3-4 charging sessions/day. In the case of fast chargers, the break-even point for its infrastructure requirements would be reached if 10-15 charging sessions occurred per day. This is currently not occurring in both levels of charging infrastructure (*De Jong, 2016)*

It has been shown through the data collected that a level 3 fast charging station costs approximately €220.000 and a curb-side model is around €80.000. A level 2 regular public charging pole costs approximately €6.000. Due to the capital intensive nature of investments and the low utilisation rates of the current regular public charging infrastructure a relatively high threshold is required to break-even. The fast charging solution is very difficult to implement quickly when the current conditions and costs are analyzed. Thus, the conversion of the Netherlands transport sector from a fossil fuel driven one to an all electric future will come at a significant expense.

On the basis of the finances presented in this Thesis it can be projected/predicted that the future of public charging infrastructure in the Netherlands will comprise a mix of regular charging and fast charging. The inherent nature of the fast chargers enables it to meet the forecasted increase in charging demand in the near future. Additionally since the NPV for fast chargers are negative significant collaboration between various parties will be required to ensure that suitable charging capacity is available and help increase the deployment of EVs.

When focusing on the costs of regular and fast charging facilities, the data shows that there are high overhead costs for connections at the grid operators. Since connection's is an often overlooked cost drivers, it becomes very important that grid operators should try to focus on increasing the efficiency of the charging pole installation process. In the case of fast charging, location can impact the installation cost and therefore it is important to ensure that the land costs are as financially viable as possible.

The cost for level 3 curb-side and level 2 regular public charging infrastructures in some cases may require extra trenching or directional boring to connect the station to the grid which will be an additional cost. Thus when possible it is advisable to install a multi-port stations or even multiple stations at the same location to reduce the investment cost per charger.

The low utilisation rates of most level 2 public regular charging poles impedes any chances of the project breaking even. Considering the advent of new charging infrastructure, it becomes important to have the correct supply of charging solutions in terms of capacity along with a balance between fast and regular charging facilities

– which help keep transition towards electric powered vehicles cost efficient. The deployment of many fast chargers will result in unbalanced peak demand and installing many regular charging poles for every car is not cost efficient at current utilisation rates because this will mean that every EV will need its own charging pole – which is not the ideal solution. As seen in the fast charging cost calculations a possible solution is the integration of a battery and solar powered system. The calculations and NPV show that currently this is very expensive due to the high costs of battery capacity. Fast chargers are necessary in order to fulfil the charging demand when EVs occupy the majority market share in the transport sector. *(De Jong, 2016)*

Given the NPV's for the projects the government can assist project developers by subsidizing the charging cost difference i.e. the revenue collected from the public – total costs; this difference will need to be borne by the government. These costs can only be financed through taxation and any other governmental revenue.

Standardization of charging infrastructure along with competitive market forces can help reduce the costs thus allow for economies of scale.

There are positive externalities benefit society by introducing EV's and charging infrastructure will compensate for the increased costs for example promote social responsibility through activities such as planning vehicle charging times ahead of time.

The main limitations when performing the NPV calculations which formed the basis for the financial implications are as follows:

1. De Jong's study collected much data from many sources and used averages in his report. This may cause errors to arise in the data values because it is impossible to verify the accuracy in the data collection from these sources.
2. The charging behavior of drivers was used to determine the energy use/day and therefore income/day from the charging. However because this is a very independent and variable parameter approximations had to made in the study due to lack of direct data.
3. Low revenue from the electricity sale can be attributed to the 'start-up' period for a charging station i.e. the time is takes for a driver to find this new station as well as the time required for the station to get popular (therefore lead to

increase in electricity sale). This will therefore impact the averages used in the calculations. *(From points 1-3 source: De Jong, 2016)*

4. The rapid development of the EV ecosystem can mean that the conclusions drawn from the Thesis are subject to change.

6.3 EV Infrastructure Financial Barriers and Potential Solutions

The financial calculation results presented earlier in this chapter clearly demonstrate that the costs for public level 2 and level 3 charging stations are a capital intensive investment for infrastructure stakeholders. Hence, instead of the government bearing the brunt of the costs for EV infrastructure, private investors/stakeholders can play a larger role and work closely with government to further funds to promote installation of public EV infrastructure. *(McCormack et.al 2013 and Frades et.al, 2014)*

The amount of additional investments that can be sourced from private stakeholders will highly depend on the following factors:

1. Travel need of the driver including their driving behaviour
2. The effectiveness of the charging station to reduce EV owners fear of range anxiety
3. Technological advancement in the charging station as well as the capacity of future batteries
4. Government EV goals and policies to stimulate further market penetration. (*From points 1-4 source: Frades et.al, 2014)*

The finances available for a project are the crucial criterion which will determine its feasibility. The two primary financial barriers that prevent the private sector from part-taking in the EV infrastructure development projects are:

1. The lack of a profitable business case which addresses the gaps that is present in an EV infrastructure project.
2. If the project is long term, there is a risk that there may be a lack of capital flows to keep the venture profitable. This will also prove a barrier for scaling-up the project *(From points 1-2 source: Kassakian, 2013)*

Focusing on the first barrier, when a private stakeholder(s) decides to participate and fund a project, the investor(s) will expect that the capital and operational costs will be recouped. In EV infrastructure this is usually achieved through direct revenue from charging fees and or indirect increases from revenues that the charging station possess. The direct revenue from EV infrastructure is usually found in two models namely the pay-per-use and subscriptions. In the former model, a flat rate is charged to the consumer based on either number of sessions, energy consumed and the time connected to the charging station. *(McCormack, 2013)* The latter model focuses on charging a pre-use fee to utilize the charging services and amenities (at a discounted cost) that are offered by the company/entity offering the subscription. Indirect revenues from EV infrastructure is greatly dependent on the stakeholders involved however examples of such revenue would be earning a percentage of profits from a public location (ex. shopping malls) due to having EV owners flock to them and grid companies because of potential EV's have as energy storage carriers and controlling energy demands. *(Frades et.al, 2014)* Despite the revenue options that charging infrastructure possess, the profitability of the business case is impacted by the following:

1. The immense capital that is required to install a single level 2/3 public charging station. This parameter is highly variable as it depends on the location of the charging station and existing regulatory framework of nation/region where the station is being installed. *(De Jong, 2016)*
2. Current demands for public charging stations are very low and this market is currently being dominated by private/residential chargers. It is also difficult to estimate the future demand for such stations. *(IEA, 2017)*
3. EV driver may be unaware of public charging stations and/or prefer charging their vehicle at home. Some drivers may not wish to wait significant times to charge their vehicle. *(IEA,2017)*
4. EV drivers may be able to charge their vehicles at a cheaper rate if they use their residential charger over utilizing public amenities mainly due to the fact that electricity rates are cheaper if used residentially. *(Chang et.al, 2012)*
5. Charging station operators may have 'host' charges from grid operators for the usage of level 2 /3 charging. The typical charge is a 'demand charge' on electricity consumers which is based on the customer's highest rate of power use during a given billing period – this can increase the charging price for consumer and therefore dissuade them. *(Chang et.al, 2012)*

6. The lack of standardization in charging outlets on EV's may further dissuade drivers from utilizing these facilities, increase costs for charging stations due to continuous technological development/ different repairs and maintenance procedure required for each type of charger, increase transaction fees and prevent infrastructure from being established. *(Frades et.al, 2014)*
7. Investors always have the option to charge a very high interest rate and dictate the investment horizon if they conclude the business proposition to be risky. *(Frades et.al, 2014)*

It is due to these factors that a profitable business case cannot be made for charging infrastructure projects whose sole revenue stream is based on electricity prices and energy consumption. This also stresses the importance of these projects diversifying their revenue streams to increase the profitability of the project. Socio-economic factors such as driving behaviour, charging times, percentage of EV owners all impact this barrier. *(Chang et.al, 2012; Kassakian, 2013 and Frades et.al, 2014)*

As EV technology becomes increasingly popular and established – so does the corresponding infrastructure. Hence, when planning for the future it becomes important that infrastructure projects have sufficient capital flow to maintain and upgrade the charging stations. The barriers which can hamper/block future capital flows are as follows:

1. As mentioned earlier, the absence of standardization in infrastructure components will increase the capital flow required to keep the system efficient as well as prevent the rise of secondary financial markets i.e. allow other market players to contribute to the project. If standardization was achieved projects would be more attractive to banks, allow securities with similar financial profiles to other existing securities to be sold in the secondary market, further increasing liquidity and decreasing the cost of capital for the project. *(NPE, 2017)*
2. Following on from the first point, if no secondary markets are available then it limits the market players for EV infrastructure. These markets play a vital role for buyer and sellers to 'get a piece of the action' in this area of the EV

ecosystem. The presence of such markets will help investor be confident to invest more finance into charging infrastructure. *(Tal et.al, 2017)*

3. Most investors do not have detailed information about the financial performance, costs, prices, rewards, market competition among other factors of EV charging station. Thus they will charge higher interest rates in lieu of this gap. *(Frades et.al, 2014)*
4. The current EV infrastructure market has low liquidity and therefore investors who have doubts on the project cannot sell their securities easily which results in higher opportunity cost (time value of money). Banks and Insurance companies which have stringent liquidity requirements from projects they invest in, which will thus contribute to higher capital costs for any early infrastructure investments. *(Frades et.al, 2014)*

If these two barriers to EV infrastructure are eliminated, all the required changes which have been mentioned in the aforementioned lists shall come into effect. These positive actions if implemented will create a cycle of investments, capital flow and infrastructure deployment that will accelerate the transition to an all electric future. This cycle can be seen in Figure 38.

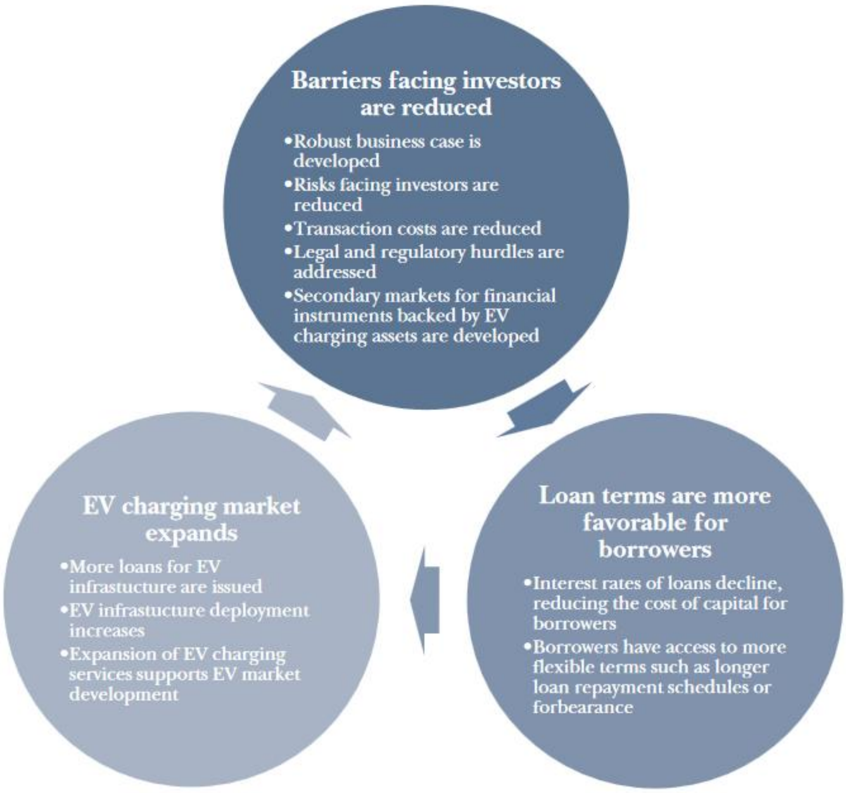


Figure 38: The potential cycle which can be established should infrastructure barriers be reduced/eliminated *(Source: Frades et.al, 2014)*

To ensure that this investment cycle is realised, investors can use tools to help eliminate the barriers faced in the EV infrastructure market. Wealthy investors can offer grants and rebates to infrastructure project developers – to reduce cost barriers. These grants can also help attract further private investment from other stakeholders as well as ease fund raising activities for developer therefore help the project by subsidizing costs. *(Dutch Government, 2016 and Frades et.al, 2014)*

Investors will usually lend money to the project directly to reduce the capital costs of the project. Investors may also wish to team up with other partners to co-finance the project and therefore reduce the overall risk which they face. Certain investor such as banks can offer project owners 'forbearance' wherein the borrower can defer repayment without defaulting – however this will expose the investor to risk. Once the loan is repaid – these funds can opportunistically be used to issue new loans. *(Climate Bond Initiative, 2016 and Frades et.al, 2014)*

Investor can also purchase project equity to expand access to low cost capital as well as have the opportunity to get a return on their investment. On the contrary these investors will experience more risk than lenders since equity always faces investment losses before debt. Institutions such as banks can reduce capital costs by providing interest rate buy downs – these are agreements between parties to subsidize the high interest rates offered by private investors. To further appease the exposure to risks for private stakeholders, banks can provide them with loan loss reserves, loan guarantees and debt service reserve funds to ensure that private investors are compensated should the borrow have overdue payments or defaults. These are credit enhancement methods which are used for engagement with private investors and therefore increase the probability of investment into the project. *(Climate Bond Initiative, 2016 and Frades et.al, 2014)*

Certain stakeholders can engage in warehousing i.e. a third party will buy, sell, and hold onto financial products with the vision of developing a secondary market for the project. The creation of a secondary market can occur in two distinct ways:

1. When primary investors pool their money into a project which has yet to be established, they will experience a liquidity constraint. Warehousing allows investors to recapitalize their assets and therefore enable them to issue more

loans. This helps upcoming markets to grow and results in the development of secondary markets. *(Tal et.al, 2017 and Frades et.al, 2014)*

2. If loans are warehoused over a period of time their repayments build – a process known as seasoning. Through the use of seasoning debt instruments these warehoused loans can elucidate the credit quality of the borrowers – which reduces any perception of risk from primary and secondary market players. (*Frades et.al, 2014)*

Finally, private investors can serve as a repository of information on infrastructure projects and provide stakeholders with the detailed information they desire. They can also serve as platforms to communicate benefits of EV infrastructure and connect parties from the public and private realms to help realise a common goal. *(Melaina et.al, 2017 and Yang et.al, 2016)*

Therefore in summary to overcome the barrier of developing a profitable business case, the following actions can be taken by investors – refer to Table 11

Table 11: Summary of the options private sector has to make EV infrastructure business model viable in near-term *(Sources: Tal et.al, 2017; Melaina et.al, 2017; Yang et.al, 2016; Climate Bond Initiative, 2016 and Frades et.al, 2014)*

Barrier Solution	Tools available to private investor	Outcomes
Share the upfront costs /risks with the project manager during initial phase of project	Grants and Rebates	Immediate access to capital and will help subsidize costs
	Demand/Request for Project Equity	A similar outcome to grants and rebates but with the expectation of 'return on investment'
Perform outreach and co-ordination activities to reduce risk and capital costs	Data collection and dissemination	This will keep existing and potential investors informed on the project therefore reducing their

		perception of risk. This will also promote actions to implement standards
	Initiating partnerships between a variety of stakeholders	Risks and costs for the project can be spread out.
Provide access to low-cost capital	Interest rate buy-downs	Increase investments and reduce capital required
	Direct lending	Provide finance to the project at lower interest rate and longer loan times
	Co-lending	Increase the number of investor in the project therefore distributing risk
	Loan loss reserve, loan guarantees and debt reserve fund	Credit enhancement tools which will provide a guarantee to investors in the event of projects losses and overdue payments
	Develop education programmes	The keep all stakeholders informed about EV infrastructure projects and their financial potential.

To ensure that EV projects have sufficient capital flow in the long when EV technology is mainstream the following actions can be taken by investors – refer to Table 12.

Table 12: Summary of the options private sector has to ensure capital flows for EV infrastructure projects in long-term *(Sources: Tal et.al, 2017; Melaina et.al, 2017; Yang et.al, 2016; Climate Bond Initiative, 2016 and Frades et.al, 2014)*

Barrier Solution	Tools available to private investor	Outcomes
Development of secondary markets for EV infrastructure loan and leases	Primary market investments and credit enhancement programmes	Increases the supply of financial products to the secondary market, promote standardization and increase project liquidity.
	Warehousing loans and leases	Increases liquidity of project as well as provides investors a history of the repayments of the financial products.
	Information dissemination	Sharing information about the repayments of financial products will help other players to develop and contribute to the secondary market.
Perform outreach and co-ordination activities to reduce risk and capital costs	Warehousing loan and leases	This will allow for sufficient number of loans to be securitized. This also allows for standard contracts to be prepared as well as credit terms to purchase the loans and leases.
	Data collection	Data collected by secondary market players can attract further

		investments as well as provide information of performance of securities. Assets can be pooled along with other securities therefore making project financially attractive.
	Warehousing securities	Increase liquidity of project and can act as a reservoir of information for investor to appease their sense of risk.

Despite the barriers for attracting private investments into EV charging infrastructure projects, there are many tools that private investors can utilize to overcome these barriers. It has been clearly shown from the NPV calculations that revenue streams from electricity sale alone cannot make these projects financially viable and therefore intensive co-operation between the public and private sector is required.

7. Conclusions

The transport sector needs to become more sustainable if the international climate agreements are to be fulfilled. Passenger cars are one of the most dominant transport modes but they are still powered by fossil fuel – which therefore means they emit GHG's that contribute to the adverse effects of climate change. Thus, to ensure this mode complies with the sustainable goals set by the international community, there have been significant efforts to transition from fossil fuel cars to electric vehicles.

As shown in the report EV's are very environmentally friendly and are much more efficient than current vehicle fleets. In this regard, the EU has taken bold steps to ensure that by 2030 most sectors are either carbon free or less carbon intensive. The Netherlands is current leader in the EV market and has ambitions to be a completely all EV nation by 2030. The Dutch government has many policies which provide EV owners with benefits and tax cuts – this has been done to stimulate the EV market and increase shares. While having ambitions for an all-EV future – the question of corresponding infrastructure costs also becomes very important because without the appropriate balance of charging solutions the EV ecosystem will not function. Therefore this report tried to determine if installing public level 2 and level 3 charging stations were viable. This report found that level 2 stations are viable due to their positive business case (i.e. positive NPV of € 6913 in the reference example provided). However, when focusing on level 3 fast charging stations, the business case was not viable due to a very negative NPV (i.e. - € 20.302,17 for curbside fast charging station and - € 165.802,17 in the reference example provided) which was mainly attributed to the capital intensive nature of this infrastructure project. When analyzing the costs of the level 2 and level 3 public charging infrastructure it was concluded that governments cannot bear and fund these projects alone. Hence, the role of private sector in these infrastructure projects is very crucial. The main barriers which prevent private investment in EV infrastructure projects are the lack of positive business case and uncertainty to obtain long term capital flows. While these concerns are valid, the report has also outlined possible financial tools (such as co-lending, warehousing and securitization etc.) that investor can utilize to alleviate these barriers. It is through effective co-operation between the government, public and private sectors that these infrastructure projects become viable – the Dutch government has recognised this characteristic of such project and is working on policies to facilitate better and efficient PPP’s. Additionally with the development of technology it has been forecasted that these the initial investments in these projects will drastically reduce.

This report concludes that EV’s have the tremendous potential to change the transport sector completely. The Netherlands has embraced this potential and is setting an example for other nations to follow – while also learning from their competitors. Currently public charging infrastructure is expensive but, with the pursuit of effective policies and rapid technological development – the deployment of EV charging infrastructure will surge and sustainable transportation will be realised.

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Abbreviations

- AC – Alternate Current
- ASI – Avoid-Shift-Improve
- BEV – Battery Electric Vehicle
- CCS – Combined Charging System
- CO_2 – Carbon Dioxide
- COP – Conference of Parties
- CPO – Charging Point Operator
- DC – Direct Current
- EC – European Commission
- EEA – European Environment Agency
- EFSI - European Fund for Strategic Investments
- EJ – Exajoules
- EV – Electric Vehicles
- EVI – Electric Vehicle Initiative
- EVSE – Electric Vehicle Supply Equipment i.e. Charging Infrastructure
- FET – Formula E-Team
- GHG – Green House Gases
- $GtCO_2$ – Gigatonne of CO_2
- ICCPD - In-Cable Control and Protective Device
- ICE – Internal Combustion Engine
- IEA – International Energy Agency
- IPCC – Intergovernmental Panel on Climate Change
- IRENA – International Renewable Energy Agency
- kW – kilowatt
- kWh – kilowatt hour
- MIA - Environmental Investment Tax Scheme
- MJ – Megajoule
- MRA E - Metropoolregio Amsterdam Elektrisch
- MSP - Mobility Service Provider
- NIA - Netherlands Investment Agency
- NKL - National Knowledge Platform for Public Charging Infrastructure
- NPE - German National Platform for Electric Mobility
- OECD - Organisation for Economic Co-operation and Development
- OEM – Original Equipment Manufacturers
- PHEV – Plug in Hybrid Electric Vehicles
- RE – Renewable Energy
- SDG – Sustainable Development Goals
- TCO - Total Cost of Ownership
- TFEC – Total Final Energy Consumption
- V2G – Vehicle to Grid
- VAT – Value Added Tax
- WWF – World Wide Fund for Nature

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