Master thesis

Network analysis of EV charging infrastructure in Amsterdam



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Abstract

Road transportation has a share of one fifth in the total European (EU27) CO_2 emissions. Passenger cars are responsible for around 12% of the European CO_2 emissions (EEA, 2008). The use of Electric Vehicles (EVs) can reduce the emissions. However, the EV is not yet a successful alternative for internal combustion engine (ICE) powered cars. A dense charging infrastructure is needed to reduce range anxiety and can increase the adoption of EVs (Romm, 2006). For the implementation of an EV charging infrastructure cooperation between different actors in a network is essential.

This resulted in the following research question. *How does the network of the charging infrastructure of EVs in Amsterdam affect adoption of EVs in this city?*

Which is answered by measuring the network structure (Density, Stability, Centrality) and the strength of ties (Duration/Frequency, Trust & Openness, Contractual control and Scope) of the network related to the adoption of EV infrastructure in Amsterdam (Gilsing and Nooteboom, 2005).

The results of this research suggest that the indicators density, stability, centrality, contractual control and scope have a positive effect on adoption. However, Trust & Openness could not be confirmed by the data.

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1. Introduction

1.1. Background

Climate objectives, such as reducing CO_2 emissions and air pollution, ask for new sustainable solutions. Meeting these objectives can be accomplished by consuming less energy and by using sustainable energy resources. By burning hydro carbonates for our energy needs, CO_2 is emitted. The emission of this gas is partly responsible for the climate change that we experience according to several scientists (IPCC 2007). The emissions take place by generating electricity, heating our houses and by transportation. Road transportation has a share of one fifth in the total European CO_2 emissions. Passenger cars are responsible for around 12% of the European (EU27) CO_2 emissions (EEA, 2008). So by reducing the emission by vehicles, the targets for a more sustainable world come closer. Therefore the European Commission has formulated a directive that prescribes that 10% of the transport fuels should be sustainable in 2020 (2009/28/EC). Also the European Commission has formulated a directive for fuel quality (2009/30/EC), which states that the emission of CO_2 during the fuel lifecycle has to be reduced with 6% in 2020. In this directive, Electric Vehicles (EVs) are considered as CO_2 emission free, because the CO_2 emission is already accounted for in electricity production. So the use of EVs can certainly help to meet the objective of the directive.

However, the EV is not yet a successful alternative for internal combustion engine (ICE) powered cars. The number of EV users is very low compared to ICE users. In the Netherlands only 40.000 electric passengers cars were registered on a total of 7.6 million passenger cars in January 2010 (CBS, 2010). Several researcher have investigated the barriers for EV. The largest barriers for EV are the high purchase costs, range anxiety and the lack of infrastructure (Romm, 2006). Range anxiety is the fear of not reaching your destination caused by a depleted battery. Also the high depreciation of EVs in terms of costs is indicated as a barrier for consumers (Sovacool and Hirsh, 2009). In this research we will focus on the infrastructure of charging points. By installing a dense charging infrastructure, range anxiety will be reduced because the possibility to charge in case of a nearly depleted battery is increased. This should encourage users to buy an EV.

To increase the sales of EVs, potential users need to become familiar with the new technology and adopt new the technology. According to Rogers (1995) the adoption of an innovation is dependent on five characteristics: relative advantage, compatibility, complexity, trialability and observability. For the adoption of EVs compatibility is one of the most relevant issues (Struben and Sterman, 2008). Compatibility is the degree to which an innovation is perceived to be consistent with the existing values, experience and needs of potential adopters (Rogers 1995). For electric vehicles, the way of charging a vehicle is not consistent with current ICE powered cars. Charging a battery for several hours asks for other routines compared to fuelling a car for several minutes. Not only the routines are different, also a charging infrastructure is lacking. This makes the existing infrastructure incompatible with the needed infrastructure for EV. Compared to the dense fuel station infrastructure in the Netherlands with more than 4200 fuel stations with 18600 fuel pumps and an average filling time of 5 minutes (Bovag, 2010) the charging infrastructure for EVs is underdeveloped. In 2010 only 1700 single charging points were registered, including electric bicycle, scooter and boat charging points[1]. Considering an average charging time of 8 hours, the capacity is insufficient for charging large numbers of vehicles.

By implementing a charging infrastructure, adoption of EV can be increased. Therefore a well functioning infrastructure is necessary, which is only possible by cooperation between different organizations. There is an increasing consensus that interfirm relations affect the performance of an innovation (Porter, 1990; Hagedoorn, 1993). A recent collaboration between Philips and Sara Lee resulted in the successful Senseo coffee machine, for example (Hagdorn, 2007). When these interfirm relations are formal, we can speak of alliances. An important function of alliances is that they function as 'pipelines' through which information and knowledge flows between firms. Several firms with interfirm alliances form a network. These networks can focus on exploration, or 'broadening' of their competences or on exploitation, the 'deepening' of their competences (Gilsing and Nooteboom, 2005). Exploration networks are characterized as aiming at experimentation with novel combinations and new technologies as its key outcome. Exploitation networks are characterized as aiming for the joint maximization of complementary assets, in view of commercializing newly explored technology, with new products and services as its key outcome (Koza and Lewin, 1998), (Rothaermel, 2001). For the EV charging infrastructure it is interesting to investigate if the type of network affects adoption of EVs. An exploitation network should have a more positive effect on adoption than an exploration network (Gilsing and Nooteboom, 2005). This is because actors within an exploitation network are focused on creating market share. Actors within an exploration network are focused on creating new technologies and are not directly focused on market share.

To investigate to what extent the development of a charging infrastructure has an exploration or an exploitation network, we focus on the case of the EV project in Amsterdam. Because most activities concerning EV are located in Amsterdam, the focus is on the EV charging infrastructure in Amsterdam. Compared to other cities in the Netherlands and Europe, Amsterdam is leading in developing a charging infrastructure. Experiences from Amsterdam are applied in other cities and used for national policies. In this city, many projects are started to stimulate the use of EVs. There are subsidies for companies that invest in EVs, and charging stations are developed throughout the city. By analyzing the network concerning the charging infrastructure in Amsterdam, we will investigate to what extent the network has an exploration or an exploitation character. The network is formed among others by the local government, electricity companies, charging station manufacturers and car manufacturers. The aim is to investigate how this network affects the adoption of EV in Amsterdam. For the adoption of EV it is important that an exploitation network is realized at this stage. This exploitation network can cause an increased user-base and therefore stimulate adoption.

Hopefully, this research can contribute to the knowledge about the influence of networks on adoption. When the influence of networks on adoption can be better understood, policy makers can use this knowledge during the development of networks. If governments are stimulating an innovation, policies about networks can be useful for effective stimulation. Specifically for EV charging infrastructure networks, the good practices of the Amsterdam charging infrastructure network could be used by other municipalities.

[1] Oplaadpalen.nl: last accessed on 25-12-2010

By measuring the characteristics of the network, such as density, stability and intensity for example, the exploration/exploitation level can be determined. Interviews with the actors will be used to measure the characteristics of the network. For measuring adoption the number of sold EVs in Amsterdam will be used.

1.2. Research question

The problem definition as described above results in the following research question and sub questions.

Research question:

How does the network of the charging infrastructure of EVs in Amsterdam affect adoption of EVs in this city?

Sub questions:

- *What are the characteristics of the network of EV charging infrastructure in Amsterdam?*
    - *Who are the actors in the network of EV charging infrastructure in Amsterdam?*
    - *What are the interactions between the actors in the network of EV charging infrastructure in Amsterdam?*
- *What is the degree of adoption of EV in Amsterdam?*

1.3. Scope

For this research, the network of actors involved with the charging infrastructure for electric cars in Amsterdam from 2009 until 2011 is investigated. The geographical scope was limited to Amsterdam because in this city most relevant activities take place concerning EV and all relevant parties are involved. In 2009 the project 'Amsterdam Elektrisch' was initiated by the municipality. Therefore this year is also the start of this research.

1.4. Outline of the thesis

The thesis contains the following chapters. In chapter 2, the theoretical background of this research will be elaborated. In chapter 3, the EV charging industry will be described. In chapter 5, the method to acquire and analyze the data will be presented. In chapter 6 the results will be presented and analyzed. In chapter 7, the results will be discussed and policy and theoretical implications will be presented. In chapter 8, the conclusions will be presented.

3. Theory

In order to understand to what extent the adoption of EV can be affected by the network, the theoretical concepts will have to be introduced. First, the product lifecycle will be explained, then adoption and an adoption model will be introduced. Next, the network concepts will be explained. This chapter will end with a conceptual model and seven propositions.

3.1. Product lifecycle model

For each product a lifecycle can be determined. For many products four phases can be identified (Utterback and Abernathy, 1975). Market introduction is the first stage. In this early stage the focus is on performance maximizing. The technology is not performing at an optimal level yet, and customer requirements are not yet defined. A rapid rate of product change can be expected to expand customer requirements. The technology to meet the market needs can come from several sources. Standards have still to be defined and the focus is more on product innovation than on process innovation.

In the second phase sales start to grow and the focus will be on sales-maximizing. Competition between firms that is based on product differentiation will be initiated, to create unique selling points and to increase market share. Some product designs will begin to dominate the market because they are meeting the user requirements. Process innovations will be stimulated by the increased demand. With high demand, investing in large production facilities is worthwhile, because when production costs decrease profits can increase.

In the third phase maturity will be reached. The product variety is reduced and competition is based on price, because a dominant design has been defined. The focus in this phase is on process innovations in order to reduce costs be able to make a profit. Therefore, equipment suppliers have relative large incentives to innovate, because producers will buy the most efficient equipment.

In the last phase the sales are reduced and a new technology meets the market needs. Sometimes the 'sailing ship effect' occurs when a new technology is introduced. In order to compete with the new technology the incumbent technology improves beyond the expected limits to meet the new market needs. The result can be that the incumbent technology is preferred above the new technology. Figure 3.1 shows the different stages of product and process innovation (Utterback and Abernathy, 1975). Product innovation starts with a high rate of innovation, which declines over time. Process innovation starts low and over time due to increased demand and the need for cost reduction the rate of process innovation increases.

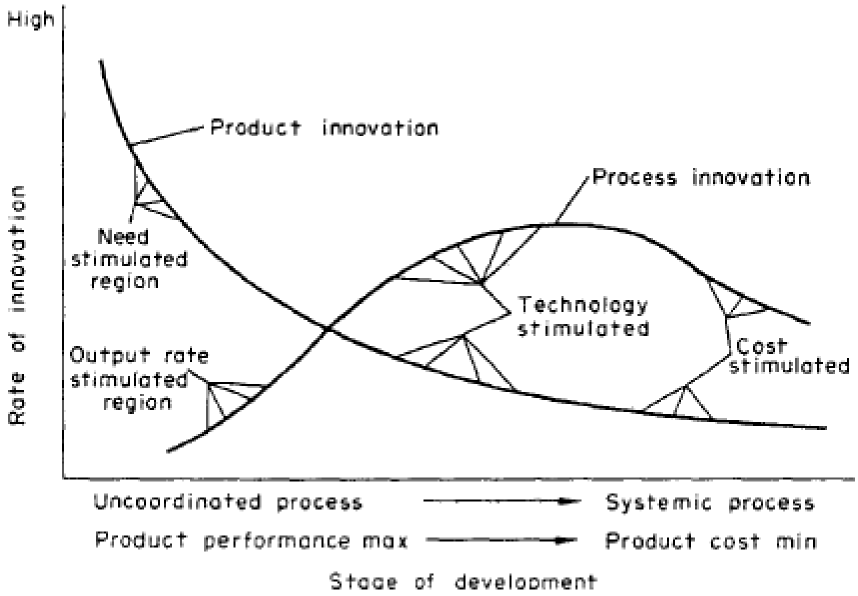


Figure 3.1: Product and process innovation over time.

3.2. Adoption

For a successful innovation diffusion is needed. This is the process by which an innovation is communicated through certain channels over time among the members of a social system (Rogers, 1995). Adoption can be defined as the implementation of an innovation after it is spread by diffusion. Rogers (1995) identifies five characteristics of innovation that are relevant for the adoption decision of consumers. The decision to adopt an innovation is based on the perceived attributes of the innovation.

Relative advantage; This is the degree to which an innovation is perceived as better than the current idea. It can be measured in economic terms, but also in terms of social prestige, convenience and satisfaction. The perceived advantage of the innovation is more important than the objective advantage. The rate of adoption will be more rapid if there is a great relative perceived advantage.

Compatibility; This is the degree to which an innovation is perceived to be consistent with the existing values, experience and needs of potential adopters. If an idea is not compatible with norms and values of a social system the adoption will be less rapid. Sometimes, first a new value system has to be developed, which is a slow process in most cases.

Complexity; Complexity is the degree to which an innovation is perceived as difficult to understand and use. Innovations that are easily understood will have a more rapid adoption than innovations that are more complicated or ask for new skills and understanding.

Trialability; The degree to which an innovation may be experimented with on a limited basis is the trialability. When new ideas can be tried and implemented on a small scale they can be adopted more rapidly than innovations that can only implemented on large scale. By trying on a small scale, the risk and uncertainty for the user is reduced. If there are positive results during the experiments, it is more likely that the user will adopt the innovation.

Observability; This is the degree to which the result of the innovation is visible to others. When it is easy to see the result of the innovation, the chance for adoption is larger. Peer discussions are stimulated and evaluation information is often requested. When an innovation is not observable the rate of adoption is generally slower.

The attributes are not measured objectively, because the perceived value of the adopter is important. The perceptions are heterogeneous throughout the population. Each adopter has its own selection criteria for accepting or rejecting an innovation. There are five adopter innovativeness categories identified by Rogers. The categories are different in size of market share;

First the innovators with a 2,5% share of the market: Innovators are the first category to adopt the innovation. They are willing to take risks, they are young, wealthy, very social and have interaction with other innovators (Rogers, 1962).

The second category are the early adopters with 13,5% market share. Early adopters are younger in age, have a higher social status, are more wealthier and have advanced education.

The third category is the early majority with a 34% share of the market. Individuals in this category adopt an innovation after a varying degree of time. This time is longer than the first two categories. They are slower in the adoption process, have above average social status and they have contact with early adopters.

The late majority with 34% of the market share is the fourth category. Consumers in this category will adopt an innovation after the average consumer. The late majority consumers are typically skeptical about an innovation, have below average social status, very little financial capacity, when compared to the early majority.

The last category are the laggards with 16% of the market. Laggards tend to be focused on traditions, have the lowest social status and the lowest financial capacity. So for diffusion the innovators and early adopters are important in the initial diffusion, but for a large diffusion the adoption by the early and late majority is also important and will cause wide diffusion. The initial diffusion can cause economies of scale and a price reduction of EV. Also installing a charging infrastructure is more profitable for investors when there is a large user-base available. Therefore innovators, starting the user-base, are very important for the adoption of EV. Figure 3.2 shows the distribution of adopters over time (Rogers, 1995).

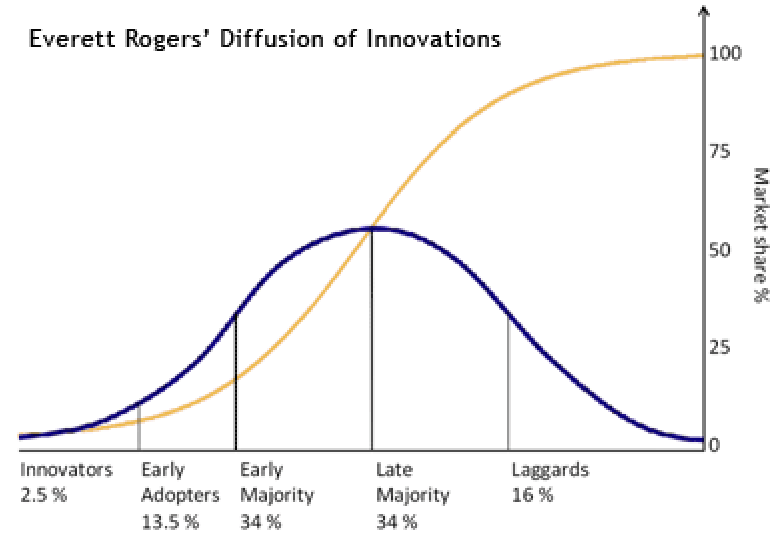


Figure 3.2: Distribution of adopters (Rogers, 1995).

Researchers have investigated these five characteristics for EV(Struben and Sterman, 2008). The relative advantage for EV are fuel costs, maintenance costs, tax or parking advantages, no direct emissions and a silent propulsion (Huétink et al., 2010). Also driving is less difficult, due to the lacking gearbox. By using road shows and EV car rentals the trialability is not a large barrier (Garling and Thøgersen, 2001). In Amsterdam Greenwheels is starting with EV for short rentals[2]. Also the observability will not be a problem. EVs parked and connected with a power plug will be very observable on the street (Garling and Thøgersen, 2001). Compatibility is the largest issue for EV (Garling and Thøgersen, 2001). Two compatibility issues for EV compared with ICE cars are identified. The drive range of an EV is relatively short compared to an ICE car. So in the perception of the user the drive range is insufficient and therefore not compatible with the ideas of what a sufficient drive range should be (Garling and Thøgersen, 2001). Although most trips are less than the maximum range of an EV, consumers perceive this as incompatible (Garling and Thøgersen, 2001). The other incompatibility is the charging/refueling method. Recharging after every trip is different from refueling after approximately 600 km. Because drivers are used to refuel when the fuel tank is nearly empty, the way an EV needs to be recharged is incompatible with the old way. Users need to develop new routines to overcome this incompatibility.

The adoption of an innovation can be described as an interaction between the users and the potential users by the Bass diffusion model (Bass, 1969).

$$\frac{f(t)}{1-F(t)} = p + qF(t)$$

Where:

- *f(t)* is he rate of change of the installed base fraction
- *F(t)* is the installed base fraction

[2] http://www.volkskrant.nl/vk/nl/2680/Economie/archief/article/detail/974402/2010/01/14/Groen-en-elektrisch-horen-bij-Greenwheels.dhtml Last accessed on 2-1-2010.

- *p* is the coefficient of innovation
- *q* is the coefficient of imitation

To answer the research question this model will be used to determine at which stage of adoption EVs are. Necessary are the actual number of users, the potential users and the time since market introduction.

So for a successful adoption of EV these incompatibilities should be reduced. One of the solutions is to create a dense charging infrastructure (Morrow et al., 2008). To create a charging infrastructure different actors are involved. The EV manufacturer and the charge point producer have to match their products, because both products have cooperate together. But also the power company, the legislator and the charge point producer have to agree about standards, because it is undesirable if each region has its own standards. So therefore cooperation is essential for developing charging infrastructure. For cooperation between multiple actors, networks need to be created. In paragraph 3.3, the literature on networks will be discussed.

3.3. Networks

Organizations involved with the coordination of activities concerning adoption of an innovation can be identified as actors in a network. According to Nooteboom (2005) these inter-firm networks can have positive effects on corporate performance. Access to heterogeneous sources of knowledge is the key driving factor when inter-firm ties are formed (Duysters and Verspagen, 2004). These sources of knowledge can accelerate innovation and corporate performance.

Nooteboom investigated two types of networks. Exploratory networks on the one hand and exploitation networks on the other. Both networks have different characteristics. The attributes identified by Nooteboom are divided in network structure characteristics and tie strength characteristics. The exploratory network is required in the first stage of an innovation, according to the product-lifecycle-model. In the growth phase the network should shift from an exploratory focus to an exploitation focus (Gilsing and Nooteboom, 2005).

3.3.1. Network structure

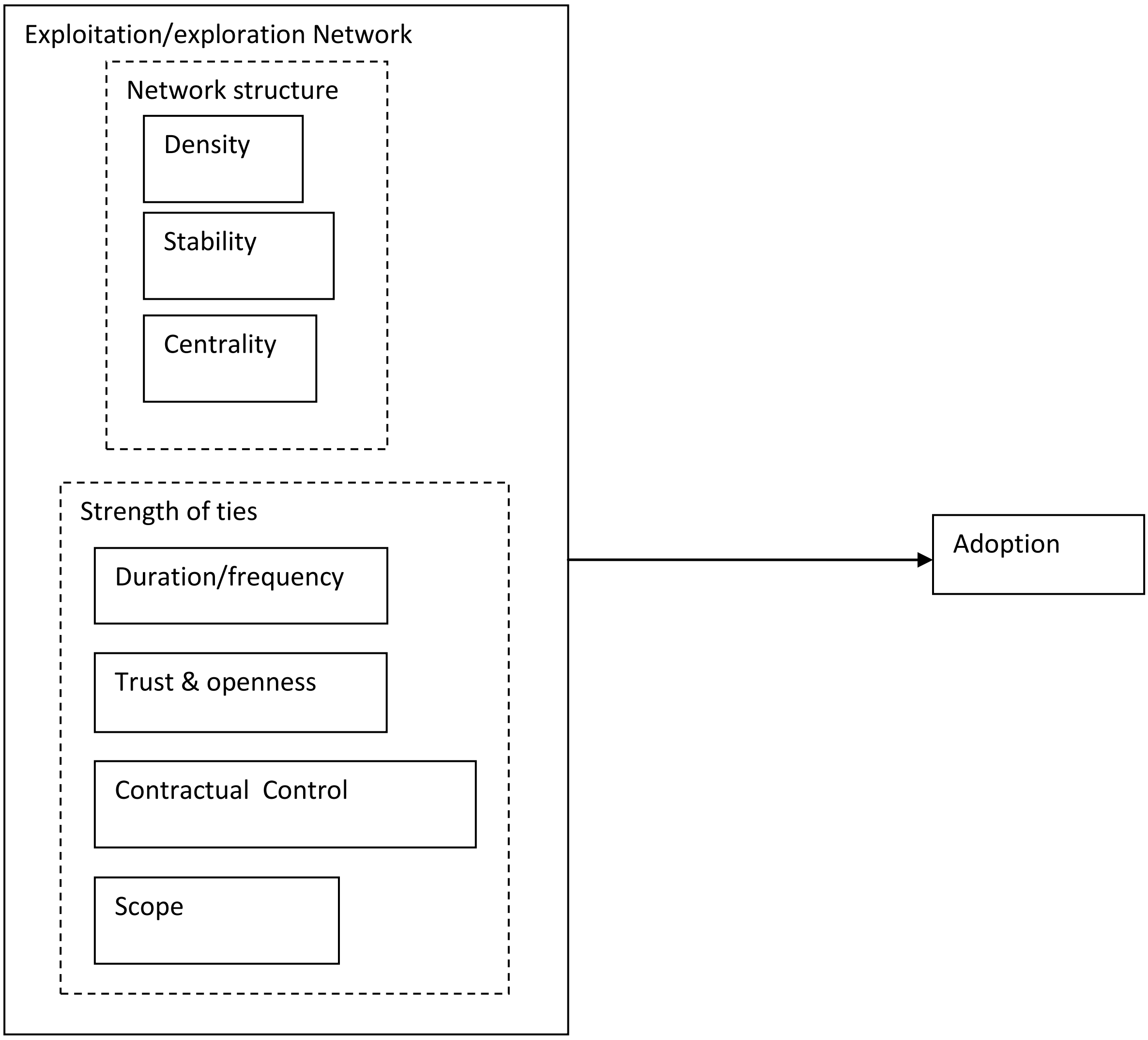
The network structure is characterized by density, stability and centrality. Density is the number of actors in the network in proportion to the total number of possible connections. Dense network ties are important for exploration because of redundancy. If an actor leaves the network, a second connection makes sure the knowledge is still within the network. In case of an exploitation network, maintaining dense network ties is more costly and redundancy is less important. Knowledge is already diffused. Stability is the frequency with which actors will enter and exit the network. For an exploration network, the stability can be low to maintain variety. An exploitation network is characterized by large stability, as a result of the dominant design and the stabilization of knowledge. Centrality is the number of direct ties to other actors in the network. If a firm has more direct ties than others in the network, it has a central position. Exploration networks have low centrality, because there is still uncertainty about which actors will emerge and survive in what configuration. Exploitation networks have a high degree of centrality, because it will increase an efficient coordination. Especially for systemic technologies, like charging infrastructures, centrality is important to ensure that different components of the system remain in tune with each other (Langlois and Robertson, 1995).

3.3.2. Tie strength

Tie strength can be characterized by four dimensions (Gilsing and Nooteboom, 2005). Intensity, the amount of time actors spent on their tie, is the first dimension. This can be expressed in the frequency of interaction and the duration of the relationship. An exploratory network is characterized by a high frequency and low duration. This is because long duration conflicts with flexibility and high frequency is necessary for knowledge diffusion. An exploitation network will have opposite characteristics. There will be a long duration, because of large investments and less frequent because knowledge is already diffused and a dominant design is already established. The second dimension is trust and openness. Exploration networks will have high trust and openness, because there is a need for flexibility. In this stage contracts and other formal documents are decreasing the flexibility and are less feasible because of uncertainties. For exploitation networks the trust and openness is low, because the frequency of interaction is less and the individual interests are larger. This results in dimension three; contractual control. This is less feasible for exploration networks. Uncertainties make it hard to secure agreements or knowledge by contracts. But for exploitation networks it is important to reduce the uncertainty by contracts. The last dimension is the scope of ties. This is the content of the tie, divided in the width and depth of knowledge. An exploration network will have a wide scope, because of the wide range of uncertainties. An exploitation network, on the other hand, will have a small scope, because there is less uncertainty.

When technologies evolve, firms need other characteristics for their network. To deepen the technology and to make it profitable, the focus of the firm has to be on exploitation. So when firms are unable to change their exploration network to an exploitation network, adoption is less probable.

3.4. Conceptual Model



3.5. Propositions

According to the conceptual model the following proposition can be made:

P1. If the network of EV charging infrastructure in Amsterdam is not dense, this will explain a large adoption.

P2. If the network of EV charging infrastructure in Amsterdam is stable, this will explain a large adoption.

P3. If the network of EV charging infrastructure in Amsterdam has a large centrality, this will explain a large adoption.

P4. If the network of EV charging infrastructure in Amsterdam has ties with low frequencies and long duration, this will explain a large adoption.

P5. If the network of EV charging infrastructure in Amsterdam has low trust and openness, this will explain a large adoption.

P6. If the network of EV charging infrastructure in Amsterdam has high contractual control, this will explain a large adoption.

P7. If the network of EV charging infrastructure in Amsterdam has a small scope, this will explain a large adoption.

4. Industry description

Because the charging infrastructure for EVs is quite complex and several technological components, like the battery management system, charge cable and charge point, have to be harmonized, it is useful to explain the technology. This will also clarify the role of the actors involved with the infrastructure. First the charging technology in the car will be explained. Secondly, the technology within the charge cable and the charge point will be described. Thirdly, the electrical grid will be described. At last, the latest developments concerning EV charging will be described.

4.1. Technology

4.1.1. Car

Instead of an internal combustion engine, an EV has an electric motor and batteries. Modern electrical vehicles have Li-ion batteries with a capacity of around 24 kWh for the Nissan Leaf. Battery management will take care of the charging and discharging process. Charging takes place in two phases. In the first phase the battery can be charged for 70-80% relatively fast. In the second phase the battery can be charged up to 100%, but this will take relatively long. During discharging (driving) the battery management system takes care that the battery is not discharged completely. This will reduce the quality and the lifetime of the battery.

To charge the battery electricity is needed, which is supplied via a plug. Each car manufacturer has its own plug standard in the car. The plug, which connects the cable to the charging point, is standardized in Amsterdam and also in the rest of the Netherlands. Since April 2010 the 'Mennekes' plug has been chosen as standard, because surrounding countries already use this standard and it is expected as the European standard. A new standard was necessary, because ordinary wall plugs are not designed for high currents and frequent loosening. Also data communication was not possible with other plugs. The importance of communication will be explained n the next paragraph. Figure 4.1 shows the design of the Mennekes plug and socket.

Figure 4.1: The Mennekes plug and socket.

4.1.2. Charge point

For charging electric vehicles in public space standards are used. Not only the type of plug and socket, but also the way of providing electricity is standardized. In general, there are four methods of charging. Figure 4.2 provides a schematic overview of these different charging methods. The first is called 'mode 1', which is charging by using an ordinary wall socket. There is no communication between the car and the grid. The battery management system within the car does not know how many amperes are available from the socket. This results in a potential unsafe situation, due to the risk of overload. During overload, equipment will heat up and the risk of fire increases. Therefore this charge method is undesirable for EVs.

The increase safety during charging 'Mode 2' charging is developed. 'Mode 2' charging is using an 'in cable control box' to secure a safe connection between the standard wall socket and the car. The car is connected to the box and the box is connected to the wall socket. If the wall socket is not provided with safety ground for example, the box will recognize this and will interrupt the charging process. Also the available capacity is monitored by the box to reduce the risk of overload.

A separate box between the socket and the car is undesirable, because of potential vandalism and the extra weight. Therefore the safety measures are integrated in the charge point with 'mode 3' charging. Only after a set of checks the electricity will be delivered to the car. The system checks if the plugs are installed correctly and if the battery system is aware of the capacity of the cable and the charge point, to prevent an overload. Available capacity in the charge point, the cable and the charger within the car are synchronized. All components are performing on the lowest available capacity to reduce the risk of overload. The plug for the charge point is also secured to prevent sparks and cannot be loosened if there is voltage applied. In the future, data communication can also be used to identify the car for billing the used electricity. At the moment a separate pass is used for identification to reduce complexity of the system. In Amsterdam all public charging points have to be mode 3.

Besides 'normal' charging, which takes up to 8 hours to complete charging, also 'fast' charging is developed to reduce charging times. If a charge point is able to charge the battery for 80% within half an hour, it is called a fast charge point. The charging process is controlled within the charge point and not within the car. This is called 'mode 4' charging. There are only a few of these chargers placed at the moment. Also not every electric car is suitable for fast charging, because communication between the battery and the charge point is necessary and the car will be supplied with direct current (DC) and not with alternating current (AC), which is normally used. The DC is necessary for reducing the charging time. Not every EV is prepared for DC.

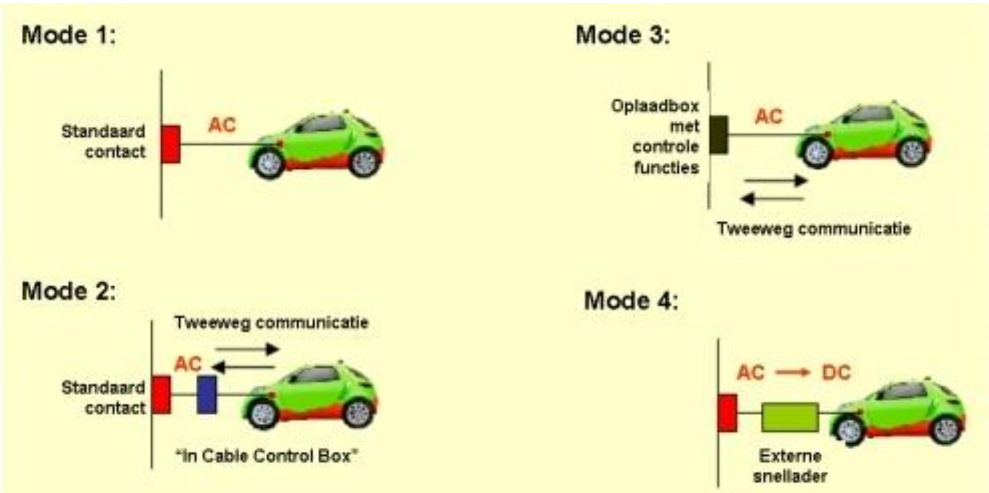


Figure 4.2: Four different kinds of charging methods (Source: The European Engineering Industries Association)

Within the mode 3 charging point, different tasks have to be fulfilled. First the car and the driver have to be identified with a pass. If the driver is subscribed to the energy provider, the socket of the charge point can be accessed and the plug can be inserted into the socket. Then the connection has to be checked safety and capacity. During charging the number of kilowatt-hours have to be measured in order to pay the energy company. The last optional task is a payment system. In Amsterdam the electricity is free for consumers until 31st of March 2012. So there are no payment systems installed for paying at the charge point. The local government is paying the electricity bills to the electricity company. Due to the relative large investments costs for a payment system and the small amount of users and therefore low benefits, there is no payment system at the charge point.

4.1.3. Grid

The charge point is connected to the local grid. The local grid is connected via the mid-voltage grid to the national high voltage grid and to the power plants. The installed capacity of the local grid depends on the expected consumption of electricity in the area. Residential areas do not consume the same amount of electricity as heavy industries for example. Therefore the capacity of the local grid for residential areas is less than for industrial areas. By introducing EVs the consumption of electricity in residential areas can exceed the capacity of the grid. This can cause problems with the reliability of the grid.

On grid level, charging EVs asks for adaption of grid capacity when the number of EVs will increase. With the low number of EVs that are charging at the moment the capacity of the grid is sufficient. However, if there are more than a million vehicles that need to be charged, the capacity is insufficient. Especially if all vehicles are connected to the grid at the same time and the charging process also starts at the same time, the insufficient capacity can cause power failures. With the current charge methods the charge process starts immediately after inserting the plug, even if the driver does not need his EV for a long while and immediate charging is not necessary. Therefore, pilot tests are running to monitor the effects of EV charging on the grid and to control the charging processes externally. External control means that the grid operator can decide when the charging starts and stops. By using charging profiles the grid operator can make priority decisions for each EV.

Charging profiles are being developed in order to distribute electricity consumption more evenly over time. With these profiles the user can choose for different charging times at different costs. There are different profiles possible. If the driver is in a hurry, for example, he wants the charging process to start immediately. If the driver only needs his EV the next morning the start time does not matter but it should be finished before 8 o'clock in the morning. If the driver wants a low energy bill there is a profile that only starts charging if the electricity price is below a certain value. By using different prices for the profiles, users will choose the best profile for their application. For these profiles, communication between the grid, the charging point and the user is needed.

4.2. Latest developments

In this section the situation concerning EV worldwide and the European situation are described in order to have a better understanding of the Amsterdam case. Developments in Amsterdam are not always insulated but have interaction with other institutes. National or even European standards concerning charging are an example for these interactions.

4.2.1. Worldwide

At this moment (Spring 2011) there are only a few car manufacturers that actually sell electric cars. Considering the traditional manufacturers, only Nissan, Renault, Peugeot, Citroen and Mitsubishi have models that can be purchased. Other companies have test programs or are developing EVs. Also new companies have entered the EV market. The most successful in terms of market share are Tesla, Think and Tazzari.

To reduce the range anxiety there are also manufacturers that produce electric cars that are equipped with a generator to supply the electricity in case the batteries are empty. Chevrolet and also daughter Opel have developed Volt and Ampera with range extenders. To minimize the use of the generator, this type of EVs also need a charging infrastructure. Hybrid cars that have an ICE and batteries for extra power do not use the charging infrastructure. Plug-in hybrids however, will make use of the infrastructure. This type of car can use electricity from the grid to charge the battery instead of using the ICE in order to reduce fuel consumption. The difference between the Plug-in hybrid and the EV with range extender is the way the ICE operates. If the battery is depleted the plug-in hybrid is using his ICE directly for propulsion. The range extender however, is used to provide electricity for the electric motor for propulsion. There is no direct transmission between the ICE and the wheels.

On the car side the plug contact is not standardized worldwide. Manufacturers developed plugs in accordance with their homeland legislation. The same plugs are also used for exported EVs. So Japanese manufacturers use the Yazaki-plug, French manufacturers use the Marechal-plug, in the Netherlands the 'Mennekes' plug is used as standard and some manufacturers use the Suco standard. This plug is used for boats and on camp sides. So sometimes imported EVs are not compliant to the local legislation. Figure 4.3 shows the Yazaki, Marechal and Suco plug.

Figure 4.3: The Yazaki, Marechal and Suco plug

Battery charging developments are focused on three major issues. The first issue is 'fast charging', when the battery is charged within 30 minutes. Fast charging can reduce range anxiety because users are able to charge the vehicle in a relative short period. Most of the research effort is spent on keeping the battery in condition. The lifetime of the battery can be reduced during fast charging, which is undesirable due to the high replacement costs. The second development is changing the battery. The idea is that it will take some time to develop batteries with enough capacity for a large range and charging times will not soon meet the time an ICE car is refueled. By changing the batteries within several minutes the user can drive further as the battery is charged in the station.

Disadvantages are the large investment costs, the car manufacturers have to take the swap system into account during design and a radical business case has to be developed because the ownership of the battery and the car are split. The third issue is wireless or induction charging. This is the same technology that is used in electric toothbrushes. In Figure 4.4 the wireless charging technology is explained. At the moment this technology for charging EVs is still in an experimental phase. For charging during parking, developments are focused on static charging. Advantage of this technology is the absence of wires and therefore potential dangerous situations or vandalism. Also less handling for the user is a benefit, because the user does not have to unroll the charge cable. Disadvantages are the decreasing efficiency of the charge process and the large costs. Even more advanced is to use this technology dynamic, meaning that coils are integrated in the road, instead of in the parking lots. When an EV is passing by it is charged during driving. Advantage is the 'eternal' driving range as long as roads are equipped with this technology. Therefore range anxiety is reduced and the driver does not have to worry about the charging process. The large investment costs and increased maintenance costs for the road are disadvantages of this technology. Because coils are integrated within the road, new road maintenance methods need to be developed.

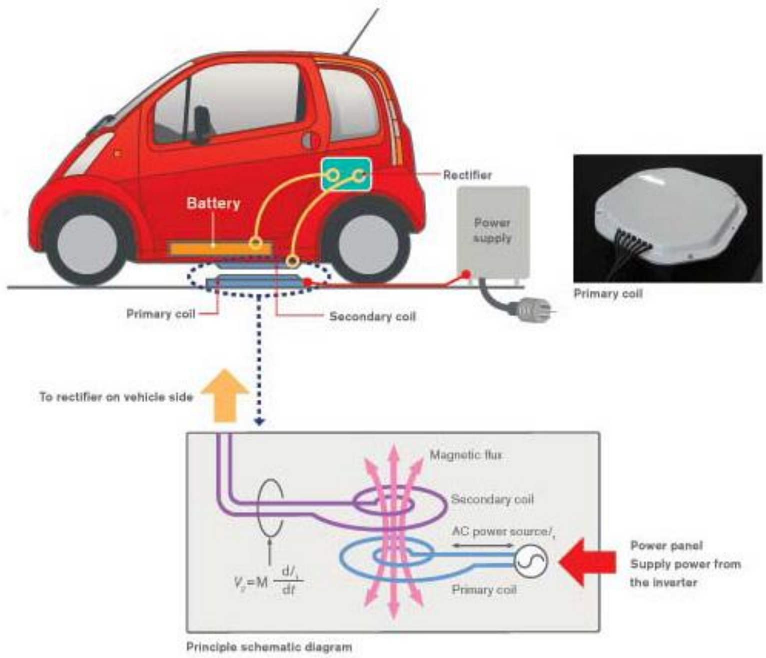


Figure 4.4: Explanation of the wireless charging technology (Source: http://www.designboom.com/weblog/cat/23/view/7202/nissan-wireless-charging-for-electronic-cars.html)

4.2.2. Europe

In Europe different activities take place concerning EV. First, all electric equipment, the EV, the charging cable and the charge point need to have a CE certificate, before it is allowed to be sold in Europe. With this certificate the manufacturer declares that his product meets a set of minimal safety requirements. Not all foreign plugs, used in countries outside Europe meet these requirements.

The European Commission understands that one uniform plug for all countries and all EVs would be necessary for a successful adoption. Cars do not stop at the border, like most household appliances. Therefore a standard is being developed. Mid-2011 the standard should be released. Some individual

European countries (Germany, Sweden, Belgium and the Netherlands) have chosen the 'Mennekes' plug and socket as standard and did not wait for an official European standard.

4.2.3. The Netherlands

In the Netherlands the previous government started a large stimulation initiative for EV. A special taskforce was established, called Formule E-team. Within this team the industry, government and knowledge institutes are cooperating with the aim to realize 'brake troughs' in infrastructure, batteries and availability.

Also the grid operators in the Netherlands have established a foundation to stimulate the charging infrastructure. This foundation 'Stichting E-laad.nl' is interested in the consequences for the electricity grid when EVs are charged. The foundation also provides charging points to EV users and municipalities.

25 Dutch companies and governmental organizations have formed a consortium (DC-TEC) for a tender of 3000 EVs. By joining their demand, prices can drop and a market can be created. The vehicles should compete with ICE cars concerning total cost of ownership, load capacity, load volume and acceleration. The driving range has to be between 100 and 150 kilometers.

5. Method

In this chapter, the method that is used to answer the research question will be explained. This includes the research strategy, the unit of analysis, the type of data collection and the method of analysis.

5.1. Research strategy

The research question of this thesis is explanatory, because we want to know how the network of charging infrastructure in Amsterdam affects adoption. The development of EV has a contemporary character: The events are still happening, it is not a closed story. Because of the need to understand the mechanism behind adoption, the contemporary character of the subject, and the fact that there is no control over the events, a case study research is appropriate to answer the research question (Yin, 2003). A single case study is used, because the charging infrastructure network in Amsterdam is quite unique. In other cities the support for EV from the municipality and commercial organizations is not as extensive as in Amsterdam.

A disadvantage of a single case study is that generalization to a population is difficult. However, for testing a well-formulated theory with propositions a single case is useful. This research will therefore not generalize to a population but to the theory on networks and adoption. This is possible with the remark that the propositions are tested on only one case and that the outcome could be different with other cases.

5.2. Unit of analysis

The aim of this thesis is to understand the role of networks in increasing the adoption of EVs in Amsterdam. More specifically, the aim is to know how the characteristics of the network can increase adoption. Therefore the unit of analysis is the network, not individual firms or organizations. The variables are network structure in three dimensions (stability, density and centrality), strength of ties in five dimensions (duration, frequency, trust & openness, contractual control and scope) and adoption (increase of EVs and charging points). The variables are used to investigate the network characteristics and whether this network increases adoption.

5.3. Operationalization

The characteristics of a network structure are measured by the indicators of Gilsing and Nooteboom (2005). Table 5.1 in Appendix A provides an overview of concepts, indicators and scales.

Stability

The stability of the network is measured by the entry and exit rate of actors. If in a certain year 5 actors enter the network and 3 leave the network, the stability is 5/3. A stability around 1 is indicated as stable. If the stability is below 0,75 or above 1,25 the stability is low.

Density

The density is determined by the ratio between actual ties and maximum possible ties. This will be measured for 2009, 2010 and 2011. A density above 0,75 is high, between 0,25 and 0,75 is medium and below 0,25 is indicated as low.

Centrality

The centrality is measured by the number of direct ties. The actor with the largest number of direct ties to other actors has the largest centrality. If all actors have the same number of ties, the centrality is low. If a few actors have significantly more ties than other actors the centrality is high.

Duration/Frequency

For the duration of a tie, the time in years for interaction between two actors is used. Since the network only exists since 2009, the duration is relative. So a duration of two years is long, one year is medium and shorter than a year is short. The frequency of the ties is measured by the number of interactions. An interaction can be a meeting or a phone conversation. The frequency is measured by a scale with 4 categories. The highest frequency is daily, then weekly, then monthly and the lowest frequency is less than monthly.

Trust & Openness

Trust & Openness is the extent to which knowledge moves freely between organizations. This is indicated as low if there is no exchange of knowledge, medium if there is one-way exchange, and high if there is two-way exchange.

Contractual Control

Contractual control is measured by asking if contracts are used to formalize the network ties. This can be answered by yes or no.

Scope

The scope is determined by the range of issues that is covered between the actors. This is narrow if there is only a specific issue, medium if there are two or more issues and high if the issues are technological and non-technological. A specific issue can be the specifications of the charge point or the payment system. Non-technological issues are operational or financial topics, like the request procedures for a charge point.

Adoption

To measure the adoption of EV, the Bass diffusion model is used.

$$\frac{f(t)}{1-F(t)} = p + qF(t)$$

Where:

- *f(t)* is he rate of change of the installed base fraction
- *F(t)* is the installed base fraction
- *p* is the coefficient of innovation (average = 0.03)
- *q* is the coefficient of imitation (average = 0.38)

The installed base fraction for EV in Amsterdam in 2009 is 0, because no EVs or charge points were installed.

With this model the expected number of users can be predicted. By comparing the expected number of users to the actual number of users, the degree of adoption can be measured. If the actual number of users is 1000 and the predicted number of users should be 2000, the adoption is only 50%.

5.4. Data collection

The case is the development of the charging infrastructure for electric vehicles in Amsterdam. By limiting the case to the region of Amsterdam, a clear network is identified. Because developments in Amsterdam are ahead of European developments, lessons could be applied widely[3].

For this research two types of data were required. Firstly, industry reports and governmental reports are investigated to identify the actors in the network. Secondly, interviews with the identified actors were necessary to determine the indicators. Semi-structured interviews were used to obtain the values for the indicators and to keep the possibility open for extra background information from the actors. The semi-structured interview started with open questions about the actor and the relations with others and finished with the closed questions for the indicators. Table 5.2 in Appendix B provides the open questions for the semi-structured interview.

To narrow the number of interviews, only actors that were mentioned by several actors were interviewed. The following actors accepted the invitation for an interview: Amsterdam Elektrisch, Nuon, Essent, (Al)Liander, Elmonet, the New Motion, Mister Green, Nissan and EV-box. At last, the outcome of the network analysis is presented to the actors in the network, to validate the data.

5.5. Data analysis

For the network analysis the software program UCINET is used. With this program the network is mapped and attributes are made visible. By creating a matrix with all actors and ties, the program is able to map the network and to calculate the centrality and density for example. By plotting maps for each indicator, analysis is possible.

[3] http://www.amsterdam.nl/parkeren-verkeer/elektrisch-vervoer/@365975/amsterdam_elektrisch/ Last accessed on 13-3-2011

6. Analysis

In this chapter, first the actors in the EV charging infrastructure network in Amsterdam are described in section 6.1.1. Then in section 6.1.2 the relations between the actors are described. In section 6.2 the indicators are discussed and in 6.3 the propositions are tested.

6.1. Case Amsterdam

6.1.1. Actors

The actors in the EV charging infrastructure network can be divided in different groups of actors. Actors from the government are playing a large role, but also energy companies and car manufacturers are important actors. In this section, the most important actors from the government, energy companies, car manufacturers, mobility service providers and charge point producers are discussed.

Government

Amsterdam Elektrisch

In Amsterdam the air pollution (NO_2 emission) is above standard on many locations. Exposure to this high concentration is harmful for the health of the citizens in Amsterdam. Also the trend does not show a decline in the period 1999-2007. Therefore a taskforce is introduced to reduce the air pollution in Amsterdam. One of the main focus areas of this taskforce is to reduce the emission by road transport. The idea was to introduce electric vehicles to reduce the emissions and meet the standard. The taskforce "Amsterdam Elektrisch" was founded to stimulate the introduction of EVs. This taskforce has the purpose to stimulate EVs in Amsterdam. To measure the result of the policy objectives, two targets are set. The first target is to have 10.000 EVs in Amsterdam by 2015. The second target is that 5% of the driven city kilometers is made by EVs[4] in 2015. The taskforce provided subsidies for entrepreneurs and started a tender for 100 public charge points in Amsterdam. The objective of this taskforce is to stimulate EV in order to reduce air pollution (Amsterdam Elektrisch, 2011).

Formule E-team

This team, the Formule E-team, is founded by the Dutch Ministry of Economic Affairs, to stimulate EVs. Its aim is to realize a national, well functioning infrastructure of charge points, to stimulate battery research and to increase the availability of EVs. In this team, the industry, government and knowledge institutions work together. They focus on national consensus about standards concerning charging- and payment methods. This team introduced the Mennekes plug as standard for charging an EV. Another activity of the team is the interoperability between charge point networks, so that an user can charge his EV at any public charge point, even if it is not owned by his provider. This is comparable with ATM's, also with a cash card from another bank it is possible to use the ATM. By initiating this interoperability closed and local infrastructures are prevented. For the user a more effective infrastructure is available. So harmonization with other EV charge infrastructures is also for Amsterdam important because more users can take advantage of the charge points.

[4] Stand van Zaken 2010

Urban districts of Amsterdam

The districts of Amsterdam are involved with the installation of the charge point. The central municipality finances the charge points, but the districts decide if and where the charge points are placed. In cooperation with the electricity grid operator the final location of the charge point is established.

Energy

(Al)Liander

In Amsterdam Liander is the local grid operator. They own the electricity grid and each public charge point is connected to this grid. They decide if it is possible to install a charge point in a specific place. Their interest is to provide a stable availability of electricity. Therefore the grid operator is monitoring the use of the charge points to obtain an understanding of needed capacity for large-scale EV use. Liander is part of Alliander, a national grid operator that also includes Liandon for the high voltage network. EV projects are coordinated by Alliander. They consider EV as an important part of a sustainable energy transition (Alliander, 2011). Liander is united in a national foundation (E-laad.nl) with other grid operators to reinforce their knowledge about EV. In Amsterdam E-laad.nl is only represented by Liander. So E-laad.nl is not interviewed as an actor in Amsterdam. For installation activities Liander is cooperating with Structon, a building company.

Nuon

Nuon is an energy provider in Amsterdam. Before the government-imposed unbundling of energy companies and grid operators, Nuon and Liander belonged to the same company. Nuon provides gas and electricity products to energy consumers. For this commercial party, EV charging points is a new service. When Amsterdam Elektrisch started a tender in 2009 for the exploitation of charge points, Nuon and Liander won the tender for 100 charge points. Liander was responsible for the installation and the connection to the grid and Nuon was responsible for the customer side and the production of the electricity (Nuon, 2011). They used the Coulomb charge points for this tender.

Essent

Essent is another energy provider, and was recently bought by a large German energy provider RWE. This is also a commercial party, which offers energy services that are comparable to those of Nuon. Recently a second tender was introduced by Amsterdam Elektrisch for the exploitation of 1000 extra charge points. Nuon and Essent both won this tender and will install the charge points in cooperation with Liander. RWE is also experimenting with EV charge points in Germany, therefore Essent is using the RWE charge points for the tender (Essent, 2011).

Mobility Service Providers

Buying an EV comes with more complex side effects than buying a new ICE car. Different types of chargers, plugs and charge passes make it more complex for users. To fit this need for extra service, mobility service providers entered the EV-market. Their goal is to sell EVs as a package, including the car, a charge point near your home, a proper plug, a card for using other charge points and if necessary also substitute transport is arranged in case long distances have to be covered. These actors are bridging the customer needs and other commercial parties or governments.

The New Motion

The New Motion was founded in 2009 by an early adopter of EV. When he had bought an EV, the use of it was not as easy as an ICE car. Therefore he started a company to sell EVs without the barriers, he had experienced. Funds from venture capitalists and a lottery make it possible to do research and develop products that are needed for removing the barriers. Therefore the company developed CE certified charge cables (The New Motion, 2011). They also take care of the delivery of the Nissan Leaf including a charge point and card. Also for the Opel Ampera a comparable package will be available. Another barrier they want to take away is the range anxiety by installing fast-charge stations. In cooperation with different investors 25 fast chargers will be placed near restaurants and fuel stations all over the Netherlands[5]. With the fast charger it is possible to charge the EV for 80% within half an hour.

Mister Green

Mister Green originated as an electric scooter retailer and diversified its business into electric cars. They offer comparable services as those provided by The New Motion. Their focus is, however, on small light-weight electric cars (Mister Green, 2011).

Elmonet

Elmonet is also a retailer of EVs. They offer the same services as Mister Green and The New Motion, but they have a wider range of products. They offer passenger cars and small delivery trucks, but also scooters, bicycles and other electric vehicles.

<u>Charge point producers</u>

EV-Box

EV-box is a national charge point producer. They developed a charge point that is built in a modular way, in order to have easy upgrade possibilities (EV-box, 2011). Payment systems or different plugs can be added or replaced without purchasing a new charge point. The charge point is designed to have enough space and connections to install additional systems in the future. Owners can start with a basic charge point with only a connector for example. When it is worthwhile to invest in a payment system, this can be integrated without replacing the charge point They focus on charge facilities in private or semi-private locations. On private parking lots for companies or parking garages for example these charge points can be installed. The objective of EV-Box is to make a profit by selling charge points.

Coulomb

Coulomb Technologies is an American producer of charge points. The charge point can use Radio Frequency Identification (RFID) for access. A chip on a card only needs to be placed near the charge

[5] http://www.zerauto.nl/index.php?page=Nieuws&pid=2&id=271 last accessed 29-5-2011

point for access to the connector socket. These charge points also can send a SMS to the driver if the charging process is complete. These charge points are used by Nuon for the exploitation of the first 100 charge points in Amsterdam. Coulomb Technologies has the objective of making a profit by selling charge points.

RWE

RWE is the holding company of Essent. Both companies had their own EV-program before they merged. RWE already developed a charge point, therefore RWE will deliver their charge points to Essent for the second tender in Amsterdam (Essent, 2011). By using their own charge points RWE can make a profit by selling electricity and the charge point.

Epyon

Epyon is a Dutch producer of charge points. They focus primarily on fast-charging. With fast charging high voltage currents are needed to charge the battery. Communication between the battery management system and the charge point is essential. In Amsterdam a fast charger is placed near the Nissan dealer. Nissan Leaf drivers can charge their car here within 30 minutes for 80%.

Figure 6.1: The EV-Box, Coulomb, RWE and Epyon charge points.

<u>Car manufacturers</u>

There are only a few EV cars available in Amsterdam. Most are small specialized EVs with a relatively high consumer price, like the Think City and the Tazzari. Also converted ICE cars are available. Since the beginning of 2011, the first large conventional car manufacturers introduced their EVs. For EV manufacturers a charging infrastructure is important for successful sales. So their interest is that the infrastructure is suitable for their product.

Nissan

Nissan has introduced the Leaf, which is a full electric vehicle that fits five persons and has quite ordinary looks. The first batch is delivered recently (April 2011) from the dealer in Amsterdam (Nissan, 2011). Because the Nissan Leaf has the Japanese Yazaki connector, a CE certified cable had to be developed to connect the Leaf to the standardized Mennekes connector.

PSA/Mitsubishi

PSA (Peugeot and Citroen) and Mitsubishi developed a car together that is available in Amsterdam. Peugeot calls it the 'Ion', Citroen the 'C-zero' and Mitsubishi the 'i-MiEV'. Greenwheels, a national car sharing company, has purchased several Ions for their business.

6.1.2. Relations

In this section the relations between the different actors will be discussed. For this analysis, an illustration from Ucinet will also be used. In this illustration the network ties are represented by arrows (Figure 6.2). Because it is unnecessary for answering the research question to discuss all ties, only the ties of the four actors with the largest overall centrality are discussed. These are the actors with the largest influence on the network: Amsterdam Elektrisch, the New Motion, (Al)liander and Nuon will be discussed.

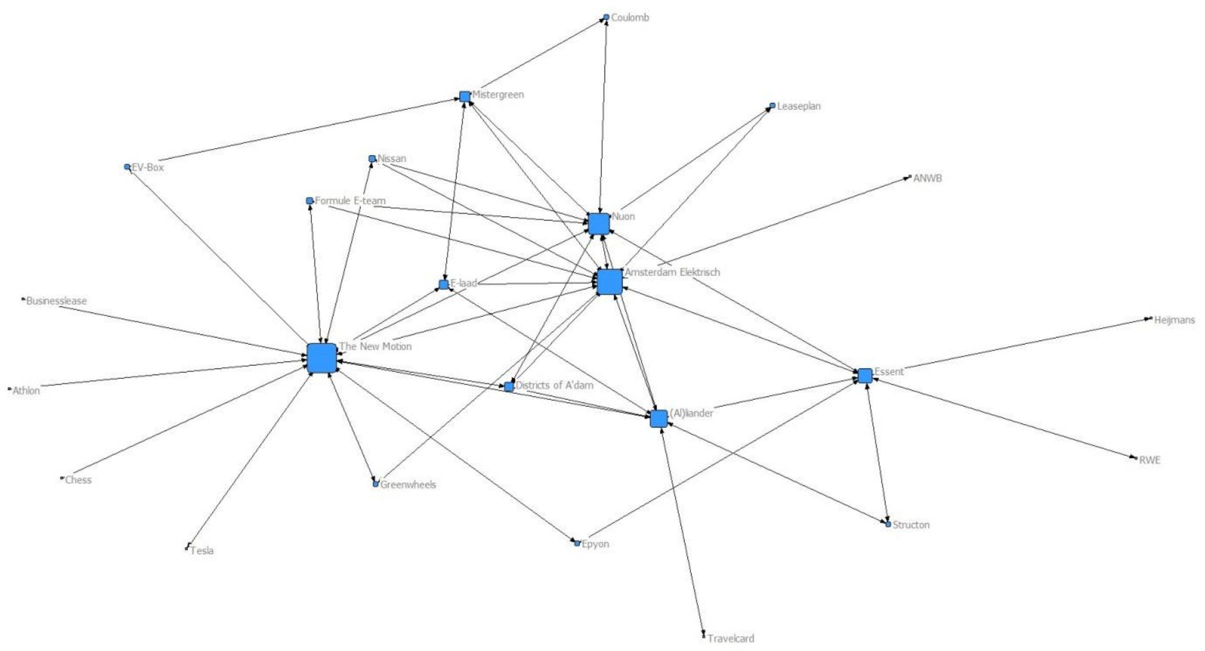


Figure 6.2: Network for EV charging infrastructure.

Amsterdam Elektrisch

Amsterdam Elektrisch has relations with most of the actors in the network, since the start of the taskforce in 2009. With all these actors, there is still a relationship. Ties can be divided in operational ties and strategic ties. Operational ties are formed with actors like Nuon, the districts of Amsterdam and Liander, about the installation of the charge points. The strategic ties are formed with E-laad, Formule E-team and also energy companies like Nuon and Liander. The strategic ties are formed to create standards and harmonization with other EV charge infrastructures in the Netherlands. The difference between operational and strategic ties is the frequency of interaction and the level of involved personnel. Operational ties are more frequent and also operational employees are involved. For strategic ties the frequency is lower and management is involved more often. The last type of relationship is with the mobility service providers (MSP). These actors are helping customers with their needs concerning EV. Requests for charge points or subsidies are submitted by MSP's. But also the municipal EV fleet is maintained by the MSP's (Amsterdam Elektrisch, 2011).

The New Motion

Also New Motion's connections are mostly established since 2009. Only Chess is an exception, which has a relationship with New Motion since 2004. Chess is a former partner of the owner of New Motion. Operational contacts are weekly or twice a month, and concern the installation of charge points. For EV owners in Amsterdam without a private parking lot a public charge point near their home is important for the usability of the EV. Therefore, a proper communication between the New Motion and Amsterdam Elektrisch is very important to be sure a charge point is available when the customer receives his EV. The same holds for the charging cards to use the charge points. The requests for charging cards have to be submitted to Nuon or Essent, if any delay occurs the customer cannot use his EV.

To improve the usability of the EV, the New Motion is developing a network of fast chargers with Epyon and Liander (The New Motion, 2011). This new technology is still in development, and therefore technological but also financial subjects are discussed between New Motion, Epyon and Liander.

For the introduction of several EVs in the Netherlands New Motion prepares the adjustments for the local EV charging infrastructure. For Nissan a special cable was designed to connect the Japanese plug to the European Mennekes plug (The New Motion, 2011).

(Al)Liander

Contacts with Amsterdam Elektrisch are since the beginning of the taskforce and also a relationship with Nuon considering EV is since 2009. Only the relationship with Essent and Travelcard is since 2010/2011. For the first tender of 100 charge points Liander and Amsterdam Elektrisch developed the specifications. Liander was the technology expert and Amsterdam Elektrisch was able to define the user requirements. At the moment the specifications are set and operational contacts about the location of the charge points are most relevant (Alliander, 2011).

Therefore Liander is communicating with Nuon, Essent and Amsterdam Elektrisch, as explained before. On a technology level (Al)liander is experimenting with the New Motion about fast charging and charging behind the electricity meter. In that case the owner of the EV will be billed instead of the owner of the meter. This should encourage people to be willing that EV owners can charge their vehicle at their property without suffer for the costs (Alliander, 2011).

Nuon

Most of Nuon's contacts are since the beginning of the EV charging infrastructure network involved. Only Nissan is involved later in 2010. The relationships with Amsterdam Elektrisch, Liander are already discussed before. Also the relationships with MSP's like New Motion are already discussed. These relationships are concerning the requests for charging cards to use the charge point (Nuon, 2011).

6.2. Indicators: network and adoption

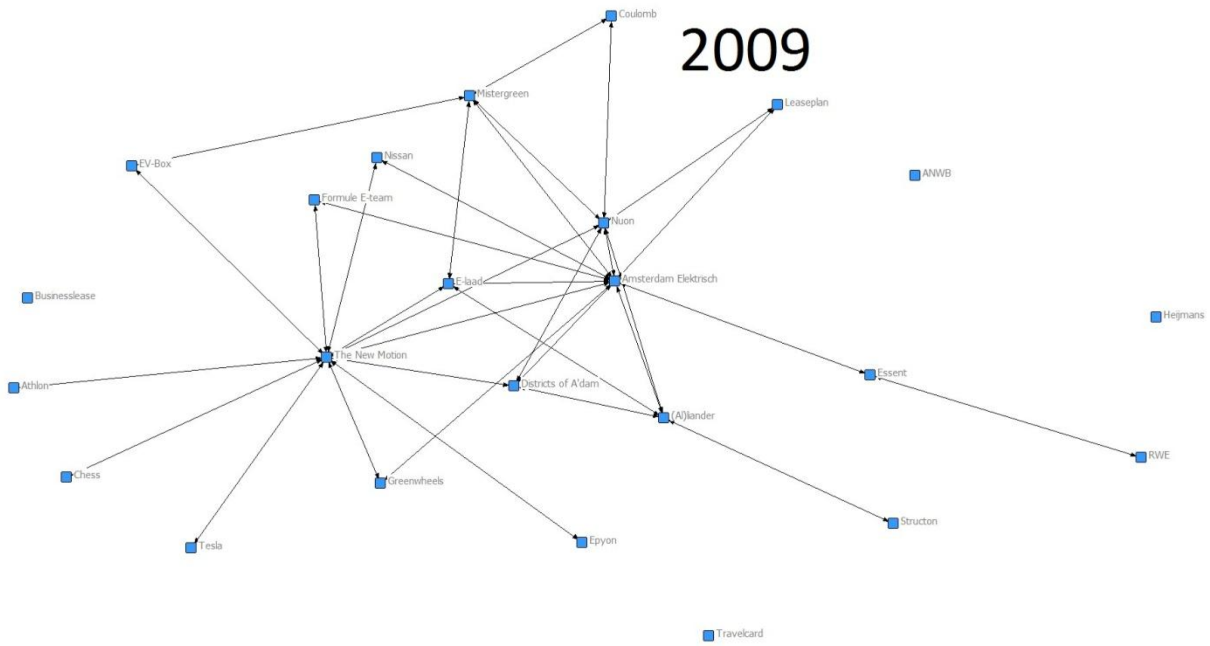
In this section, the characteristics of the network and the indicators of adoption will be discussed.

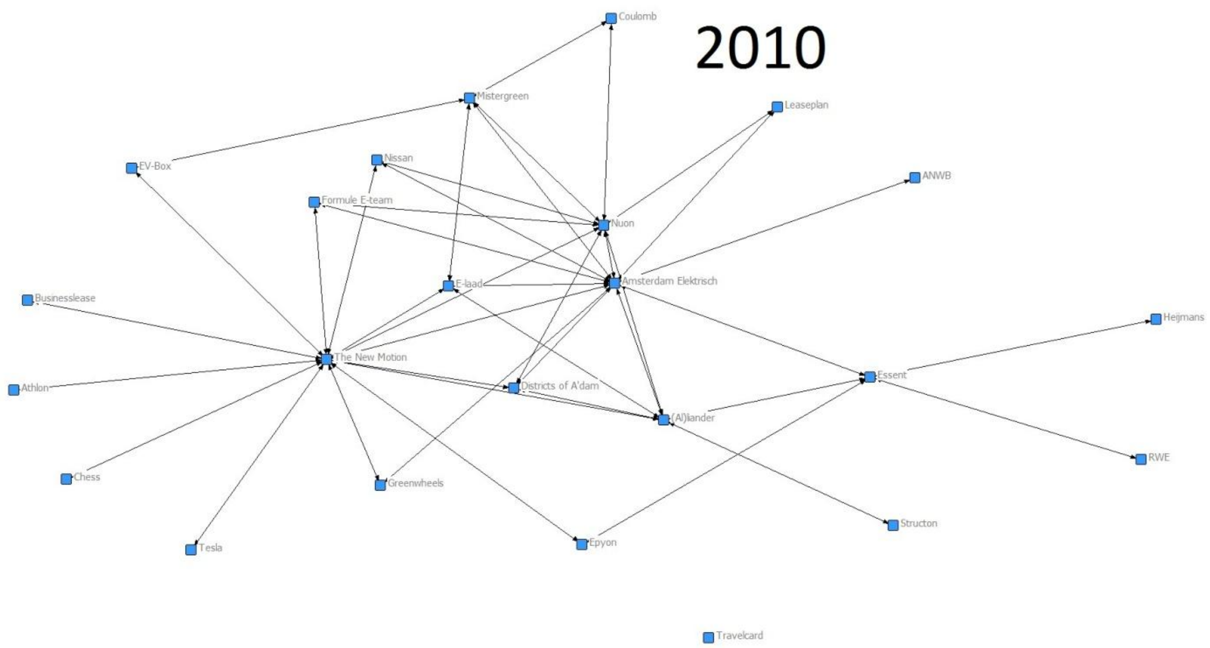
6.2.1. Density

The density is the relation between the actual number of ties and possible number of ties. For the EV infrastructure network 24 actors are identified in this research. That means that there are 24*24-24 = 552 possible ties. In this network 90 ties are counted. One tie is a one-way relation, so two-way relations are counted as 2 ties. With these numbers the network has a density of 0.16, which is relatively low.

6.2.2. Stability

In the network of EV infrastructure in Amsterdam, stability is high. Since the beginning of the network in 2009 no actors have left the network. Only actors have entered the network. In 2009 68 of the 90 ties were developed (Figure 6.3). In 2010 16 ties were added to the network and in 2011 6 ties completed the network of 90 ties (Figure 6.3). So the network started with a relative large number of actors that still are participating within the network. Figure 6.3 shows the small increase of actors in the network of EV infrastructure in Amsterdam over time. Because only a few ties were added since the beginning, the EV charge infrastructure network in Amsterdam is stable.


2009
Coulomb
Mistergreen
Leaseplan
EV-Box
Nissan
ANWB
Formule E-team
Nuon
E-laad
Amsterdam Elektrisch
Businesslease
Heijmans
The New Motion
Essent
Athlon
Districts of A'dam
(Al)liander
RWE
Chess
Greenwheels
Structon
Tesla
Epyon
Travelcard


2010
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EV-Box
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ANWB
Formule E-team
Nuon
E-laad
Amsterdam Elektrisch
Businesslease
Heijmans
The New Motion
Essent
Athlon
Districts of A'dam
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Greenwheels
Structon
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Epyon
Travelcard

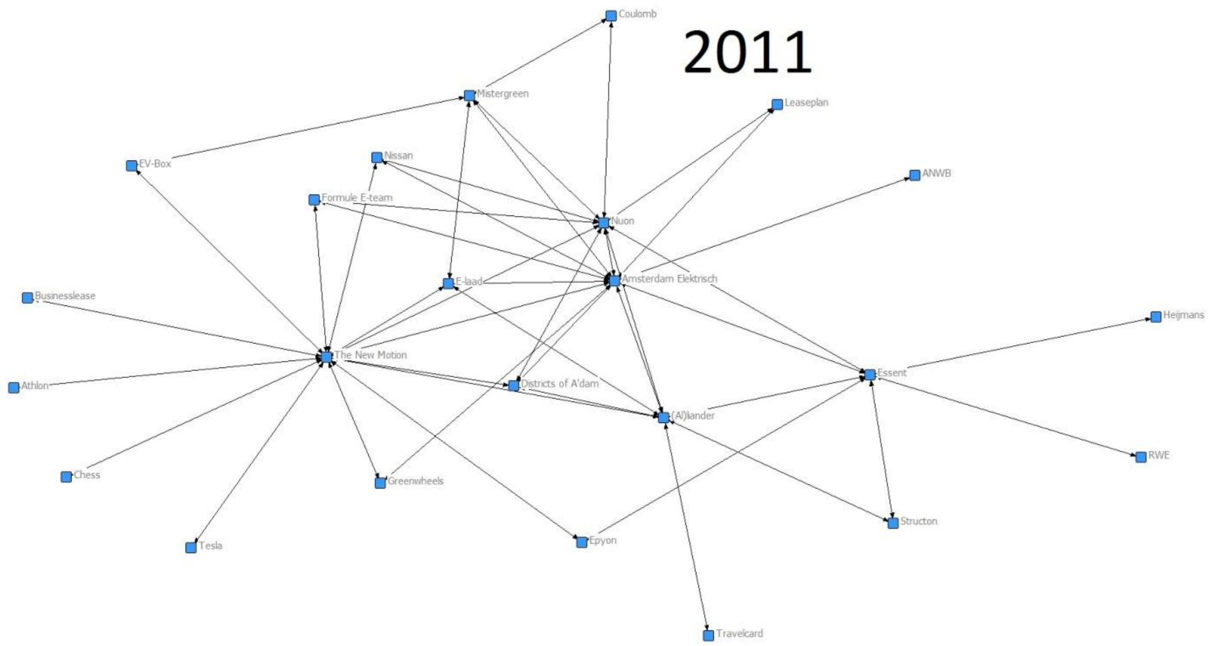


Figure 6.3: Network ties in 2009, 2010, 2011.

6.2.3. Centrality

For the EV charge infrastructure network the degree centrality is measured. This is the number of ties each actor has. Amsterdam Elektrisch, The New Motion, Nuon and (Al)liander have the most ties. The other actors have significantly less ties. This means that relatively few actors (4 out of 24) are central in the network, which means the centrality is high. Figure 6.4 shows the degree centrality for the EV charge infrastructure network.

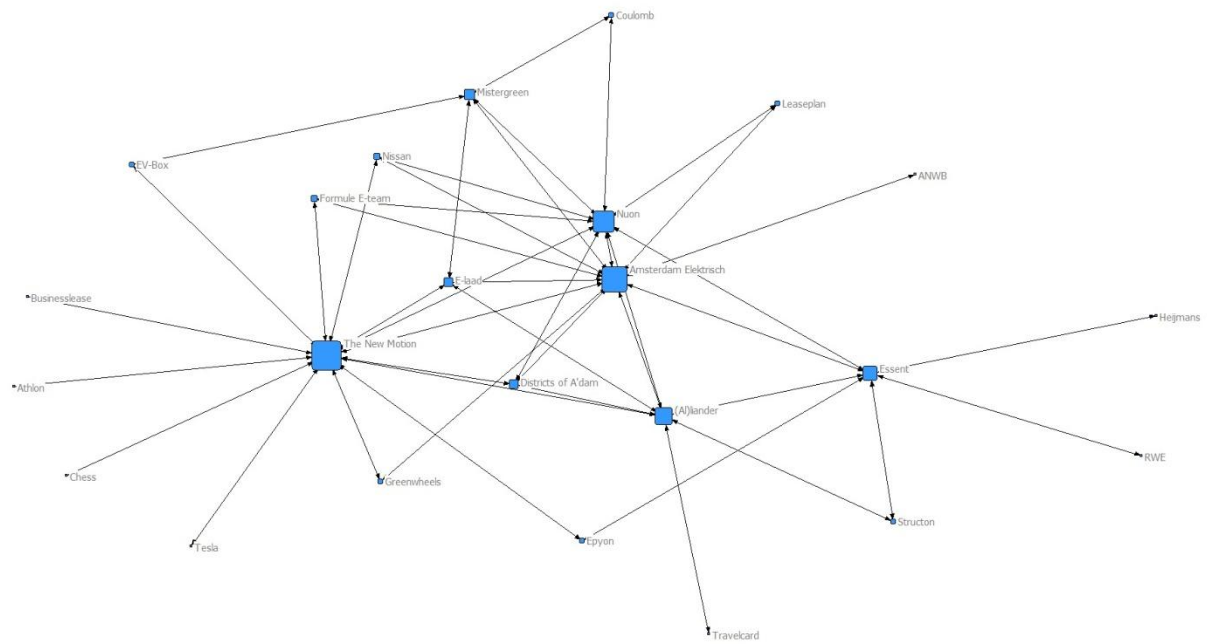
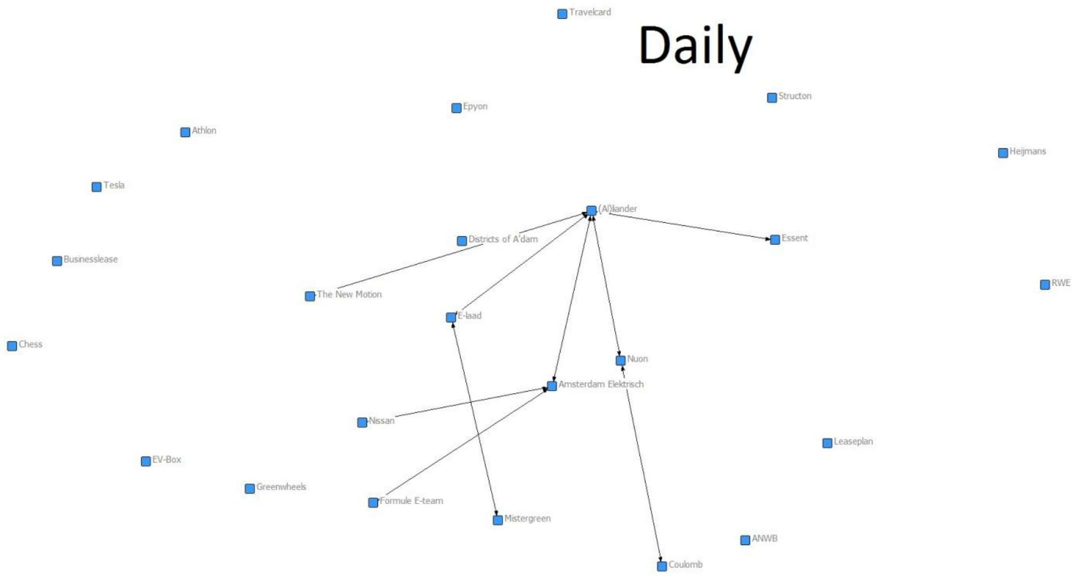
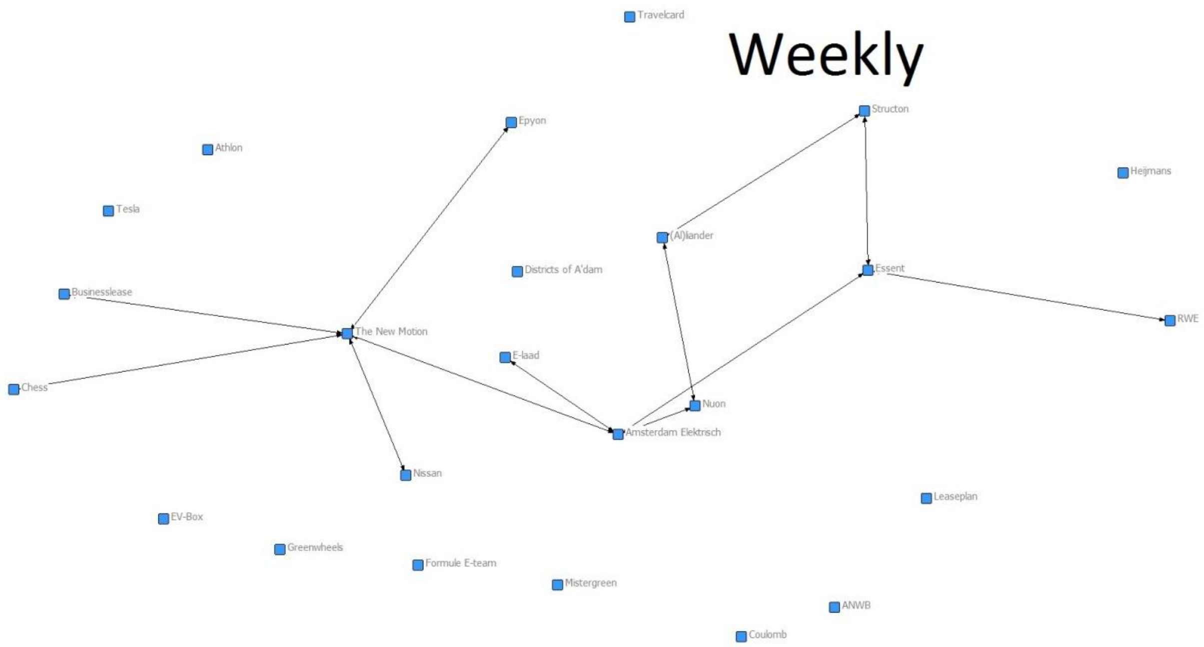


Figure 6.4: Centrality of the EV infrastructure network.

6.2.4. Duration/frequency

The duration of the ties is on average 1,7 years. This seems to be short but the network exists only for 2 years so the average duration is relatively long. The frequency is divided in daily, weekly, monthly and less than monthly. 18 ties were on a daily basis, 24 ties were on weekly basis, 36 ties were on monthly basis and 22 ties were on less than monthly basis. In total this is more than the 90 ties of the network. This is because some actors indicated a tie on weekly basis, while the connected actor indicated monthly, for example. In these cases the ties are counted twice, because selecting only one frequency would bias the research. This is also an indication that two actors do not have the same view on the frequency of the relationship. The average frequency of all ties is 25.9 days. So with a frequency of less than a month this can be identified as quite high. Figure 6.5 shows the frequencies of the meetings between the actors.





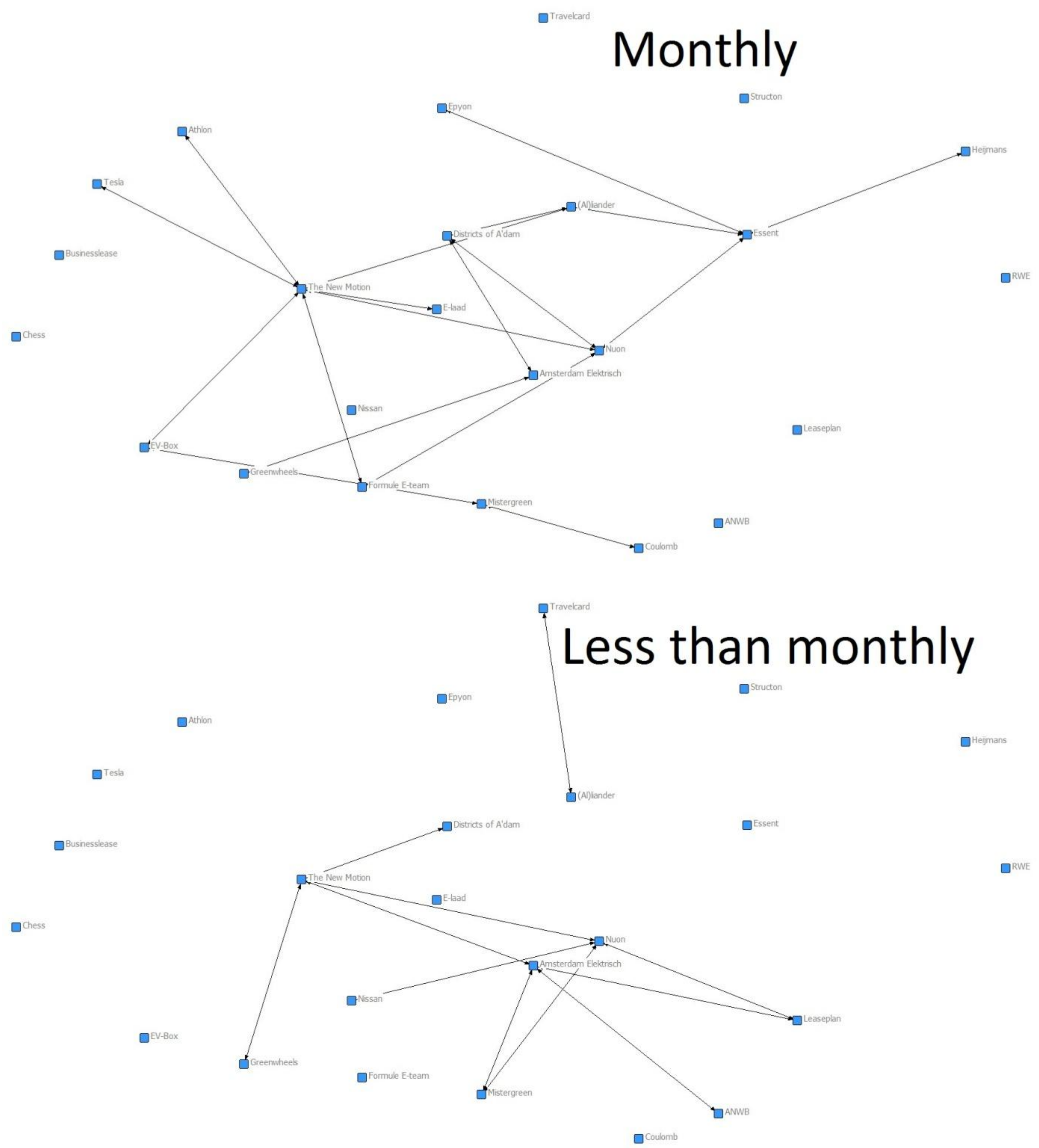


Figure 6.5: Daily, weekly, monthly and less than monthly frequency.

6.2.5. Trust/Openness

Trust/Openness was measured by the direction of the knowledge transfer. No knowledge transfer or one-way transfer is indicated as low trust and openness. Two-way knowledge transfer was indicated as high trust/openness. If there was knowledge transfer, in most cases it was indicated as 2-way transfer. In some cases there was a relationship, but not based on knowledge transfer. Some relations were based on dependency. For example the distribution of charge cards or the location for charge points were based on dependencies. The mobility service provider depends on the Nuon for the charge cards. They are committed to do the request at Nuon and cannot do this at another actor. 56 ties out of 90 were based on 2-way knowledge transfer. This indicates a relatively high level of trust. Figure 6.6 shows the knowledge transfer between actors.

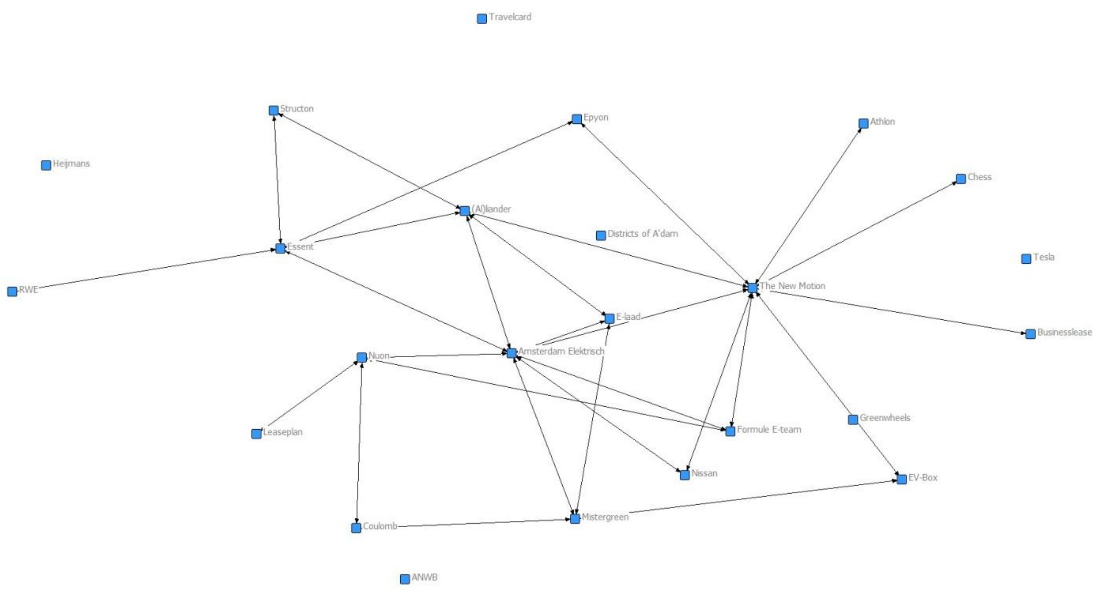


Figure 6.6: Trust/Openness in the EV charging network.

6.2.6. Contractual Control

Contractual control was measured by the ties that were formalized by contracts. 40 out of 90 ties were formalized by contracts. 44% of contractual ties is quite high for a network (Gilsing and Nooteboom, 2005). Figure 6.7 shows the actors which have contracts with other actors.

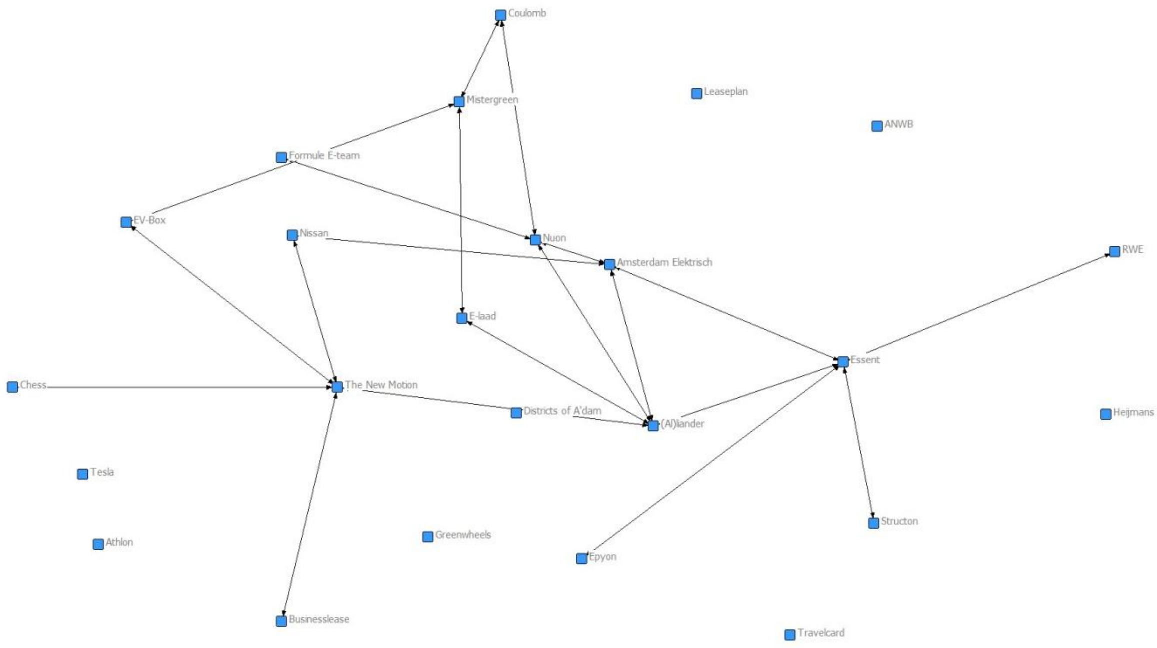
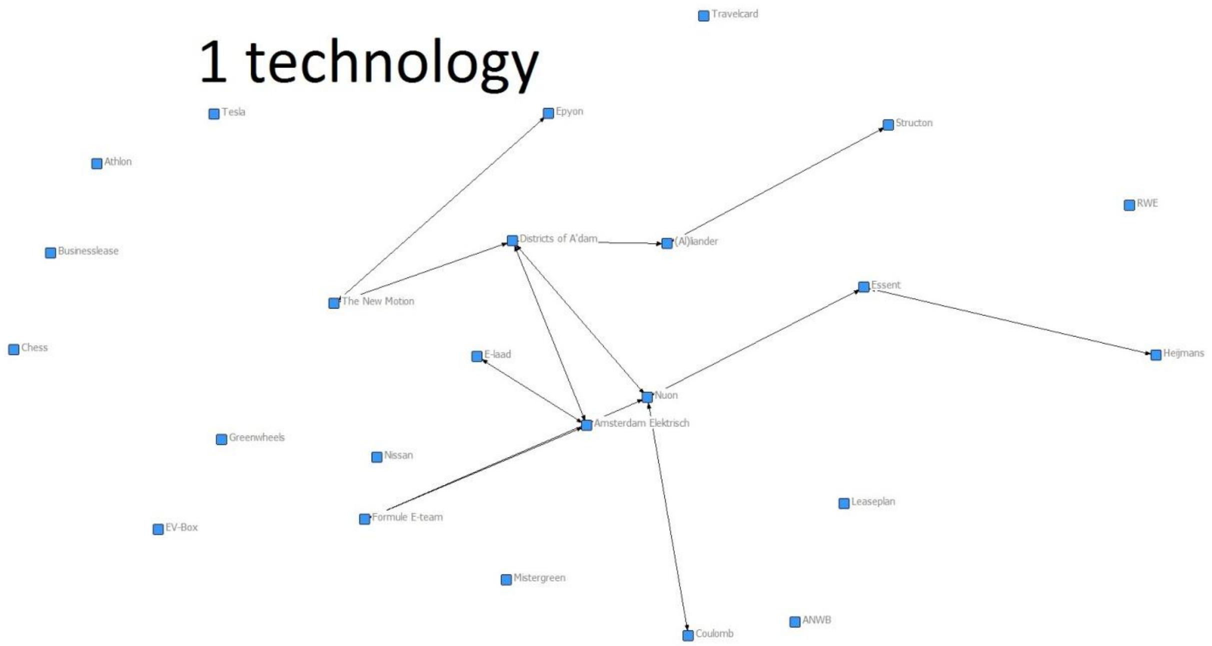
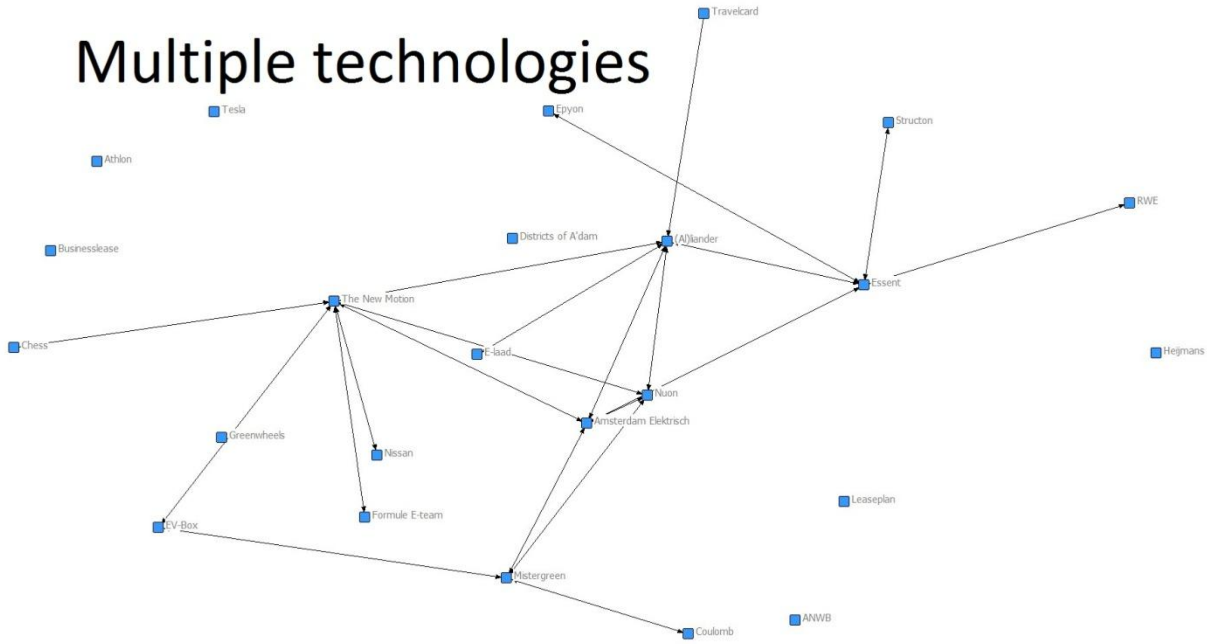


Figure 6.7: Actors with contracts.

6.2.7. Scope

The scope of relations was measured by asking about the subjects of the knowledge transfer. 24 of the 90 ties were about only one technological subject. 41 ties were about several technological subjects and 56 ties were also about non-technological subjects. So the scope is quite wide. Figure 6.8 shows the network of 1 technological, multiple technological and non-technological subjects.


1 technology
Travelcard
Tesla
Epyon
Structon
Athlon
RWE
Businesslease
Districts of A'dam
(Al)liander
Essent
The New Motion
Chess
E-laad
Heijmans
Nuon
Amsterdam Elektrisch
Greenwheels
Nissan
Leaseplan
Formule E-team
EV-Box
Mistergreen
ANWB
Coulomb


Multiple technologies
Travelcard
Tesla
Epyon
Structon
Athlon
RWE
Districts of A'dam
Businesslease
(Al)liander
Essent
The New Motion
Chess
E-laad
Heijmans
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Amsterdam Elektrisch
Greenwheels
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Leaseplan
Formule E-team
EV-Box
Mistergreen
ANWB
Coulomb

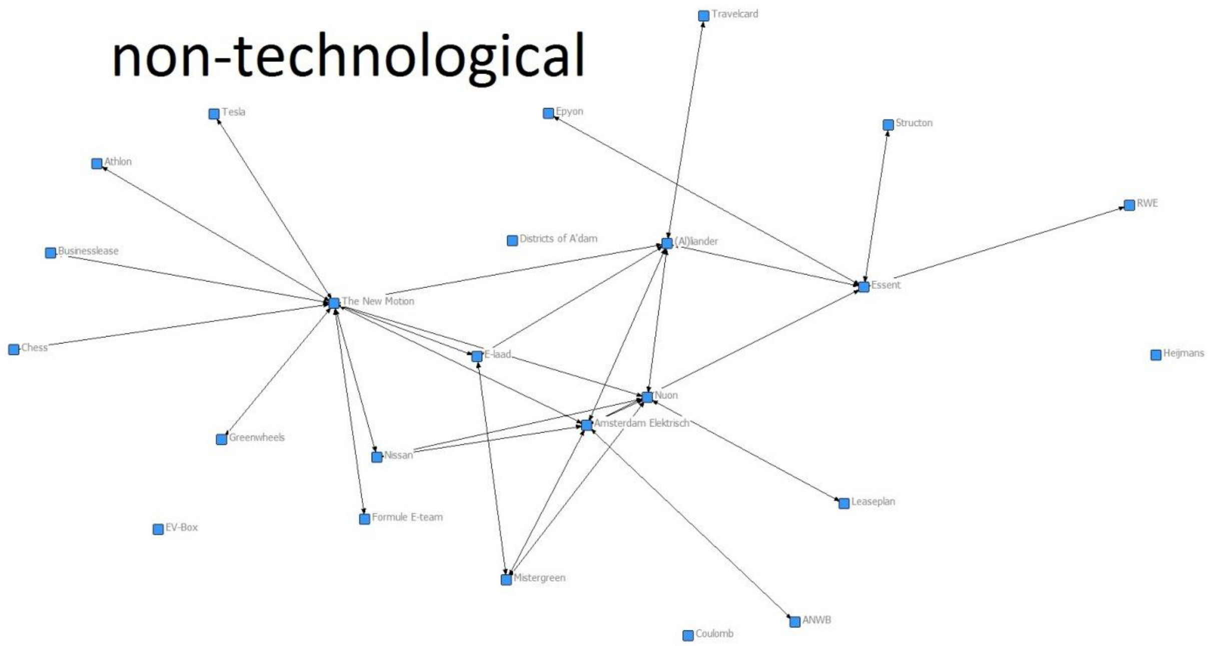

Figure 6.8: 1 technological, multiple technological and non-technological subjects.

6.2.8. Summary of independent indicators

For the EV charging infrastructure network the following results can be summarized. The density is low. The stability is high. The centrality is high. The duration is long and the frequency is high. The trust & openness is high. The contractual control is high and the scope is wide.

6.2.9. Adoption

EV in Amsterdam started in 2009. This year is taken as the start of the diffusion (year 1 in diagram 6.9). In Amsterdam +/- 300 electric cars are registered since 2009 (Amsterdam Elektrisch, 2011). The potential number of EVs in Amsterdam is 200.000[6]. If we follow the Bass diffusion model 1497 EVs should be sold at the end of year 2 (2010).That means the adoption of EVs is behind the predicted schedule and that also means that adoption is low.

[6] http://www.amsterdam.nl/parkeren-verkeer/elektrisch-vervoer/elektrisch/publicaties/documenten/plan-aanpak/

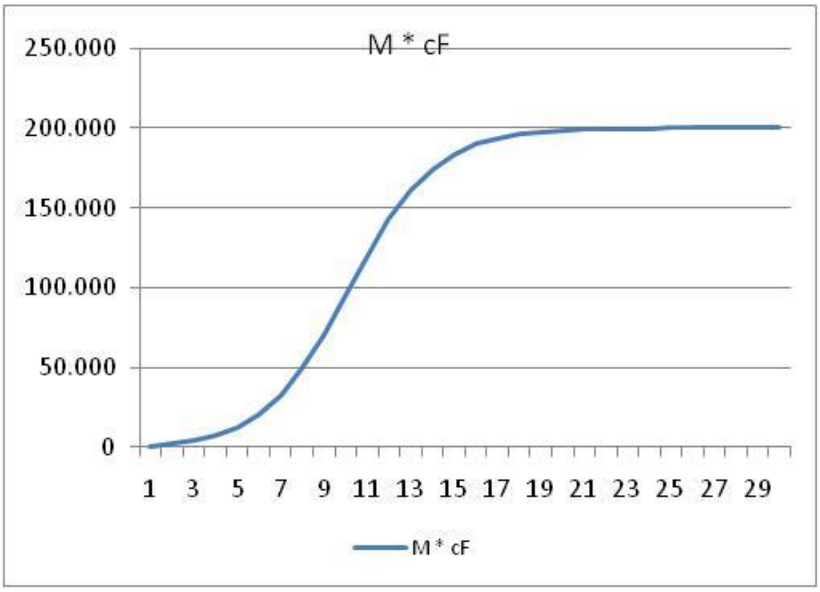

Diagram 6.9: Adoption of EV in Amsterdam

Also the adoption of charge points is investigated. If we consider the adoption of charge points, already 216 points are placed since 2009 (Amsterdam Elektrisch, 2011). The charge points will only be installed if there is an EV, that uses the charge point. In Amsterdam 1100 public points are planned to be installed (Amsterdam Elektrisch, 2011). Considering the Bass diffusion model only 8 charge points were expected to be installed until 2010. This means the adoption of EV charge points is above the predicted number of installed charge points based on the Bass diffusion model. Diagram 6.10 shows the predicted cumulative adoption of EV charge points. In that case the adoption of EV is increased because it is above the expected value.

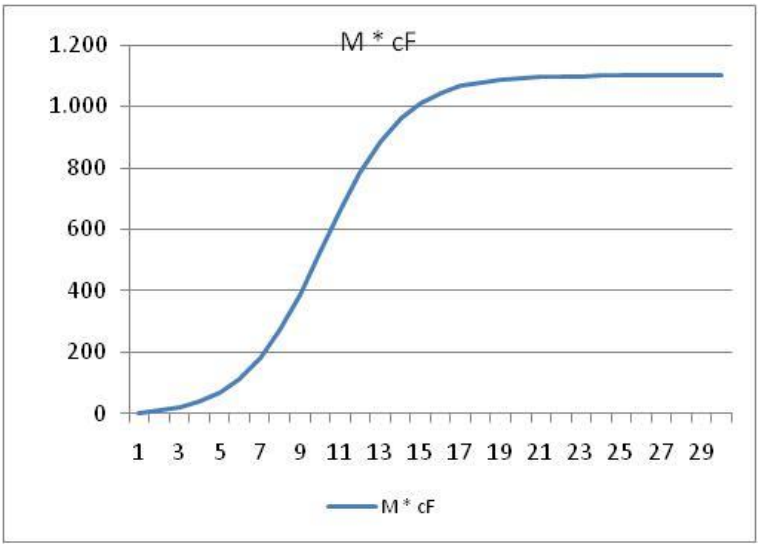

Diagram 6.9: The adoption of EV charge points in Amsterdam.

6.3. Testing Propositions

In this section the propositions concerning network characteristics and adoption of EV charging infrastructure are tested.

P1. If the network of EV charging infrastructure in Amsterdam is not dense, this will explain a large adoption. The density of the network is low and the adoption is increased, so P1 can be confirmed for the EV charging infrastructure in Amsterdam.

P2. If the network of EV charging infrastructure in Amsterdam is stable, this will explain a large adoption. The network is stable, so P2 can be confirmed for the EV charging infrastructure in Amsterdam.

P3. If the network of EV charging infrastructure in Amsterdam has a large centrality, this will explain a large adoption. The centrality is high, so P3 can be confirmed for the EV charging infrastructure in Amsterdam.

P4. If the network of EV charging infrastructure in Amsterdam has ties with low frequencies and long duration, this will explain a large adoption. The long duration can be confirmed because all actors are still participating in the network. Only the relatively high frequencies are not corresponding with the proposition. So P4 cannot entirely be confirmed.

P5. If the network of EV charging infrastructure in Amsterdam has low trust and openness, this will explain a large adoption. Also this proposition is not confirmed by the data. Because of the high 2-way knowledge transfer the trust was indicated as high.

P6. If the network of EV charging infrastructure in Amsterdam has high contractual control, this will explain a large adoption. The contractual control is high, so P6 can be confirmed for the EV charging infrastructure in Amsterdam.

P7. If the network of EV charging infrastructure in Amsterdam has a small scope, this will explain a large adoption. The scope is wide, but if we consider the subjects itself, the technological subjects concentrate on developing standards and specifications, fast charging and monitor/payment methods. Developing standards can be indicated as an exploitation activity, because by creating standards adoption will be increased. Also monitoring and especially payment methods can be indicated as an exploitation activity, because by monitoring the charging activities, business cases can be developed. The same holds for payment systems. Only fast charging can be indicated as an exploration activity, but also to increase adoption. By using fast charge technology the range anxiety and the usability of an EV will be increased.

The non-technological subjects focus on operational processes between different actors. Grid operators and power companies had to develop policies to cooperate with each other. Also the requests for installing charging points that were received by Amsterdam Elektrisch have to be delegated and monitored.

So despite the high number of multiple technological subjects the proposition for the scope of the network ties seems to have a positive effect on adoption. This can be confirmed for the EV charging infrastructure in Amsterdam.

7. Discussion

During this research several elements of discussion were identified. They can be classified into some remarks on theory, research method and indicators of the EV charging infrastructure network. In addition, some policy recommendations, and theoretical implications will be provided.

7.1. Theory

Earlier research on exploration and exploitation networks already showed that it is quite common that a network is not pure exploration or totally exploitation oriented (Gilsing and Nooteboom, 2005). Also for the charging infrastructure network this is true. Within the network some actors are doing both, they stimulate research about fast charging and they are developing commercial products for exploitation. So in general, we could state that the emphasis of the network is on exploitation, but also exploration characteristics are present. This makes it hard to conclude to which degree the network is an exploitation network. There is no theoretical base that describes how many indicators should be positive for exploitation to conclude that the network is an exploitation network.

7.2. Method

For this case the charging infrastructure for EVs in Amsterdam was investigated. Other researcher did not restrict their investigated technology network to the small geographical boundary of a city. Also in this research I found out that many actors were acting on national and some even on international level. That means that activities in Amsterdam were not independent and maybe the geographical limitations of Amsterdam were not suitable for this technology. Charging infrastructure for EVs is by definition not a locally applied technology, since EV users want to travel further than their local city. On the other hand, because of the central position of Amsterdam Elektrisch in the network, most activities were focused on Amsterdam. So using Amsterdam as a geographical boundary was justified.

Another item of discussion are the boundaries of the network. As stated in the introduction actors within the network of charging infrastructure in Amsterdam are investigated. Even with these limitations the number of actors is high and even not complete. Therefore only the actors that were identified by multiple actors were interviewed. Actors with only isolated ties were not interviewed. For a complete picture of the network also these actors would have to be interviewed to be certain that they were isolated and did not contribute to the network. This selection of actors is justified however, because the most relevant actors are identified and interviewed.

During the data collection, not all actors were willing to be interviewed, therefore it is possible that some ties are missing. However, by interviewing the most relevant actors this possibility is reduced. Another concern is the function and background of the interviewee. Not all interviewees were present since the beginning of the network and were therefore not able to answer questions about the early stage of the network in a solid way. Also the function of the interviewee was important for appropriate answers. Interviewees with more implementation tasks were focused on relations with other implementation actors and managing interviewees were able to indicate ties with actors on all levels. Also strategic answers were given on questions about the subjects of the ties. Some actors did not want to explain in detail the subject of the relationship, because they did not want to release their intentions to competitors. Also the presence of contracts was sometimes not confirmed or denied, which also indicates that some actors did not want to share the state of the relationship with competitors. So these answers will not improve the results for scope and contractual control of the network. On the other hand the denial of contracts is a strong indicator for exploitation activities because actors do not want that information about partnerships is premature released.

7.3. Indicators

For trust the indicator of knowledge transfer was used. One-way transfer was an indicator for low trust and two-way knowledge transfer was an indicator for high trust. However, during the research one-way knowledge transfer was not observed very often. Most interviewees stated that it was impossible to absorb knowledge without sharing knowledge. So measuring trust could be better measured by only confirming or denying knowledge transfer. If there is knowledge transfer, there is trust. If there is no knowledge transfer there is no trust.

Also the indicator frequencies of ties resulted sometimes in indefinable answers. Over time the frequencies could vary. Also the frequencies on different topics could vary. Actors could communicate daily on operational level and monthly on standards for example. So in these cases it was hard to provide an average frequency. The current frequency was used in case there was variation over time.

Adoption was measured by the number of purchased EVs in relation to the potential number of EVs. However, due to the very low number of purchased and available EVs it is hard to draw any conclusions from this. Therefore also the number of installed charging points was investigated. The results from this extra measurement were interesting for the analysis of adoption, and presented a much more realistic view of the contribution of the infrastructure network on adoption of EVs.

For future research, I would recommend a more extensive investigation of the network. The charge infrastructure network is a relatively young network and over time shake-outs or conflicts can influence the performance of the network and eventually the adoption of EV. Also the number of interviewed actors could be extended to increase the completeness of the network. In this research only the charge infrastructure network of Amsterdam was investigated, for further research the Dutch network could be investigated or a comparison between charge infrastructure networks in other cities could be made to measure the adoption performance of different networks.

7.4. Policy implications

If we consider the composition of the network, governmental and entrepreneurial actors have a central position within the network. The network is not dominated by only governmental actors or only entrepreneurial actors. This resulted in a balanced interaction between different actors. For future innovations, the composition of the network is important for the success of adoption. Actors with different backgrounds and interests are necessary to create a diversified network. Establishing the Formule E-team resulted in a harmonization between local initiatives and national policy. By implementing a national taskforce standards could be defined and best-practices could be exchanged. For a local network, interaction with national or European networks is important for increasing adoption. So establishing a national taskforce to support local innovations can stimulate adoption.

Another implication for infrastructure innovations are the roles of governmental and entrepreneurial actors. For the charging infrastructure grid operators (owned by the government) and energy companies (owned by shareholders) act on the same market. Grid operators take care for the connection to the grid and energy companies are responsible for the exploitation of the charge point. However, in practice, where both responsibilities are joined together, the division is less clear. Cooperation between a governmental actor and a commercial actor is important. Therefore a clear division of responsibilities is needed in order to stimulate cooperation and to prevent that actors hamper each other, because of conflicting interests.

If we consider the actors of the network, the users of charging points are missing. Within the network of charging infrastructure users or user platforms are not or barely involved. The ANWB, the Dutch car owners association, is not identified as a frequently involved actor. The reason users are barely involved is the lack of private users in general and the lack of EV user platforms. So it is difficult for other actors to involve individual users. At the moment, mobility service providers are spreading the customer needs through the network. However, a direct link between a user platform and the rest of the network would be useful to be more certain about the user needs.

7.5. Theoretical implications

During this research the following implications about networks are found. First, a network will not have only exploration or exploitation characteristics. Both characteristics will be present because new technologies will be developed during the exploitation phase to fulfill extra or new customer needs. From literature a more explicit network type would be expected (Nooteboom and Gilsing, 2005). The second contribution can be found in the network characteristics. The characteristic 'Trust' was expected to be low, however, with low trust both exploration and exploitation networks will hamper adoption. For efficient interaction trust is necessary during the exploration phase and the exploitation phase. The last contribution is about adoption. Measurement of adoption is hard during the first phase of adoption. Efforts by the actors are not yet contributing to a successful adoption. So due to the delay in adoption the effect of the network is difficult to measure.

8. Conclusion

In this research I wanted to investigate how the network of EV charging infrastructure affected the adoption of EVs. For this research the network of charging infrastructure in Amsterdam was examined. By interviewing the actors in the network the characteristics of the network could be measured in order to analyze the contribution of the network to the adoption of EV and EV charge points. For testing the propositions the adoption of EV charge points was used, because measuring the adoption of EV did not result in a realistic outcome, due to the very early stage of diffusion.

If we consider the propositions that enabled me to answer the research question, the next conclusions can be made.

P1. If the network of EV charging infrastructure in Amsterdam is not dense, this will explain a large adoption. This can be confirmed for the charging infrastructure in Amsterdam.

P2. If the network of EV charging infrastructure in Amsterdam is stable, this will explain a large adoption. This can be confirmed for the charging infrastructure in Amsterdam.

P3. If the network of EV charging infrastructure in Amsterdam has a large centrality, this will explain a large adoption. This can be confirmed for the charging infrastructure in Amsterdam.

P4. If the network of EV charging infrastructure in Amsterdam has ties with low frequencies and long duration, this will explain a large adoption. The long duration can be confirmed because all actors are still participating in the network. Only the relatively high frequencies are not corresponding with the proposition.

P5. If the network of EV charging infrastructure in Amsterdam has low trust and openness, this will explain a large adoption. Also this proposition is not confirmed by the data. Because of the high two-way knowledge transfer the trust was indicated as high.

P6. If the network of EV charging infrastructure in Amsterdam has high contractual control, this will explain a large adoption. This can be confirmed for the charging infrastructure in Amsterdam.

P7. If the network of EV charging infrastructure in Amsterdam has a small scope, this will explain a large adoption. This can be confirmed for the charging infrastructure in Amsterdam.

This means that five of seven propositions can be confirmed and increase adoption. Proposition P4 can be confirmed partially and the long duration will contribute to the adoption of EVs in Amsterdam. Only P6 is not confirmed by the data. However, high trust will not hamper adoption. A low trust is what is expected in an exploitation network and an exploitation network will increase adoption.

So the network for charging infrastructure affects adoption positively because of the 5 confirmed propositions. That means that in Amsterdam an effective network is created to increase adoption of EV. However, because of the early stage of diffusion it is premature to state that the adoption of EVs will be successful.

To increase a successful adoption of EV, for the EV charge infrastructure network in Amsterdam the following general conclusions can be made. Firstly, the network should not be dense, because too many redundant ties will cost valuable resources to maintain and will not contribute to the adoption. Single ties between actors are sufficient for adoption. Secondly, the ties should be stable. Investments in stable ties will result in effective cooperation. Therefore long-term policies from the government and companies are necessary. Thirdly, the network should have certain central actors to increase the centrality. Central actors can provide direction and can communicate efficiently with other actors. Fourthly, by using contracts to strengthen the ties, adoption will increase. Contracts can provide stability because agreements are often made for several years. Contracts will also provide a mature impression about the technology. If companies or institutes are confident about a technology, potential users also become confident. So actors within the charge infrastructure network should be encouraged to sign contracts with each other if it will increase stability. At last, the scope of the network ties should be narrow and focused on a single technology. For the charging infrastructure in Amsterdam focusing on public charge points worked out well. After this successful implementation the focus can be shifted to fast charging.

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Appendix A

Concept	Dimension	Indicator	Question?	Scale
Stability		Number of entry/number of exits in year X	With how many organizations did you start a relationship in 2010/2011. With how many organizations did you end a relationship in 2010/2011.	List of Organizations
Density		Connections/possible connections	With which organizations did you have a relationship in 2010/2011?	List of organizations
Centrality		Number of direct ties	Derived from network	Number
Duration/Frequency	Duration	Duration of a connection in years	For Each contact: When did the relationship start? When did it end?	Years
	Frequency	Interactions	What is the frequency of the interactions?	Daily. Weekly, Monthly, Yearly
Trust/Openness		Exchange of knowledge (No, 1-way, 2-way)	Is their information exchange with each connection?	No exchange, Receiving Transmitting 2-way
Contractual Control		Use of contracts	Which ties are formalized by contracts?	Yes, with organization x, No
Scope		Range of issues(1 issue, more than 1 issue, tech and non-tech)	Which issues are connected to the relationship?	1 issue, More than 1 issue, Tech and non tech issues
Adoption		Number of sold EVs/number of potential sold EVs		

Table 5.1: Operationalization of the concepts.

Appendix B

Organization	When was the organization founded?
	What is the core business of the organization?
	Why is your organization involved with charge infrastructure?
Interviewee	What is your function?
	Since when are you involved in the network?

Table 5.2: Open questions