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Charging Point Infrastructure

− The catalyst for the electrification of the Norwegian car fleet −

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Abstract. To lower gas emissions, vehicle fleet electrification is desirable for countries with a low greenhouse emission energy mix. This study focuses on whether charging infrastructure is of importance for consumers' electric vehicle (EV) purchase decision. We test this by using EV data from Norway, one of the leading EV markets globally to date, where charging infrastructure's impact on the demand of EVs is investigated in an environment with already strong monetary incentives in place. A regional approach where all households face the same national monetary incentives allows for isolating the effect of regional infrastructure and other factors such as income, environmental awareness and traffic volumes on EV registrations. The panel data (2007M1-2013M12) from the Norwegian governmental transport administration (Opplysningsrådet for Veitrafikken) is used in a fixed effects model specification. To our knowledge, no study investigating charging infrastructure for EV markets has ever been conducted in a panel dataset setting, most likely due to data restrictions. Findings show that charging infrastructure is significant for households' vehicle purchasing decision where one additional charging point per regional square kilometre gives an increase of between 15 to 21 additional EVs per 10,000 households. Governmental intervention is necessary for fleet electrification and optimal policy for EV substitution of the conventional car fleet can only be designed when fully understanding the combined effect of subsidy, infrastructural and utilization policies.

Keywords: Electric Vehicles, EV, Charging infrastructure, Charging point, Electrification, Transportation Economics

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“You and I come by road or rail, but economists travel on infrastructure.”

- Margaret Thatcher

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Further, our very dear friends and colleagues Christian Siebert and Mark Conrad deserve medals for sharp feedback and proofreading. For our everyday thesis support, we think of Rexxar and this quote:

”The smallest feline is a masterpiece.”

- Leonardo da Vinci

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1. Introduction

Governments globally are concerned about the humanitarian and economic effects of global warming. Light-weight vehicles today account for 10 percent of global energy use and green-house emissions (Solomon, et al., 2007). This has led many large economies, for example Germany and France, to implement monetary incentives such as tax reductions on electric vehicles (EVs) to facilitate electrification of the vehicle fleet and hence reduce emissions (Parkin and Tschampa, 2014). These kinds of incentives most likely have a positive effect on the EV market but as EVs differ from conventional vehicles, interventions only targeting monetary incentives may not be enough for the market to take off. *Range*, i.e. how far you can drive before you have to charge, is a known problem for EVs as this can limit the EV owners' travelling behaviour when there are not enough charging points available. In this study we aim at investigating the impact of charging infrastructure on consumer EV demand as we believe infrastructure, as well as monetary incentives, is of crucial importance for electrification of the vehicle fleet.

To test *the impact of charging infrastructure on the electric vehicle market* we use EV data from Norway whose government has set a goal of 50,000 zero emission vehicles by 2018 (Figenbaum and Kolbenstvedt, 2013) and has implemented financial support programmes for developing the charging infrastructure as well as policies targeting monetary incentives and other benefits. The Norwegian EV market growth has been massive for the last four years: the number of registered EVs increased from 2,500 in 2009 to almost 20,000 in 2013 where EVs represent almost one percent of the total 2013 car fleet (Statistics Norway, Grønn Bil, 2015). As the infrastructural support programmes made it possible to charge EVs at additional places besides the home (at car parks, shopping malls, schools, hospitals, etc.), we argue that the development of the infrastructure most likely was an accelerating factor for the electrification of the market. Hence, our hypothesis is that *charging infrastructure has a significant positive impact on the electric vehicle market.*

Past studies focus primarily on the effect of monetary incentives on the electrical market comparing countries' tax subsidies and other implemented monetary incentives (Chandra et al., 2010; Gallagher and Muehlegger, 2011; and Sierzchula et al., 2014), however, little attention has been given to the effect of charging infrastructure. Hence, we identify a large gap in the current literature and aim at providing evidence of how much charging infrastructure impacts EV ownership.

We use data from 2007 and 2013 as the charging infrastructure increased substantially during this period of time with help from the public support programmes. All regions in Norway face the same VAT exemptions and other tax incentives as well as other benefits such as access to bus lanes. Further, all regions face the same average retail prices on cars based on car manufacturers list prices as well as little variations in fuel prices on petrol and diesel. The development of the charging infrastructure, however, has varied to a large extent between the regions, which makes it possible to estimate the effect of charging infrastructure on the number of registered EVs on a regional level. Also the impact of other factors such as income, environmental awareness and traffic volumes on EV registrations is estimated.

We do not include hybrid vehicles for three reasons. Firstly, hybrids can be fuelled by conventional fuel if charging points are not available. Secondly, range concern of the battery is likely to be less severe with hybrids due to dual fuel types. Thirdly, the hybrids numbers are scare in Norway with a total of 691 registered vehicles in December 2013.

Our results show that the number of charging points per regional square kilometre has a positive and significant effect on household EV registrations across all specifications of the model, both looking at Norway at large and in a subset. The magnitude of effects differs somewhat between the model specifications, but the primary model–a fixed effect model controlling for the models available in the market and other factors–indicates that one additional charging point per regional square kilometre gives an average increase of between 15 to 21 additional EVs per 10,000 households. Hence, the results are in line with our hypothesis that charging infrastructure has a positive impact on the EV market.

As EV technology matures, prices are likely to continue to fall and converge to that of conventional vehicles. This is primarily a result of falling prices to produce effective batteries (Liebreich, 2013). However, there are still large pre-subsidy differences in retail prices between countries. In the case of Norwegian 2013 prices to customer, the Nissan Leaf (USD 42,500) is to be considered competitive to the 1.3–liter Volkswagen Golf (USD 42,500) in both price and performance. Comparatively, for the same time period in United Kingdom the Nissan Leaf retailed at over 120 percent the price of the Volkswagen Golf (Doyle and Adomaitis, 2013). At converged prices, other aspects such as the ease of charging and operational costs are increasingly important for the consumer purchasing decision. Norway is a high income country with strong purchasing power. Combined with the fact that the total fiscal incentives per EV base price provided exceeds 50 percent, which is in fact the highest level in the world before California with an incentive rate of just over 35 percent (Mock and Yang, 2014), we argue that convenience factors have been increasingly important for the developments in Norway. Even though infrastructural policy can be used as a stand-alone regional stimulation instrument, it is most effectively used as a complement to nationwide monetary policies when prices of standard combustion vehicles and EVs are not similar. This study adds to the current body of work by showing that it is possible to change EV demand through infrastructure.

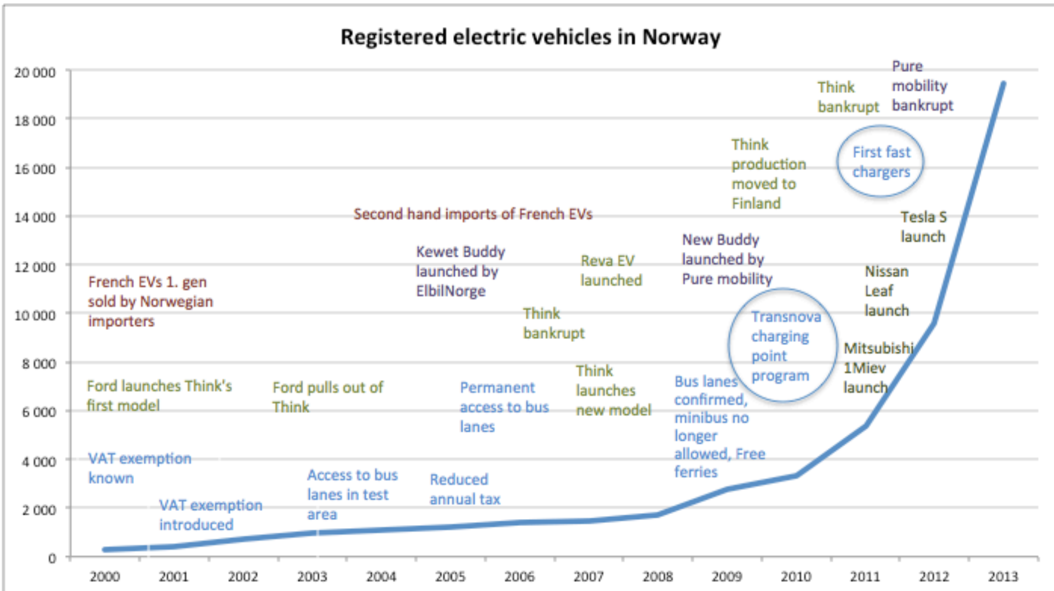
2. Background

This chapter gives an overview of the Norwegian EV market, environmental considerations, EV range issues and charging infrastructure support programmes.

2.1 Norwegian EV market phases - A brief historical overview

The Norwegian EV market has gone through several phases in recent years: from late *early market stage,* through *market introduction phase* to *early market expansion phase* (Figenbaum and Kolbenstvedt, 2013). This means that this study is focusing on electrification policy for primarily undeveloped EV markets. It is important to have an understanding about the development and adoption of technology throughout these years and the introduction of the various incentives to fully understand the driving mechanisms of the market.

Figure 2.1.1: Registered EVs in Norway from 2000-2013. Source: Events described in Figenbaum and Kolbenstvedt, 2013, and data from Grønn Bil, 2015. Authors' own picture processing.



From the years of 2000 to 2009, during the early market phase, the EV market was characterised by smaller and less technical advanced models such as Think and Kewet, both with Norwegian origins. However, the supply was limited and Norway had to rely to a great extent on the import of mainly French EVs (e.g. Renault, Peugeot, and Citroën). There were many incentives initiated in this phase, mainly monetary: free parking (1999), VAT (2001), road toll reduction (2004), and EV access to bus lane driving (2005), all applicable throughout the country. The vehicles in this era were neither equally comfortable nor secure as internal combustion vehicles in the same price range, and consumers traded comfort and security for access to benefits (Figenbaum and Kolbenstvedt, 2013).

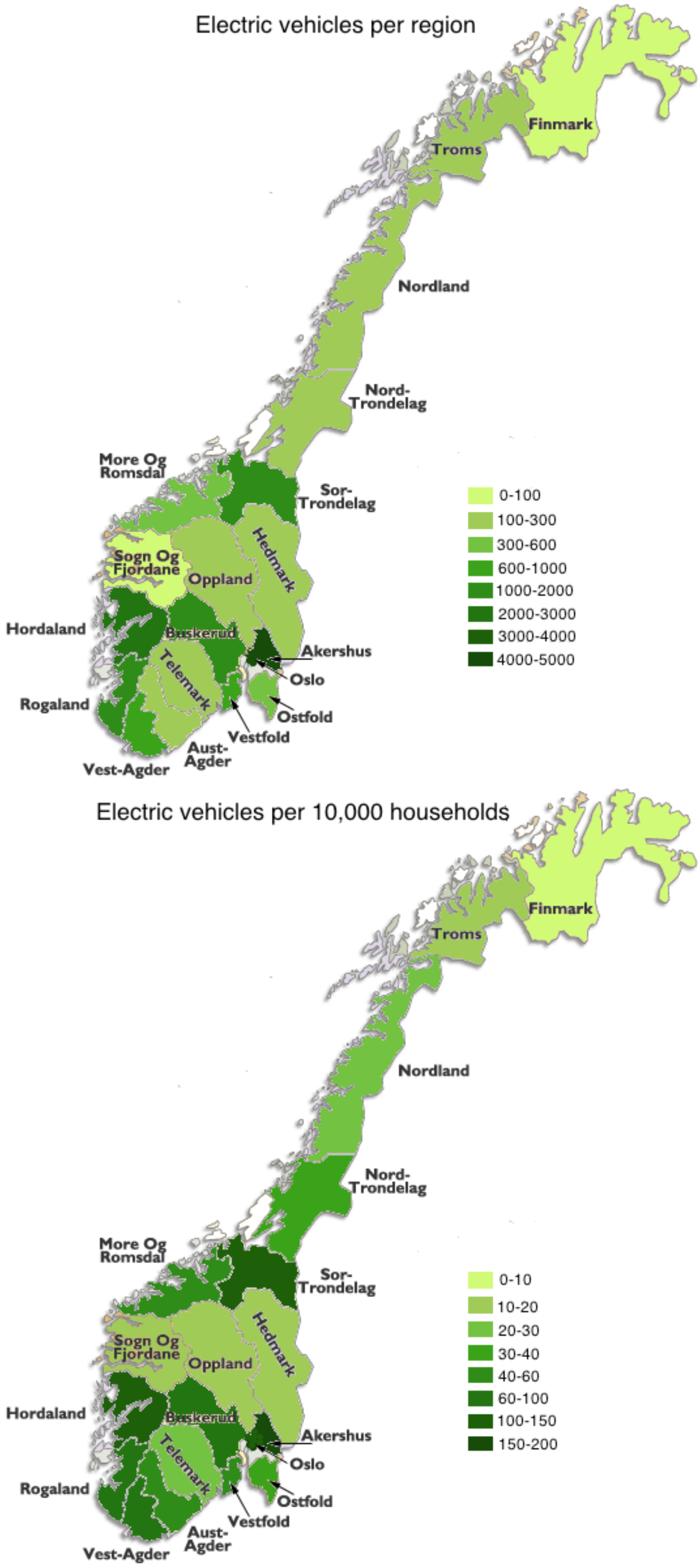
During the market introduction phase, from 2009 to 2013, the government organization Transnova, detailed in Chapter 2.5, made it possible to establish charging points on a larger scale than before, leading to a substantial expansion of the charging infrastructure. Also, many updated and new models and makes entered the market such as Mitsubishi, Peugeot, Citroën and Nissan. This stream of new market entrants induced a downward price pressure, causing Norwegian manufacturers to default. During this period, EV sales increased substantially and represented approximately 3 percent of all new car sales in 2012 (Figenbaum and Kolbenstvedt, 2013).

In 2013, the market expansion phase began. An increasing number of car dealers carried EVs in their product range, and most vehicles are sold to private households (Grønn Bil, 2015). Sales of EVs have increased dramatically since 2011 without new governmental policy initiatives launched in the market. Figenbaum and Kolbenstvedt (2013) argue that it was not a lack of initiatives that limited the market until the market introduction phase but rather a shortage of attractive models.

2.2 The Norwegian EV market - Geographic distribution

Norway is divided into 19 administrative regions (Norwegian: *fylker*) and since 2007, the number of registered EVs has increased significantly throughout the country. However, the market growth has differed in magnitude between the regions, which can be seen in *Figure 2.2.1,* displaying the distribution of registered EVs in Norway in December 2013. It is evident that the southern regions accounted for the largest number of registered EVs both in absolute numbers and per 10,000 households and that Oslo and Akershus stand out, followed by Hordaland, Sor-Trondelag and Buskerud. The northern regions Finnmark and Troms and the midland regions Sogn og Fjordane, Oppland and Hedmark have the lowest number of registered EVs.

Figure 2.2.1: Registered EVs per region in Norway in December 2013. Shown in absolute numbers and on a per 10,000 households level. Source: Data from Grønn Bil (2015). Authors' own picture processing.

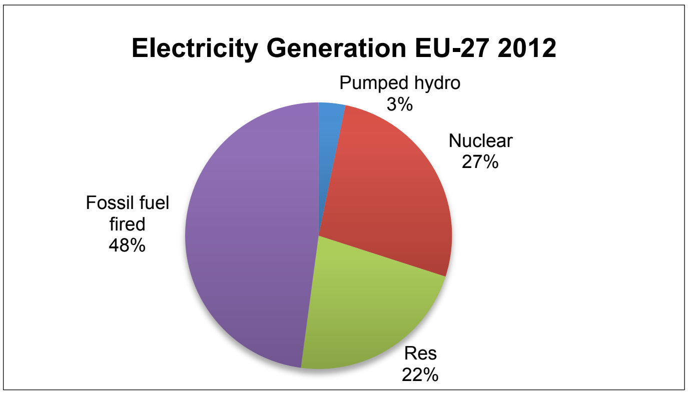


2.3 Environmental aspects of EVs compared to conventional vehicles

To successfully reduce carbon emissions by electrification of the vehicle fleet there are two environmental impacts of EVs to be concerned about: Firstly, how the electricity that fuels the EV is generated, and secondly what environmental impact the manufacturing of the EV and its batteries has compared to a conventional car. In a lifecycle perspective, including not only the emissions for extracting, preparing and distributing energy but also the production of the vehicles, the CO2-emissions are still lower from EVs than similar sized internal combustion vehicles provided that the energy mix of the country is emission free to a high degree (Parkin and Tschampa, 2014).

Taking all emissions into account, the Norwegian EV quickly becomes superior to the internal combustion vehicle from an environmental perspective thanks to the Norwegian energy mix where 96.1 percent of Norwegian electricity production came from hydropower and 1.4 percent from wind power in 2013 (Statistics Norway, 2015). However, the Norwegian power mix looks very different from the European average (*Figure 2.3.1*), where the share of fossil fuels in Norway was 2.5 percent compared to the EU-27 average of 48.3 percent in 2012. This implies that even though EVs are found to be more environmentally friendly compared to conventional vehicles on a European level (Hawkins et al., 2013), the pro-environmental effect is much larger for countries with smaller shares of fossil fuels in their energy mix, like in the case of Norway. EVs that are fuelled by the average European energy mix offer a 10 to 24 percent decrease in global warming potential compared to conventional vehicles when the entire life cycle of 150,000 kilometres is taken into account (Hawkins et al., 2013).

Figure 2.3.1: Electricity generation on average in EU-27 in 2012. Source: Eurelectric (2013). Authors' own picture processing.



2.4 EV range problematic

One issue for EVs noted in several studies is the *range*, i.e. how far you can drive before you need to recharge the car battery. In Figenbaum and Kolbenstvedt (2013), several results from previous surveys between 2006 and 2011 are shown, which show the proportion of interviewees that claimed EV range to be a problem divided in various population groups and EV owners. It is evident that range is a significant problem for both types of groups. In the annual survey by the Norwegian Electric Vehicle Association, increased range was reported to be the most important factor for the increase of the EV market in the future (Norwegian Electric Vehicle Association, 2013). Further, in a 2014 survey of 10 percent of the Norwegian EV owners as respondents, charging infrastructure was ranked as the most central regional feature after nationwide benefits such as VAT and road-tax exemption (Haugneland, 2014).

The range issue consists of two factors: the car battery capability and the availability of charging points which make it possible to charge the EV in a convenient manner. A well-developed charging infrastructure makes it possible for owners of EVs to use their EV also for longer trips. This implies that every EV on the market drives more miles, which replaces miles driven by internal combustion vehicles (Figenbaum and Kolbenstvedt, 2013).

2.5 Charging infrastructure support

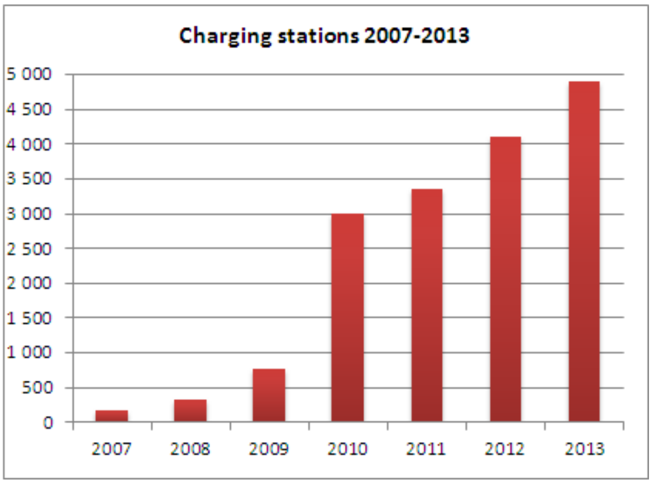
Investments targeting an expansion of charging points have been realized in Norway through the governmental Transnova programme, initiated in 2009. Transnova is formally organized as a part of the Norwegian Public Roads Administration aiming at supporting low greenhouse gas emission technology in the transport sector. In 2009, a NOK 50 million grant was approved to Transnova to support the development of charging points for electric cars and plug-in hybrids. The programme was to run over three years and provide financial support of up to NOK 30,000 for the establishment of charging points (Figenbaum and Kolbenstvedt, 2013).

Legal entities could apply to receive support, i.e. “all” except private individuals, and the funds were assigned to normal charging points that can be installed on a wall or on a charging post, which is similar to those used in household charging. With such a charging point, full charging of a car takes around 6 to 10 hours. Establishment of 1,820 normal charging points received financial support during 2009 and 2010 and all the points were in place before October 1st, 2010 (Center for International and Environmental Research, 2010).

When cars with fast-charge capability became available in early 2011, Transnova launched another support programme for fast chargers. Around NOK 15 million was granted for the establishment of 70 fast chargers between 2011 and 2013. Transnova’s contribution was limited to NOK 200,000 per point where the approximate cost of establishing a fast charging point in Norway ranges from NOK 0.5 to 1 million (Figenbaum and Kolbenstvedt, 2013).

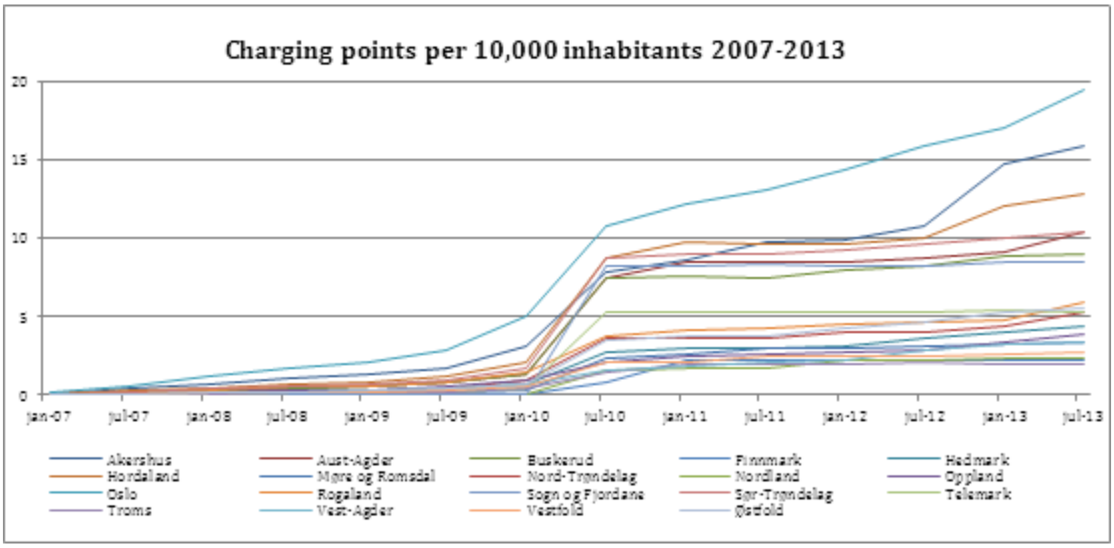
The Transnova support programme led to a massive increase in the total amount of charging points in Norway where the 1,820 normal charging points receiving support accounted for 80 percent of all the newly established points between 2009 and 2010. The establishment of the 70 fast chargers that received support during 2011 to 2013 only accounted for 4 percent of total established points during these years. The total number of charging points from 2007 to 2013 in Norway is shown in *Figure 2.4.2*.

Figure 2.4.1: Total number of charging points in Norway. Source: Data from Grønn Bil (2015). Authors' own picture processing.



A first-come-first-served principle without a geographic distribution plan was adopted in the Transnova programmes, which made the establishment of new charging points differ around Norway (Figenbaum and Kolbenstvedt, 2013). *Figure 2.4.3,* showing the amount of charging points per 10,000 inhabitants from 2007 to 2013, reveals that the number of charging points differs significantly between the regions.

Figure 2.4.2: Total number of charging points per 10,000 inhabitants on a regional basis. Source: Data from Grønn Bil (2015). Authors' own picture processing.



It is evident that most regions had very few charging points before the implementation of the Transnova. Post implementation, the amount of points differed notably among the regions. After 2010, the increase of points is modest in all regions with the exception of Oslo and Akershus, which is probably a result of independent infrastructure support programmes.

The significant increase of the number of charging points would have contributed to an easing of the range issue many associate with EVs, which would increase EV purchases. As the number of charging points differs regionally, it is expected that the amount of EVs differ, where higher EV registrations are to be found in regions that have been the frontrunner in the establishment of charging points.

3. Current state of knowledge of the impact of charging infrastructure on EV markets

Focus has primarily been on estimating the effect of financial incentives on the EV market comparing countries' tax subsidies and other monetary incentives such as fuel savings. Diamond (2009) and Gallagher and Muehlegger (2011) analyse the role of different type of incentives in the United States. Diamond (2009) finds a weak relationship between monetary incentives and market share, while he also finds that gasoline price has a large effect on hybrid electric vehicles. Contrary, Chandra et al. (2010) study the effect of tax rebates on hybrid electric vehicle sales in Canada and finds that 26 percent of EVs can be attributed to tax rebate and that there indeed was a crowding out effect of combustion vehicles. Gallagher and Muehlegger (2011) study the efficiency of state sales tax waivers, income tax credits and non-tax financial incentives and find that the type of tax is equally important as the level of subsidy. For example, sales tax waivers were found to be ten times more efficient than income tax reduction. There is no consensus on the actual effect of monetary EV policy in the current literature. At the very least, one can say that the debate is more on how large the effect is rather than the positive sign, and how to best utilize tax money for the optimal effect.

Some studies have assessed the cost effectiveness of policies targeting charging infrastructure. Schroeder (2012) looks at profitability of rolling out fast charging infrastructure in Germany at 2011 EV penetration rates, but not how the infrastructure affects the penetration *per se*. Policies in the United States currently include subsidies linked to EV battery capacity and charging installations aiming at reducing gasoline consumption. Peterson and Michalek (2013) compare the cost effectiveness of these incentives and find that it is preferred that more drivers to switch to hybrid electric vehicles and claim that charging infrastructure installations are more expensive than increased battery capacity per gallon gasoline saved.

Sierzchula et al. (2014) investigate EV adoption and the influence of various monetary initiatives, charging infrastructure and local presence of production across a series of 30 countries. The authors recommend policy to be a combination of monetary and infrastructural policy since the two are complementary and most effective when combined. The authors find that charging point infrastructure in fact is the most correlated with EV adoption across countries. Further, several survey-based studies investigating factors important for EV ownership have shown the importance of charging infrastructure. In the annual survey of EV owners by the Norwegian Electric Vehicle Association, increased range was reported to be the most important factor for the increase of the EV market in the future (Norwegian Electric Vehicle Association, 2013). Christensen, Nørrelund and Olsen (2010) studied the travel behaviour of potential EV drivers and the need for charging in Denmark. They showed that charging facilities are needed but only very few at each location and that fast charging infrastructure is important if EVs should be spread to more than a small share of the population. However, we question the validity of these results as the authors struggled with insufficient EV data and analyse data regarding the use of conventional cars instead.

Even if the *importance* of charging infrastructure on the EV market has been stated in previous studies, little attention has been given estimating *to what extent* charging infrastructure impacts the market. We believe one reason for this is the lack of data, both on EVs and charging infrastructure. In Norway, on the other hand, sales and registrations of EVs and established charging points are publicly available through Grønn Bil and The Norwegian Electric Vehicle Association, respectively, which have been implemented and maintained in cooperation with Transnova. Comparatively, Norway has one –accurate–publicly available source of all charging points nationwide, whereas for example Sweden relies on different websites such as www.uppladdning.nu and www.fortum.com. Furthermore, Grønn Bil provides monthly regional data for several years on sales and registrations of Norwegian EVs split by make and model and complete data on all established charging points, which from what we know is not available for any other EV market globally, complicating analysis in this field.

4. Research questions

4.1. Research questions and hypotheses

In this study our main focus is to *estimate the effect of charging infrastructure on the EV market on a regional level*. Our hypothesis is that *charging infrastructure has a significant positive effect on the EV market on a regional level*. We test this by using EV data from Norway, which is one of the leading EV markets globally to date, where charging infrastructure's impact on the demand of EVs is investigated in an environment with already strong policies targeting monetary incentives in place. A regional approach where all households face the same national monetary incentives allows for isolating the effect of regional infrastructure on EV registrations. We will also estimate the effect of other factors such as income, environmental awareness and traffic volumes on the EV market on a regional level. Our hypotheses are that income and environmental awareness have positive impact whereas traffic volumes have a negative impact on the EV market. The motivations for these hypotheses are found in Chapter 5.

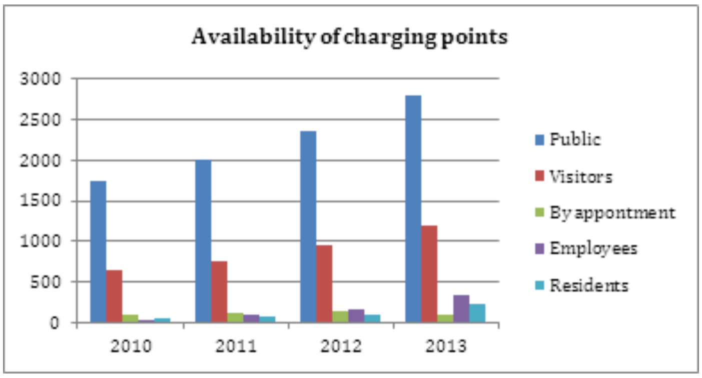
Our main results show how much charging infrastructure impacts consumers' EV demand. The results are of importance for policy decisions aiming at shifting the car fleet to become electrical to reduce carbon emissions.

4.2. Causality motivation

The below assumptions are important in order to investigate the impact of charging infrastructure on EV demand as they motivate causality between established charging points in Norway and EV registrations on a regional level.

Whether establishment of charging infrastructure improves the range faced by Norwegian consumers, which in turn may affect their EV demand, depend on the availability of the newly established charging points. In *Figure 2.4.4* we see the availability of charging points and since most charging points are public (e.g. street parking spaces or car parks) and for visitors (assumes site errand at shopping centre etc.), and not with restrictive access (for residents or employees only), all consumers can use the vast majority of the newly established points (NOBIL, 2015).

Figure 4.2.1: Availability of charging points by user type in Norway. Source: Data from NOBIL (2015). Authors' own picture processing.



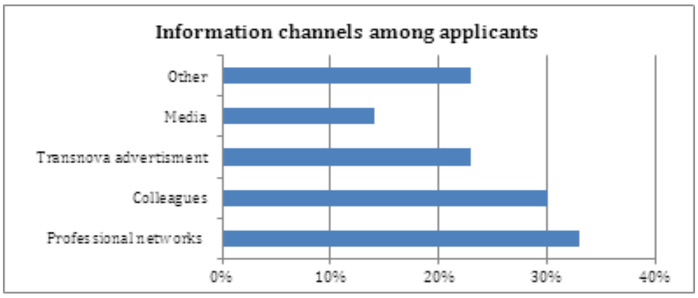
Assumption 1. The development of the charging infrastructure in Norway increased the accessibility of charging points for the average EV consumer, mitigating the technical range issue.

For normal charging points, which accounted for most of the newly established charging points, the usage is free of charge in all regions. Hence, a newly established normal charging point should have similar effects on consumers in all regions provided equal charging point density per square kilometre. However, the cost of charging at fast chargers differs slightly depending on location and operator (Figenbaum and Kolbenstvedt, 2013), which could lead to different effect on consumers among the regions. Nevertheless, as price differences are small, and as the number of established fast charging points in relation to normal charging points is very small, the difference in effect is probably negligible for the studied period.

Assumption 2. Charging infrastructure (per square kilometre) has the same effect on the average EV consumer in all regions.

Regarding the public awareness of the Transnova programme, Eva Solvi, Director of Transnova, stated that the Transnova programme was completely unknown in the market before implementation (Solvi, 2012). This implies that there is little risk that the population bought EVs on expectations about future expansion of the charging infrastructure. This argument is strengthened seeing to the results in an evaluation regarding Transnova information channels made two years after the launch of the Transnova, seen in *Figure 2.4.5.*

Figure 4.2.2: Information channels among Transnova participants. Source: Norway, Ministry of Transport (2010). Authors' own picture processing.



As only around 35 percent of the applicants in the evaluation answered that they had received information about the Transnova programme in media or through Transnova advertisement, the average Norwegian household were probably not fully informed of the implementation of the programme. This is strengthened by the fact that there was no geographical distribution plan in Transnova, making it difficult to predict where and to whom the support was being granted.

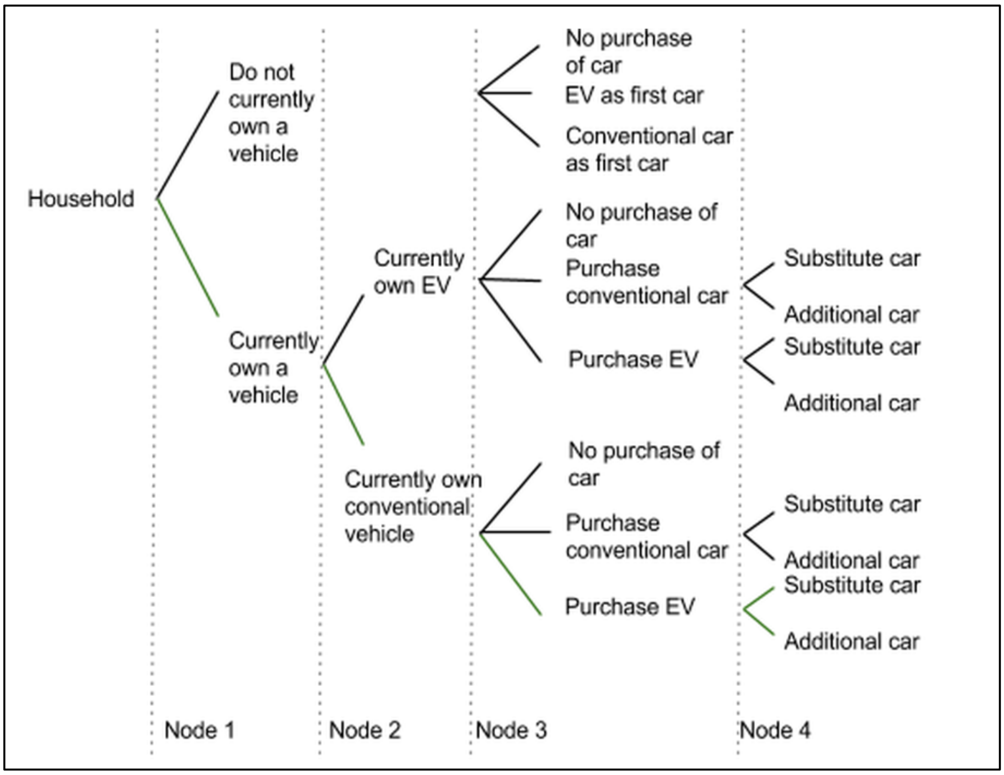
Assumption 3. The general knowledge of where the charging points were to be established through the Transnova programme was low among the average Norwegian households.

Taking the above assumptions into consideration, it is reasonable to believe that the established charging infrastructure had the largest effect on EV registrations *ex post*. The alternative would be if the effect would be *ex ante*, hence affect the EV registrations before the establishment; however, for this to happen, consumers would have to be informed beforehand of the exact locations of where the points would be established, which does not apply in this case. It is more reasonable to believe that the consumers were affected by the establishment of charging infrastructure with a time lag.

5. EV purchase decision

In order to understand what has driven the market growth of EVs in Norway it is important to understand the characteristics of Norwegian household mobility and micro-level choices of a consumer. We look at households' demands of individual mobility, which can be met in various ways, shown by the logic tree below. By analysing the choices they make we can identify what factors are important for the vehicle purchase decision and hence the development of the EV market. This serves as basis for the motivation of included variables in the later specified regression estimating the effect of charging infrastructure on EVs on a regional level.

Figure 5.1.1: The choices faced by households satisfying their demand for individual mobility. Authors' own picture processing.



Node 1. At Node 1, households' choose to meet their individual mobility demand by owning one, multiple or zero vehicles. Regarding households' demand for mobility, average vehicle kilometres driven per household have decreased slightly by 2.9 percent from 2007 to 2013 (Statistics Norway, 2015). As household size has diminished only slightly, the changes on households' kilometres driven are small enough to be argued that their demand for individual mobility has been constant during the period. If owning zero vehicles, households meet their mobility demand through more or less environmentally friendly alternatives such as public transportation, biking, electric biking or by walking. The distribution of car ownership is displayed in *Table 5.1.1*.

Table 5.1.1: Distribution of household car ownership. Source: Data from Vågane et al., (2011). Authors' own table processing.

Number of cars in household	1992 (%)	2001 (%)	2005 (%)	2009 (%)
0	15	15	13	15
1	53	52	48	43
2	27	28	32	34
3 or more cars	5	5	7	8
Sum	**100**	**100**	**100**	**100**

A total of 15 percent of all households in Norway do not own a car, 85 percent of all households thus own at least one vehicle (Vågane et al., 2011). For the purpose of this study, as share of households owning no cars has been constant during the time period studied, we are focusing on households holding one vehicle or more.

Node 2. At Node 2, households that choose to meet their demand of individual mobility by owning a vehicle choose between owning a conventional car or an EV as their first vehicle. Recent studies conducted by the Norwegian Institute of Transport Economics (TØI) show that only 3 percent of EV owners report the EV to be the only vehicle and in Figenbaum and Kolbenstvedt (2013, table 21) we see that a small fraction, 7 to 9 percent, of households owning EVs in 2009/2012 consists of having one vehicle; something also supported in Econ (2006), Vågane et al. (2011), Rødseth (2009), Haugneland (2012) and Mitsubishi (2012). This implies that the vast majority of EV owners own one or more conventional cars prior to the EV purchase, which is expected due to the early range constrictions of EVs (Figenbaum and Kolbenstvedt, 2013). Further, the EV share of total registered cars of all fuel types has been, and is still, fairly low (0.08 percent in 2008 compared 0.73 percent in 2013, Statistics Norway). In conclusion, the vast majority of households owning vehicles own a conventional vehicle as their first vehicle.

Node 3. At node 3, the household owning one conventional vehicle chooses whether to purchase an additional car (EV or conventional) or not purchase an additional car. Seen in *Table 5.1.1*, there is an increasing trend in owning more cars per household. This is strengthened by Statistics Norway that reports that the total vehicle stock has increased by 16.1 percent. As the number of households has increased by 9.4 percent (Statistics Norway, 2015), households own more vehicles in 2013 compared to 2007 on average. In other words, the households are meeting their demand for individual mobility with more cars on a regional level.

The question is what *factors* drive households to purchase an EV instead of a conventional car. This is an important step as by identifying these factors we can motivate the choice of variables included in our regression estimating the effect of charging infrastructure on EVs on a regional level.

In a survey based study made by Haugneland and Kvisle (2013), 41 percent of their sample answered that saving money was the most important reason why they choose to purchase an EV. In Norway, several monetary incentives have been introduced in recent years with the aim to incentivize customers to purchase EVs instead of conventional cars. In 2001, a purchase VAT exemption on EVs was introduced where the VAT on motor vehicles are 25 percent in comparison (0 percent on EVs). Since price is one important factor in consumers' vehicle purchase decision (Halsør et al, 2010), this incentive has most likely affected households in their decision whether to purchase an EV or a conventional vehicle. Without the incentive, the cost of an EV was much higher than a conventional car, especially the earlier models introduced on the market, but with the incentive the electric car purchase price was made competitive with the price of conventional cars due a converging retail price facing consumers (Figenbaum and Kolbenstvedt, 2013). Additionally, in 2004, the annual motor vehicle tax on EVs was heavily reduced where the annual amount in 2013 was NOK 465 for EVs compared to NOK 3,190 for a motor vehicle (<7,500 kg) and NOK 3,675 for a diesel car without filter (Directorate of Customs and Excise Norway, 2015). Also free public parking and exemption of road tolls have been introduced for EVs. Taking all the monetary benefits into account, Grønn bil estimates that the benefit on an annual basis of owning an EV instead of an electric hybrid such as Toyota Prius in Oslo is estimated at USD 3,336 per car (Hannisdahl, 2013). This figure is rather large, possibly explaining the very low number of registered hybrids in Norway.

Besides all the monetary incentives described above, the fact that you avoid the high price on gasoline most likely incentivizes households to purchase an EV instead of a conventional car. The gasoline price has been shown to have an impact on the demand for cars where Li, Timmins and von Haefen (2009) and Klier and Linn (2010) show that higher gasoline prices shift the demand towards cars with higher fuel economy, i.e. more fuel efficient vehicles. It is then possible to believe that higher gasoline prices also increase the demand for EVs, even though no study has yet proved this. Logic reasoning would be that the cost of charging an EV, i.e. the electricity price, also has an effect on EV sales.

In 2005, EVs were allowed to drive in bus lanes. During rush hours, this saves time for the EV driver and hence it is reasonable to believe that the introduction of this rule boosted the EV market. This argument is strengthened in Haugneland and Kvisle (2013) where 22 percent of the sample claimed "saving time" was an important criterion for purchasing an EV.

Income has been included in previous literature studying the demand for cars (Li, Timmins and von Haefen, 2009, and Klier and Linn, 2010) but that income would explain the distribution between rechargeable and non-rechargeable cars has not been clearly stated. However, income distribution could be an important factor in households' vehicle purchase decision as income probably differentiates early and late buyer/adopter groups (Infrastruktur for ladbare biler i Akershus, Hedmark, Oppland og Østfold, 2012). Also, it is rational that income levels matter for additional purchases of cars, and we know that EVs are often purchased as additional cars. Further, as the first EV models introduced in the market were more expensive than conventional cars, it is reasonable to believe that high-income households were more eligible to purchase an EV than households with low-income households.

The opportunity to influence their own individual environmental impact has been shown to be an important feature why people choose to purchase EVs instead of conventional cars. In some Norwegian studies, EV owners have been proved to be more environmentally aware than investigated cross-section samples of the population. (Figenbaum, 1994; Figenbaum and Kolbenstvedt, 2013). Statoil Fuel and Retail/Response (2012) found that 62 percent thinks the environment is important for future selection of transportation when asking a cross-section population in Norway. A study conducted by the Electric Vehicle Association shows that 38 percent of its members choose the environment as the reason of why they choose to purchase EVs (Haugneland, 2012).

Due to range restrictions of an EV, the distance between charging points is essential for an EV owner as scarcely accessible charging points restrict EV owners' usage of their EVs to a large extent. This is stated in several previous studies, described in more detail in Chapter 2.4, where both EV owners and various population groups claim EV range to be a problem. Hence, how well the charging infrastructure is developed in a households' neighboring area most likely matters in the decision whether to purchase a conventional car or an EV.

The driving range issue is made up by both poor car battery capabilities and scarcely available charging points. The EV models introduced later on in the Norwegian market have made large technical advancements, which have reduced the range issue and most likely impacted households' purchase decision in favour of EVs. The range issue faced by EV owners also depends on their driving distances where drivers who drive long distances have more evident range issues than those who drive short distances as they need to charge their EVs more frequently.

Another factor that affects households' purchasing decision is the increasing media coverage of EVs through the mechanisms of recognition as well as social image of owning an EV. The media coverage of EV technology in Norway, with the keyword "*elbil*" (translates into electrical car), has increased more than six fold in the period 2007 to 2013. In 2013, printed media had 1,641 mentions of electrical cars, while online media had 3,967 mentions (Retriever, 2015).

Node 4. At Node 4, households purchasing an EV choose whether it should be an additional vehicle or substitute another vehicle. There is no consensus in previous studies whether EVs work as substitutes of conventional cars or as additional cars. A survey of car use done by TØI in 1993 found that 77 percent of those living in urban areas would consider an EV as an additional vehicle (Ramjerdi et al. 1996); a result in line with that found by Kløckner (2013) whose results indicated that most EV purchases give an additional vehicle and do not substitute another vehicle. However, a study conducted by TØI in 2014 show that 69 percent of the EVs in households replaced other vehicles and in 28 percent of the cases the EV was an additional car. This provides evidence that the intentions and use of EVs have changed the past couple of years for the owners; probably as the range issue has eased for EVs.

Given that household need for individual mobility is constant, the increased number of EVs owned by households leads to less carbon emissions in total on a household level as they replace kilometres driven by conventional cars. The effect of EVs substituting conventional cars is a 1:1 substituting effect and the EVs used as additional cars may have a more partial effect where households use EVs for shorter trips and conventional cars for longer trips (due to potential range restrictions of EVs). There is little current knowledge on the exact utilization degree of an EV to be found in the literature. In either case, lower carbon emissions from households are attained, which is desirable from a policy point of view aiming at reducing carbon emissions.

6. Empirical framework

Given the EV purchase decision, in this chapter we explain which variables we include and describe the data we are using. We also specify our regression and the empirical strategy we choose to answer our research questions.

6.1 Variable description

In *Figure 2.2.1*, we note that there are large differences in EV ownership on a disaggregated level in Norway and expect that the variation in the charging infrastructure throughout the country explains a large share of this difference. We choose to include charging points per square kilometres in our regression where we expect to find a positive relationship between the number of charging points and number of EVs on a regional level.

Income is included as a variable as it likely impacts households' EV purchase decision and also varies on a disaggregated level throughout the country. We choose after-tax income since tax levels vary significantly on regional basis and expect that higher income leads to more registered EVs.

As we expect that households that are more aware of the environment tend to purchase more EVs than households that are less environmentally friendly, we include recycling rates per household in the regression. While one might think of other more suitable variables capturing pro-environmental preferences (e.g. green party representation within regions, public spending on environmental efforts, or household purchases of nearby farmed foods) many of these are unsuitable for Norway or there is no data available on disaggregated level. For instance, the Green Party on municipality level only attracted 0.3 percent of voters and the share has been constant since first running in the 1991 elections (Statistics Norway, 2015). Other variables, like data on household spending on environmentally grown crops or other consumer goods, are not available. However, even if such data would be available, it is not possible to say that those variables would be a better estimate of pro-environmental preferences than recycling rates. Ideally, we would like to see a revealed environmental preference survey on households on regional level, but as no such study has been made we use recycling rates. On a weakening note for the use of recycling rates is that while recycling is free in Norway, conventional waste management is subject to fees: the variable could capture household sensitivity for conventional waste collection costs instead of increased environmental preferences.

We choose to include a variable in the regression representing the regional traffic volumes for passenger cars and expect to find a negative relationship between the variable and ownership of EVs as the range problematic increases for EV owners who drive long distances.

Figure 6.1.1 shows the EV model distribution in Norway December 2013 where five models (Mitsubishi i-MiEV, Nissan Leaf, Peugeot i-ON, Tesla S and Citroën C-Zero) accounted for a large market share (77 percent). The remaining 23 percent consisted mostly of models introduced early on in the market (Think, Buddy Electric, etc.). The model characteristics are shown in *Table 6.1.1*. It is notable that the five dominating models introduced between 2011 and 2013 are better than previous models in terms of the estimated range, maximum speed level and motor power. Also, the price level is lower or around the same level as the previous models. As the range issue connected to EVs is significantly lower for owners of these five models compared to previous models, the introduction of these probably had a positive effect on EV purchases. We therefore include model dummies representing the time the models were introduced in the Norwegian market to capture this effect. Besides range, these dummies control for factors such as reliability, driving characteristics, design and price: factors that have been valued high when considering purchasing a new car (Ramjerdi et al 1996). The dummies also control for road safety and size, which have been proved to be of importance for EV purchases (Figenbaum and Kolbenstvedt, 2013).

Figure 6.1.1: The make and model distribution of all registered EVs in Norway in December 2013, cumulative numbers. Source: Data from Grønn Bil (2015). Authors' own picture processing.

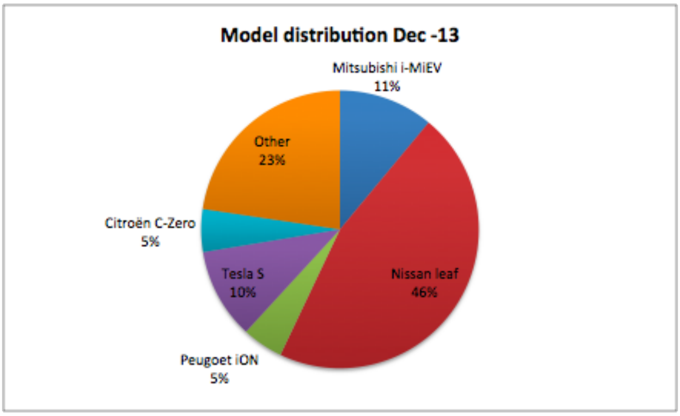


Table 6.1.1: EV model characteristics. Source: Norsk elbilforening (2015). Authors' own table processing.

Model	Price (NOK)	Motor power	Maximum speed (km/h)	Acceleration 0-100 km/h (sek)	Battery capacity (kWh)	Estimated range (km)	Introduced on market	Number registered Dec 2013
Citroën C-Zero	139900	47 kW / 64 hk	130	15,9	16	80-160	Apr 2011	981
Mitsubishi i-MiEV	143900	47 kW / 64 hk	130	15,9	16	80-160	Jan 2011	2171
Peugeot iOn	139900	47 kW / 64 hk	130	15,9	16	75-150	Apr 2011	938
Nissan Leaf	205850	80 kW / 109 hk	144	12	24	76-233	Oct 2011	9058
Tesla Model S	from 466800/528800/613600	285 kW / 387 hk	190-210	4,4-6,2	60/85	270-360/360-480	Aug 2013	2075
Others								*4455*
Byddy Electric	173700	13 kW / 18 hk	80	n.a.	14,4	80	2007	
Think	244000	24 kWh	110	n.a.	24	160	2008	
Peugeot 106	n.a.	n.a.	90	n.a.	n.a.	80-100	1995	

We assume that the monetary incentives (VAT exemption, free public parking, toll exemption and lower yearly taxes) implemented in Norway on a national level have had similar effects on the EV market throughout the country. Also, as the gasoline and electricity prices are rather similar throughout the country, we expect fluctuations in these, and the impacts on the EV market they result in, to be the same on a national level. Hence, we choose not to include these in the regression, as they do not explain the differences in EV ownership on a disaggregated level.

As for the permission to drive in bus lanes, we expect the effect has been rather small on the EV market throughout the country except in Oslo and Akershus where the effect has been more significant as the commuters in these areas face the largest rush hour delays in Norway (Figenbaum and Kolbenstvedt, 2013). However, since the bus lane permission and the monetary incentives were introduced before our dataset, and not changed during the time period studied, we will not include this in the regression.

Media coverage could influence EV ownership but since media is anything but regional in 2013, we argue that we cannot include for example regionally printed mentions of EV cars in the regression. Also, it would be capturing too little of the total media coverage of the industry and model development looking at the large number of online media mentions (Retriever, 2015).

Below is a short description of the data variables used in the regressions as well as a summary table.

Table 6.1.2: Variable description

VARIABLE NAME	VARIABLE LABEL
EV	Number of registered EVs per 10,000 households
Infrastructure	Number of EV charging points per regional square kilometer area
lIncome	Log average income per household after tax (NOK)
Recycling	Percentage of households' waste sent to recovery
lTrafficVolume	Log monthly regional aggregated traffic volumes for passenger cars (million kilometer)
iMiEV	Dummy for the introduction of Mitsubishi iMiEV
Leaf	Dummy for the introduction of Nissan Leaf
Czero_iON	Dummy for the coinciding introduction of Citroën C-Zero & Peugoet iON
S	Dummy for the introduction of Tesla S

Table 6.1.3: Variable summary

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
EV	1,596	58.79	1,751	0.0974	70,000
Infrastructure	1,596	0.0707	0.337	2.06e-05	2.907
Recycling	1,596	74.64	11.27	29	90
lTrafficVolume	1,596	3.365	0.301	2.646	3.640
iMiEV	1,596	0.429	0.495	0	1
Leaf	1,596	0.321	0.467	0	1
Czero_iON	1,596	0.393	0.489	0	1
S	1,596	0.0595	0.237	0	1

6.2 Data

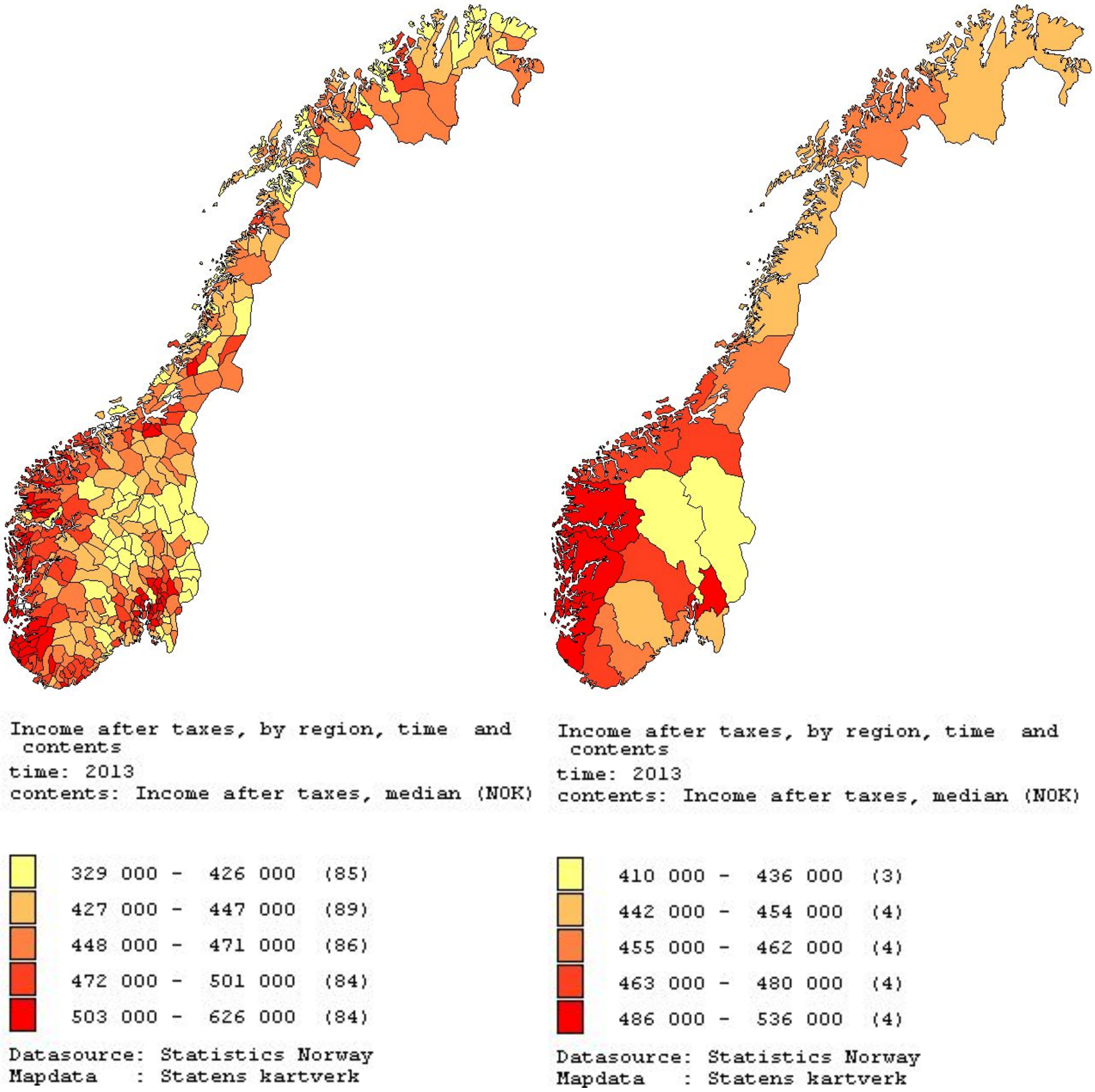
The primary data source contains registered EVs by make and model and established EV charging points in all regions in Norway on a monthly basis from 2007 to 2013. The data is gathered from the Norwegian governmental institution Opplysningsrådet for Veitrafikken AS database "Bil- og veistatistikk" through the website of Grønn Bil, a project owned by Transnova. All other data such as number of households, income, recycling rates and road traffic volumes is gathered from Statistics Norway.

Data for 2014 is not included due to shortage of controls (for example in income and in the regional distribution of fast chargers). It would have been optimal to also include 2014 as the EV fleet more than doubled in 2014 with competitive developments in the price level of Tesla S as well as a rapid development of the fast charging network during the year as driving factors. Time wise, the panel-data is collected on a monthly basis, which is ideal as the monthly variations capture the seasonal effects that occur as car purchases vary substantially throughout a year.

Considering households' driving pattern motivates the choice of regional data. We argue that households probably not exclusively drive within their municipality but also drive in the surrounding area; hence, it is not only the charging infrastructure in the households' municipality that matter in the purchase decision but also the possibility to charge in surrounding areas. Thus, we use charging infrastructure on a regional level instead of municipal level for more accurate results.

The 19 regions in Norway consist of 423 municipalities as of March 2013, with the municipalities Frei and Mosvik both consolidated into other municipalities in the period of 2007 to 2013. While the regions are different from one another, there are also differences within regions, which could possible bias our results. In *Figure 6.1.2*, the median of regional and municipal after-tax income levels are illustrated.

Figure 6.2.1: Median of regional and municipal after-tax income levels in 2013. Source: Statistics Norway (2015)



We see that after-tax median income brackets, from the lowest 20 percent to the highest 20 percent, which we have argued to be an important factor in households' EV purchase decision, differ somewhat between municipalities within the regions. However, we do not see that the regions are highly income diverse: there are differences, but this study assumes that the regions are representative of its municipalities and that there are not any considerable income gaps and hence differences in purchasing pattern within any particular region itself.

6.3 Regression specification

We will estimate the effect of the specified variables on EVs per 10,000 households by running an OLS model. However, between the regions, it is likely that there are time independent unobservable effects that are possibly correlated with the regressors. Such effects might arise from political traditions, industry history or other aspects that influence predictor values for the dependent variable (EVs on a household level per region). In this case, a fixed effects model could be appropriate to use, but one important assumption for this model is that the time-invariant characteristics are unique to the individual and is not correlated with other individual characteristics. This means that the regional error term and the constant capturing individual characteristics should not be correlated with other regional ones. We test this with the Hausman test, which tests the null hypothesis that the unique errors (u_i) are correlated with the regressors (random effects). We reject the null hypothesis and thus reject modelling the relationship with a random effects model. Hence, besides the OLS model, we apply the data to a fixed effects model to remove the effect of time-invariant characteristics, which is specified below.

$$EV_{it} = \beta_1 Infrastructure_{it} + \beta_2 lIncome_{it} + \beta_3 Recycling_{it} + \beta_4 lTrafficVolume_{it} + \beta_5 M_{it} + \alpha_i + u_{it}$$

$$for\ t = 2007M1, \ldots, 2013M12\ and\ i = 1, \ldots, 19$$

$EV_{it} = Number\ of\ registered\ EVs\ per\ 10,000\ households$

$Infrastructure_{it} = Number\ of\ charging\ points\ per\ regional\ square\ kilometer\ area$

$lIncome_{it} = Log\ average\ income\ per\ household\ after\ tax\ (NOK)$

$Recycling_{it} = Percentage\ of\ households'\ waste\ sent\ to\ recovery$

$lTrafficVolume_{it} = Log\ monthly\ regional\ aggregated\ traffic\ volumes\ for\ passenger\ cars$
$(million\ kilometers)$

$M_{it} = Model\ dummies$

$$where\ i\ is\ the\ region,\ t\ is\ the\ month,\ \beta_1 - \beta_5\ are\ coefficients,\ \alpha_i\ is\ the\ unobserved\ time-invariant\ individual\ effect$$

We test for heteroscedasticity with the Wald test for group wise heteroscedasticity in the fixed effect regression model. We reject the null hypothesis of homoscedasticity (constant variance in the error term) and conclude that there is a presence of heteroscedasticity in our data. Furthermore, as we suspect the error terms within regions to be correlated, i.e.

$E(u_{it}u_{is}) \neq 0$ for all $s \neq t$, we conduct a Wooldridge test for autocorrelation in panel data. The null hypothesis of no serial correlation is strongly rejected. To mitigate the serial correlation we use an example of Eicker-Huber-White-robust treatment of errors by including ‘clustered errors’, which keeps the assumption of zero correlation across groups (as with fixed effects), but allows the within-region correlation to be anything at all. As discussed by Baltagi (2001) and Wooldridge (2002), clustering at the panel level will produce consistent estimates of the standard errors. Since clustered errors imply robustness, using clustered errors treats both serial correlation and heteroscedasticity.

We will run the OLS model both with and without model and regional dummies and the fixed effect model described above both with and without model dummies and time-fixed effects. We expect that the infrastructure coefficient will decrease when the model dummies are included, as the new model introductions on the market mitigated the range issue of EVs. Time-fixed effects are included to take into consideration time-series variation of the dependent variable explained by time trends or other time series patterns, i.e. seasonality or price trends.

7. Results

The following section includes the regression findings of this study, including robustness checks.

7.1 Primary Results

The results from the OLS and fixed effects regressions are shown in *Table 7.1.1*. As argued above, the error terms are clustered to produce consistent estimates of the standard errors.

Table 7.1.1: Primary result from the OLS and fixed effect models

VARIABLES	(1) OLS	(2) OLS	(3) Fixed Effects	(4) Fixed Effects	(5) Fixed Effects
Infrastructure	21.08***	16.68***	18.68***	16.22***	14.93***
	(2.294)	(3.443)	(3.353)	(3.123)	(4.231)
lIncome	144.2***	97.68	216.7***	72.19***	-206.0
	(38.29)	(56.36)	(74.40)	(22.00)	(380.3)
Recycling	-0.0269	-0.495	-0.508*	-0.451*	-0.610
	(0.118)	(0.296)	(0.268)	(0.269)	(0.422)
lTrafficVolume	3.109	-152.3	-319.6	1.375	-104.2
	(3.768)	(267.5)	(282.1)	(6.031)	(380.1)
Constant	-1,876***	-699.8	-1,699***	-904.7***	3,097
	(499.6)	(407.3)	(494.8)	(271.8)	(5,354)
Observations	1,596	1,596	1,596	1,596	1,596
R-squared	0.539	0.772	0.478	0.603	0.658
Model dummies	NO	YES	NO	YES	YES
Region dummies	NO	YES			
Number of Regions	19	19	19	19	19
Regional FE			YES	YES	YES
Time FE			NO	NO	YES

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

In the model specifications, we see that one additional charging point per regional square kilometre gives an increase of between 15 to 21 additional EVs per 10,000 households. The estimates in all five specifications are significant at the 1 percent level, of the expected positive sign as well of reasonable magnitude. Hence, the main hypothesis holds: *An increased number of charging points per regional square kilometre has a positive and significant effect on EVs on regional level.* The R-squared increases when model dummies are introduced both in the OLS and fixed effect model. The explanatory power also improves when introducing time-effects in the fixed effects model. As expected, the infrastructure coefficient decreases slightly when the model dummies are introduced in both the OLS and the fixed effects model, indicating that the range issue was mitigated when the new models were introduced in the market, decreasing the need for charging infrastructure slightly.

After-tax income, which we predicted to have a positive effect on EV registrations, is of expected positive sign and significant at the one percent level only for the OLS excluding model and region dummies and the fixed effects models excluding time-fixed effects. The interpretation is that a one percentage increase in households' average income leads to an increase of 72 to 217 registered EVs per 10,000 households. We see that the coefficient decreases for both the OLS and the fixed effects model when including model dummies. As seen in *Table 6.1.1*, the new models introduced in the market had both better range and lower price than the previous models that dominated the market and hence the introduction of the new models probably made income a less important factor for an EV purchase. Including time-effects in the fixed effects model gives a negative sign of the income variable (but not significant at the 10 percent level). An interpretation could be that there is a time-trend of converging prices of EVs and conventional vehicles during our time period, making high income less important for households to choose an EV instead of a conventional car.

Our hypothesis that higher environmental awareness has a positive effect on EVs on regional level does not hold, seen to the results. The sign of the recycling variable is slightly negative in all specifications and only significant at the 10 percent level in the two fixed effects models excluding time-fixed effects. We argue that the negative sign and weak significance for recycling stems from that there is a weak connection between pro-environmental behaviour and purchasing an EV. Although environmental concern has been reported to be a strong contributing factor in many EV surveys amongst households, these reported answers might be suffering from framing issues as well as the pressure for respondents to have the “right” incentives where environmental concern might be more politically acceptable than economic or convenience preferences. It could also be the case that recycling is a poor proxy for environmental preferences of households.

Looking at traffic volumes, where our hypothesis was to find negative correlation between kilometres driven and EV registrations, we find ambiguous signs of the coefficient and no significance in any model specification. This result indicates that households’ driving patterns do not have an effect on the number of registered EVs. The prior knowledge that EVs are primarily bought as additional vehicles might be an explanation as then households primarily substitute shorter ranged travel with EVs, while use conventional vehicles for longer trips. Hence, the range issue does not become more severe for households that have large traffic volumes.

7.2 Robustness checks

The following section includes the set of robustness checks for this study.

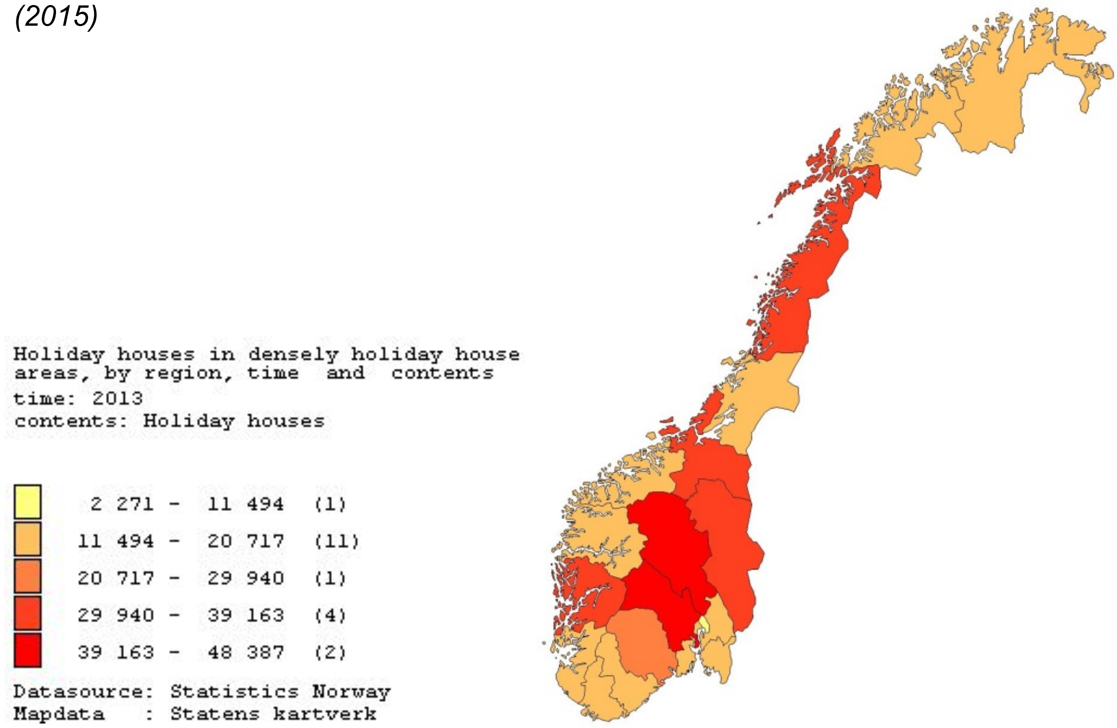
7.2.1. Subset of regions

For robustness reasons, we perform the same analysis on a subset of regions. By doing this we estimate whether charging infrastructure’s effect on EVs on a national level, shown in *Table 7.1.1*, differ from that of a subset. Hence, we test if our assumption 2 holds, namely if charging infrastructure (per square kilometre) has the same effect on the average EV consumer in all regions.

Figure 7.2.1: Subset of regions. Authors' own picture processing.

We run the regressions on all regions excluding the northern and middle regions, seen in *Figure 7.2.1*. This is done as the median income (see *Figure 6.2.1)* is more homogenous within regions in the subset compared to the excluded regions. Also, it is more plausible that the southern regions have closer cross-regional ties in terms of household mobility patterns. A large share of commuters, which have longer travel distances compared to the average in the population (Figenbaum and Kolbenstvedt, 2013), lives in the proximity of Oslo, with Akershus-Oslo being the most common commute distance. The concentration of large highways is also higher in the southern regions, making a higher share of cross-regional mobility possible. Furthermore, second homes and other types of private accommodation is the most common domestic choice for holiday accommodation in Norway (Statistics Norway, 2015), where a clear majority of holiday homes is located in the southern regions (See *Figure 7.2.2*). Taking this into consideration, it is not possible to argue that inhabitants of the oblong northern parts of Norway would to a larger extent travel by automobile to other regions for work or leisure purpose.

Figure 7.2.2: Holiday houses in Norway by region in 2013. Source: Statistics Norway (2015)



The results from the subset regression are shown below in *Table 7.2.1.*

Table 7.2.1: Subset result from running OLS and fixed effect models

VARIABLES	(1) OLS	(2) OLS	(3) Fixed Effects	(4) Fixed Effects	(5) Fixed Effects
Infrastructure	20.88***	16.95***	16.15***	16.95***	18.25***
	(2.214)	(4.233)	(4.261)	(4.208)	(4.847)
lIncome	183.5***	137.9*	247.6**	137.9*	-325.0
	(51.64)	(67.59)	(94.28)	(67.18)	(557.1)
Recycling	-0.175	-0.376	-0.483	-0.376	-0.426
	(0.162)	(0.390)	(0.354)	(0.388)	(0.560)
lTrafficVolume	5.346	-303.6	-238.8	-303.6	-433.5
	(4.641)	(391.2)	(369.9)	(388.8)	(482.3)
Constant	-2,386***	-668.6	-2,388**	-753.9	5,728
	(665.9)	(795.8)	(879.4)	(693.3)	(7,531)
Observations	1,092	1,092	1,092	1,092	1,092
R-squared	0.605	0.793	0.521	0.622	0.690
Model dummies	NO	YES	NO	YES	YES
Region dummies	NO	YES			
Number of Regions	14	14	14	14	14
Regional FE			YES	YES	YES
Time FE			NO	NO	YES

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

In line with the primary results including all regions, we see that charging infrastructure per regional square kilometre has a positive and significant effect on EVs per 10,000 households also on a subset level, here with a magnitude of 16 to 21 EVs per 10,000 households. This is in line with the results including all regions where the magnitude was 15 to 21 EVs per 10,000 households. Recycling is insignificant in all specifications, strengthening past arguments made on the variable suitability in the primary results. The same holds true for road traffic volumes. The magnitude of the income estimates is slightly larger in this subset for a natural reason: 1 percent increase of the median after-tax income in the southern region gives a higher purchasing power than in the northern regions, due to higher absolute median wages in the southern regions.

As the results from the subset of regions are in line with the primary results including all regions, the assumption that charging infrastructure has the same effect on the average EV consumer in all regions is strengthened, which is important from a policy perspective.

7.2.2. Time-fixed effects

Fixed effects models estimate the change of the dependent variable for a one unit (or one percentage for the lagged variables) increase in the explanatories controlling for unobserved regional level heterogeneity. Not included in the specification is time-series variation of the dependent variable explained by time trends or other time series patterns, i.e. seasonality. We would like to know if there are any such time trends present in the data as it would indicate which one of the fixed effects regression specifications is the most accurate. We conduct a joint test testing of whether all the time dummies for all months are equal to zero and find that we can reject the null hypothesis that the coefficients for all months are jointly equal to zero. Therefore, the fixed effects regression specification that includes time-fixed effects, named Fixed Effects (5) in the result tables, is the most appropriate. Seen in both *Table 7.1.1* and *Table 7.2.1*, this indicates that charging infrastructure has a positive and significant effect on registered EVs on a regional level whereas income, recycling and traffic volume do not have a significant effect.

7.2.3. Lags on charging infrastructure

It is possible that newly established infrastructure has a delay on EV registration due to public awareness delays and delay from ordering a car to the registration of that same car (manufacturing, delivering, etc.). Lags could also serve as a correction for any potential extraordinary waiting times for EV models, where the maximum waiting time for Tesla S in 2013 was five months. Thus, we include lags for established charging points in the fixed effects model including model dummies and time-fixed effects, Fixed Effect (5) in *Table 7.1.1*, as this specification is proved to be the most accurate. The results with a 1 to 6 month lag can be seen in *Table 7.2.2.*

Table 7.2.2: Fixed effects model with a 1 to 6 month lag of the established charging infrastructure

VARIABLES	(1) Fixed Effects	(2) Fixed Effects	(3) Fixed Effects	(4) Fixed Effects	(5) Fixed Effects	(6) Fixed Effects	(7) Fixed Effects
Infrastructure	14.93***						
	(4.231)						
l1infskm		15.29***					
		(4.275)					
l2infskm			15.64***				
			(4.320)				
l3infskm				16.02***			
				(4.371)			
l4infskm					16.39***		
					(4.427)		
l5infskm						16.77***	
						(4.493)	
l6infskm							17.15***
							(4.539)
Constant	3,097	3,001	2,998	2,883	2,806	2,716	2,612
	(5,354)	(5,269)	(5,331)	(5,246)	(5,232)	(5,218)	(5,207)
Observations	1,596	1,577	1,558	1,539	1,520	1,501	1,482
R-squared	0.658	0.658	0.658	0.658	0.658	0.657	0.657
Number of Regions	19	19	19	19	19	19	19
Model dummies	YES	YES	YES	YES	YES	YES	YES
Regional FE	YES	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We see that one additional charging point per regional square kilometre give an increase of between 15.3 to 17.2 additional EVs per 10,000 households, where the charging points are lagged with 1 to 6 months. This is a slightly larger estimate than the original model specification without a lag where the effect is 14.9 EVs per 10,000 households. The standard errors increase when introducing lags and the R-square decreases, indicating that the original model without lags is the best fit. Some of the increase in standard errors could stem from the fact of decreasing the sample size when introducing a higher order of lag. As for the magnitude of estimate is concerned, we know that by lagging a continuously increasing variable, which number of charging points is, it is only natural that the estimate is increasing as well. Hence, any lags would not necessarily capture any consumer delay in purchasing patterns. While there is little evidence that the wait times for EV models in general were longer in the period 2007 to 2013, this study recognizes that there might be downward skewedness in the results of model introductions on EV sales, for example in late 2013 and the case of Tesla S and its wait list, but that such a skewedness does not motivate using lags of infrastructure to the cost of lost observations.

7.2.4. Fast charging

One might be concerned that the effect from normal and fast charging points differ but since the number of fast chargers at the end of 2013 was still very low in comparison to normal chargers (70 fast chargers versus almost 5,000 normal chargers); we argue that this effect is negligible in this study. We, however, run the regression separating the normal charging points from fast charging points to test this but since the variables suffer from strong collinearity (75 percent) the model gives inaccurate results. Hence, a model separating the fast chargers from the normal chargers does not give more accurate result than the one aggregating the two types, as we have done in this study.

It might be possible, perhaps also suitable, for future research on 2014 and newer data to try to separate the different types of chargers since at least the 2014 fast charging developments has been much greater in magnitude than previous years.

8. Policy discussion and external validity

The findings in this study provide important insights into the electrification of the vehicle fleet of a country. But let us first remind the reader that an EV is only as environmentally friendly as the power source that fuels it: a modern diesel car with particle filter can be more environmentally friendly than an EV if the country has a high share of e.g. coal in its energy mix. Hence, the first policy implication is that electrification policies are desirable when the national energy mix is low in greenhouse gases emissions. This is important for policy makers for example on a European level to consider when setting future emission standards of individual countries.

Electrification policies are often of the monetary kind with tax reductions in different forms. We argue that fairly equal prices facing households for EVs and conventional cars are essential for reaching considerable EV holding, but that policies targeting monetary incentives will not alone lead to considerable electrification of a country's vehicle fleet. We argue, in line with Sierzchula et al. (2014), that relationship between monetary EV policies and convenience policies are symbiotic with regards to the end-result: increased EV adoption in a country. As long as there is no fully developed infrastructure for EVs or fully converged retail prices between EVs and conventional cars, there is a need for governmental intervention of both forms. With technological advancements in manufacturing and increased EV competition, the retail prices are likely to converge, which will make monetary EV policies more cost-effective. Further, the closer the retail prices of EVs and conventional cars are the more important are convenience EV policies. Policy could in theory subsidize EVs to the market price of conventional passenger cars or even below it with purpose to reduce the relative attractiveness of conventional cars. Such a subsidy could give rise to problems in the competitive environment compared to conventional cars. We argue that at some subsidy level price does not matter if households cannot fuel their vehicles in a convenient way.

On a cautious note, however, it is hard to draw conclusions on what has the larger effect: monetary EV policy or infrastructure policy. In this study, we focus on the effect of infrastructure in a fixed financial subsidy environment, but we urge to caution as to interpret the effect due to the complementary relationship as well as some other factors. There might be underlying mechanisms driving EV adoption and consumer behaviour, which might not be captured in this study. Also, in line with Sierzchula et al. (2014), we cannot say that the relationships detailed in this or any past studies necessarily holds true for future years. This is due to the innovative and rapidly changing technology within the automotive industry, and in the EV market in particular. Our finding is that the marginal effect of one additional charging point per square meter is 15 additional EVs at the current charging density. We do not fully understand the dynamics of future technology and its implication on the EV market, based on current state of knowledge. Therefore, general conclusions about future policy implication are hard to draw.

On that note, when looking at monetary EV policies of a larger set of countries, as previously done in Mock and Yang (2014), one understands that EV infrastructural policy is bound to have different effects on consumer decisions depending on the economic incentive for consumers given disperse prices of EVs and conventional vehicles. With VAT rates for EVs ranging from 0 in Norway to 25 percent in Denmark and Sweden, and a large variety of one-of and annual incentives both in format and monetary size (Mock and Yang, 2014), we are humble before the fact that our findings are on the world’s most developed EV market with perhaps also the most converged prices facing consumers. We do not give an estimate on what size effect more comprehensive infrastructural policies such as the Transnova programme, could have in any other countries. This is due to the complexity in existing monetary policy amongst countries and different statuses in charging network, as well as hybrid registrations and hybrid subsidies. Norway is also unique in some aspects, which might need to be taken into consideration designing electrification policies in general. For example, Norway has above average purchasing power, with the indication of both a higher turnover rate of the (younger) car fleet and holding more cars per household than in many other countries, also disregarding any EV subsidies. Further, in January 2007 Norway had 2.7 percent unemployment and in the backwash of financial crisis the number had increased to a mere 3.6 percent (Statistics Norway, 2015). So, is the Norwegian case of EV success restricted for high-income countries in the Nordics or can the findings be valid also externally? Dissecting the question into one cost part and one geographical part, we can make some conclusions on policy. People in richer countries buy more and newer cars with newer technology; hence policies targeting monetary incentives in less rich countries would have to be *at least* as liberal as in the current case of Norway to obtain a similar effect. Also, if a poorer country could only afford to implement *one* of the policies implemented in Norway, the effect from the policy would not be half of the effect in Norway, as the relationship between monetary and convenience policies is symbiotic. In that case, further analyses into the calibration of for example VAT exemption and strategic infrastructural development could be one way forward. As for the geography part of the validity question, the evidence speaks for a higher EV share in non-Nordic countries. The topology of Norway combined with harsh winters and precipitation mixed with milder summers requires vehicles to have strong four-wheel drive and more engine effect: both features not typically associated with EVs. Also, the range issue is made worse in this setting since an EV requires more fuel due to cooler climates. This implies that our estimates are downward biased for a warmer and flatter country, all else equal.

Further, the current available EV models are more attractive to consumers compared to the models available in the beginning of the electrification in Norway, indicating that the pace of change would be faster for any electrification policy of today. Also, fast charging is new in a technology perspective, and it is reasonable to suspect that the fast charging network once rolled-out would have an even larger effect on EV purchases than what this study has found for normal chargers. Norway has pioneered the way of electrification policy in terms of normal infrastructure, and the same policy could be copied for a combination of normal and fast chargers, customized by policy makers across countries.

A very important question to take into consideration regarding EV policy is: "What is the EV substituting and to what extent?" Norway had one (1) plug-in hybrid vehicle in 2007 (Grønn Bil, 2015). This implies that the Norwegians who act out on their pro-environmental behaviour by choosing an EV do not already own pro-environmental substitutes to any larger degree. It is more desirable for countries to transform conventional car drivers to EV drivers, than for example plug-in hybrid drivers or public transportation users. It is most desirable to have a 1:1 substitution rate for conventional vehicles, but of course even substitution from plug-in hybrid vehicles is positive, as it will result in a reduction of carbon emissions.

Utilization policies aiming at making households choose to travel by their EVs rather than conventional vehicles (e.g. toll exemption, free parking, and bus lane permit) are to be encouraged. Further, policy makers should pay close attention to near policy changes when the Norwegian EV fleet is reaching 50,000 cars in 2015/2016. Some of the EV utilization policies implemented in Norway suffer from poor scalability, examples being congestion of bus lanes and road taxes that finance road infrastructure. While some benefits of EVs are likely to be scaled down as the electrification increases, it will also be interesting to see if there are any new or modified utilization policies in the near future in Norway.

Policy so far is discussed in the absence of technology advancements of conventional vehicles. Being a more mature market, advancements are slower compared the once of EVs. We do recognize that if there were advancements making combustion cars more attractive for potential purchasers, electrification policy would have to be more aggressive than in the status quo scenario of normal paced development.

Conclusively, successful EV policy aiming at reducing carbon emissions by electrifying the vehicle fleet and can be implemented as long as the prerequisites of energy mix are right. However, the electrification can vary in time depending on the budget at hand and whether policy makers fully understand the dynamics between different types of policies and technology advancements. We argue that the infrastructural developments in Norway could not have been possible using market forces without governmental subsidies and hence government intervention of this kind is necessary to obtain substantial market growth.

9. Concluding remarks and future research

The main conclusion of this study is that charging point infrastructure has a positive impact on households' EV ownership in developing EV markets. EVs are increasingly looking to be a part of modern environmental policy and thus there is a strong need for understanding the EV purchasing decision in more detail. The modern inhabitant in society is informed and price-effective when making decisions on capital goods purchases. Also, the modern day car purchaser also has standards regarding convenience of fuelling the car. While governments have often focused on policies targeting monetary incentives to increase the EV share of the vehicle fleet, we argue that optimal policy is a combination of different types of policies. Policies increasing the purchasing power of the consumer and charging infrastructure are most effective when combined and are of a certain size. In this study, we provide evidence that the consumer is concerned with the operational use of her vehicle, and hence the importance of convenience factors in owning an EV. The contribution of this study is hence that it is possible for nations to stimulate consumer choice of specific vehicle purchases through infrastructure in addition to monetary incentives and e.g. gasoline taxation.

Future studies would be wise to include the developments in 2014 and onward for several reasons. The EV market increased by over 109 percent compared to 2013 (Statistics Norway, 2015); the market developments are much explained by Tesla S sales and extensive development of the fast charging network. In this study, it was not possible to include the most recent developments due to data restrictions in for example the income variable. Also, the role of digitalization and media on a national level could be studied to better understand how to best get the message of governmental policy across in the public. On a concluding note on future research, we urge researchers to conduct any study on data made available or affordable to purchase. There is a severe lack of knowledge about the relationship of financial incentives, infrastructure and consumer EV purchasing patterns, and there are still research gaps to be filled in order to answer what the ultimate policy for a ‘green’ shift of the transportation sector is.

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