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# The Prevalence of Energy-Related Rebound Effects in the Transportation Sector

Master Thesis within Business Administration

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# ABSTRACT

Due to society's increased involvement for the environment, topics that concern energy use and greenhouse gas emissions have evolved substantially over the past few years. The rebound effect is a matter that measures if technological innovation or implemented government policies lead to the expected decrease in energy use (thereby decreased emissions), or if the environment is actually worse off after the implementations. The rebound effects are theoretically classified as a consumer or producer issue, but it also can be divided into a direct or indirect matter.

This thesis is investigating the direct rebound effects in The Norwegian Transportation Sector on the consumer side and it also describes the underlying factors that affect travel demand. In addition, it establishes the present situation of electrical vehicle evolvement for the Norwegian population. Electrical vehicle policies by the Norwegian government are indeed incentivized implementations that are supposed to decrease the green house gas emissions. The implemented government policies might however be working against its own purposes on the rebound effect framework.

The data analysis is based on data provided by the Institute of Transport Economics, as well as Statistics Norway and the Information Council for road traffic. The model used in the data analysis is build on the framework compiled by Sarah West (2004) in form of a derived indirect utility function. Some adjustments are however made due to data availability.

The key findings of the thesis are that the Norwegian population is more elastic than other research usually concludes with, and the rebound effects lie in between 40 percent and up to 441 percent, indicating a very elastic population and the presence of a partial rebound or even backfire in some models. These results differ from other research papers about rebound effects, as it usually lies somewhere around 20 percent so one should be cautious with the interpretation of these findings. Because the rebound effect varies between models in such a significant manner, some of the models in the data analysis are not correct. However, the results indicate that the Norwegian population is very sensitive to price changes and government policies therefore need to be considered very carefully.

# PREFACE

This thesis is a product that represents the completion of a Master´s degree in Business Administration at The University of Stavanger Business School. My chosen study program is Economic Analysis and therefore the thesis is directed to this study-area. The reason I chose to write about rebound effects in the transportation sector is my personal interest for how environmental changes affects future generations and how small changes can make big differences. When proper guidance and supervision from the government is in place, people can contribute a lot in order to save the environment and ensure that our grandchildren have a sustainable world to live in.

I would like to take this opportunity to thank my supervisor Gorm Kipperberg for supportive guidance beyond all expectations – for being available at all hours and for providing motivation during difficult moments. I did not expect that writing a thesis could be so much fun, and I have learned more during this semester than during my whole course at this university. I am really grateful for the experience. I would also like to thank Roy André Øverlid Tungland-Knudsen for proofreading my thesis, as well as my fellow student, Sandra Skjæveland, for everyday-support.

Some of the data applied in the analysis in this publication are based on the "Norwegian National Travel Survey for years 2005 - 2014". This data is collected by TNS Gallup and SSB. Data is also provided by The Institute of Transport Economics (TØI) and SSB, and is prepared and made available by the Norwegian Social Science Data Services (NSD). The Ministry of Transport and Communications, Norwegian Public Roads Administration, Norwegian National Rail Administration, the Norwegian Coastal Administration, Avinor, TNS Gallup, the Institute of Transport Economics (TØI), SSB and NSD are not responsible for any of the analysis/interpretation of the data that's presented in this thesis.

I am thankful for having the opportunity to take advantage of this data as it has been playing an important role in the outcome of this thesis.

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# 1. INTRODUCTION

## 1.1 Background

Trends in a society's concerns are leading to more focus on time valuation, a better economy and an expanded green lifestyle. People are compelled by how to save more time and money. These concerns are motivating the technological development, causing innovations in technological efficiency, as well as government policies that are targeting consumer behavior towards reduced energy consumption and greenhouse gas emissions. Unfortunately, there are numerous strategic intentions targeting reduced energy consumption that's failing and are instead leading to an increased energy demand: The process when energy efficiency is leading to an increased (not decreased as expected) energy consumption is called *rebound effects*; extreme situations when energy demand is higher than before the efficiency implementation is called *backfire* (Solaymani, Kardooni, Yusoff, & Kari, 2015; Sorrell, 2009, 2011; Sorrell & Dimitropoulos, 2008).

Rebound effects can be classified in different ways and the classical approach is in terms of direct rebound effects, indirect rebound effects and economy wide rebound effects. Indirect- and economy wide rebound effects implies computable general equilibrium adjustments. Due to this phenomenon being problematic to analyze and because of limited existing evidence (Sorrell & Dimitropoulos, 2008), the direct rebound effects are used in the analytical framework of this thesis. In addition, the rebound effects can be separated into consumer side and producer side effects. Because of some producer-side effects that are crucial for the transportation sector, the background- and literature section will establish for both producer and consumer side effects, but in order to narrow down the research area, the analytical focus is being held on the consumer side of rebound effects.

Governments are pursuing improvements in energy efficiency using the economy, however there is evidence that even though the intension is to reduce the energy consumption, policies and energy-efficient technology are contributing to an increase in energy demand in some cases (Sorrell, 2011). On a microeconomic level, the questions to be asked is if the improved technological efficiency of energy will lead to a reduced consumption as calculated. For instance, will 20-kr improvements in the fuel efficiency of passenger cars lead to a corresponding 20-kr reduction in motor-fuel consumption for personal automotive travel? Economic theories suggest that it will not and because of energy efficiency-improvements reducing the marginal cost, the consumption will probably increase. For example, consumers may choose to drive further and more often, caused by a lower price per km of driving. This process is called the direct rebound effect. Another way to look at energy efficiency is in the form of indirect rebound effects. If consumers use their saved money on other goods that requires energy, the consumption will increase and is thus obstructing the intensions to improve energy efficiency.

## 1.2 Purpose of the thesis

A quarter of all energy-related CO2 emissions and more than half of the oil used world-wide are accounted from the transportation sector (IEA, 2008). The vehicles today are more energy efficient than before, but at the same time the consumers are driving for longer distances and more often. Unless the billions of tons of annual emissions decrease substantially, the GHG emissions in the atmosphere will continue to increase (EPA, 2014). Two of the main issues when the environment is discussed are global warming (the average global temperature is increasing rapidly and needs to be stopped) and sea level changes due to the melting of ice at the north and south poles. Changes in the sea level are mainly a result of the rising global temperatures and therefore the challenges caused by an increase in the average temperature are the most important to keep in focus. The reason why this problem is not an easy fix is *the Tragedy of the commons* – people acting like individuals and thinking only about their self-interest, even though it's not in their best-interest in long term (Banyan, 2016).

Research implies that the global warming and CO2 emissions are moving too fast and within 2040 there will be little to save, therefore the use of extraordinary policies to keep the world going will be needed (OECD, 2014). The Paris agreement on climate change signed by 195 countries on the COP 21 UN Climate change conference makes us believe that all the countries will take action on the climate change before the time has run out and we have still some hope to meet the targets (United Nations, 2015). In order for governments to be able to implement correct policies that motivates the population to decreases their energy demand and emissions, it's important to estimate the appropriate current situation in form of the population´s behavioral rebound effects. The basic idea is to find out which factors the inhabitants react to the most and if they are price elastic, in which case the price is the most suitable instrument for the government to work with.

## 1.3 Research questions

The underlying objective of this thesis's research is to establish rebound effect estimations in the Norwegian transportation sector and the research questions determined are as follows:

RQ1: What are the rebound effects in the transportation sector of Norway?

RQ2: What is the overall and regional electric vehicle share in Norway?

RQ3: What are the rebound effects in the Ryfast and Eiganes case?

## 1.4 Choice of methodology

This thesis is based on a quantitative research method using several secondary data sources and the research design is based on descriptive research design. The model used in the analysis is based on the research done by West (2004) and Goldberg (1998). The major part of the data applied in the analysis is pooled cross-sectional data that's based on the Norwegian National Travel Surveys for the years 2005, 2009 and 2013/2014, delivered by the Norwegian Social Science Data Services (NSD, Norsk Senter for Forskningsdata). In addition to the NSD source, data is also collected from several other foundations in order to modify variables that do not contain the dataset - the Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 – 2015 report, Statistics Norway, the Norwegian Tax Administration and the Information Council for the Road Traffic (OFV/Opplysningsrådet for Veitrafikken AS).

## 1.5 Thesis Structure

The thesis is structured as follows. First (in section 2) the background and literature section describes the rebound effect as a general matter with historical developments, as well as by giving proper definitions and classifications for the issue. Then, an overview over literature on transportation related research ends the chapter. Further, in the section 3, the theoretical framework of the energy efficiency and rebound effects are displayed with an up-building basic microeconomic view on the issues from the consumer demand-side and the following energy- and price elasticity theoretical structure. In section 4, a brief description of methodology is presented. Furthermore, in section 5 the data analysis is described in three separated parts for each analysis. This section describes the obtained results from the analysis. The first part analyzes rebound effects in the Norwegian Transportation Sector and investigates the relationship between a household's vehicle kilometer-demand and different household- and vehicle characteristics. The second part outlines the statistics of electric vehicle ownership on national and regional levels – it shows the present situation of the electric vehicle statistics in Norwegian Vehicle Park nationally. It also establishes some regional descriptive threads in conjunction to the third part of analysis. The third part of the analysis investigates the rebound effects based on the Ryfast and Eiganes sub-sea tunnel projects and estimates the price-elasticity based on the same model as in the first part of the analysis. However, the population used in the dataset is now selected by the affected municipalities from the road project. Finally, section 6 concludes the thesis and underlines for potential further research.

# 2. BACKGROUND AND LITERATURE

The structured affiliation is divided between background and literature in this chapter. The underlying background substructure starts with the historical formation of the rebound effect as an issue; the second sub-chapter gives a proper definition of the rebound effects and the third clarifies the classification of the matter. As an extended background implementation, the fourth sub-chapter explains GHG-emission decomposition, as some parts are often omitted in government-policy motives. Finally, the fifth sub-chapter presents an overview of the previous literature on the subject of rebound effects related to the transportation sector.

## 2.1 History of the rebound effects

Although historically William S. Jevons described the rebound effects already back in 1866, as he marked that more efficient steam engines would influence economic processes and increase the demand for coal (Jevons, 1865), the main early explorations of the phenomenon as an economic theory were brought to light by Khazzoom (1980) by implementing a direct increase in the demand for energy when supply increases as a consequence of improvements within technical efficiency. Khazzoom kept the focus on household electric appliances and price elasticity. Further impression on the theory was done by Leonard Brookes (1990), by applying changes in price as a factor for change in demand either directly through price elasticity or indirectly as a result of released purchasing power. His thesis initiated a new view on the subject and the following literature establishes an even more precise theory on the phenomenon.

Eventually, a new level of the efficiency matter was born – *The Khazzoom-Brookes postulate* – when using different approaches for neoclassical growth theory, Harry Saunders evolved the circumstances where improvements in energy efficiency will increase, not decrease, the energy demand (Saunders, 1992). Saunders's expanded the efficiency issue-approach on a macroeconomic level and made a connection to the economic growth caused by increased energy consumption. The fundamental approach for his work is the Cobb-Douglas production-function for substitutions between energy services, capital and labor, but also a nested CES production function is used in his approach. Saunders published a critical paper a decade later, addressing the empirical concerns towards issues for rebound effects (Saunders, 2000). While admitting that there are high requirements for analytical data studies in the field to develop a correct understanding and to initiate proper government policies, he argues that simple theoretical models can be used directly in such assignments.

Saunders´s original work was picked up by Brookes (2000) and in the background of the neoclassical model he criticizes the governments that are wrongly believing that boosting the national programs for energy efficiency is going to respond with the *free lunch* in their environmental commitments. One of the examples he mentions is the energy efficiency action taken to diffuse the 1970's OPEC price hikes that resulted in an even higher energy demand than before the energy initiatives were taken.

Great amplitude of the illuminating literature that builds the rebound effect's fundamental postulate is based on the producer side-theory, omitting the great potential on the energy consumption on the consumer side. The millennium's new thinking for environmental concerns has been expanded with the research, establishing a profound groundwork area towards consumer theory as well. Some of the more recent developments on the issue are contributed by Greening, Greene, and Difiglio (2000), Sorrell and Dimitropoulos (2008), Sorrell (2009) and Sorrell (2011).

## 2.2 Defining the rebound effects

Rebound effects are caused by energy efficiency that is a mechanism used to manage and restrain energy consumption where using less energy still provides you with the same service (IEA, 2015a). The problem with this mechanism is that even if the improvements lead to a reduction in dependence, sustainability and security of supply goals, the economy responds in a way where energy is both used and demanded even more (Allan, Gilmartin, McGregor, Swales, & Turner, 2009). The reason for this is a reduction in price when energy is produced more efficient, again leading to a substitution effect, making consumers demand even more energy output than before. This mitigation process is labeled as *rebound* and the increase in energy-use as *backfire*. Greening et al. (2000) attempts to explain the issue as a "take-back"-expression and underlines that these effects originates from an increased energy supply that again corresponds to decreased effective prices as a result of the concealed cost structure. However, the dominant part of the literature is focusing on the demand side and price changes as the fundamental variables and factors for the paradox.

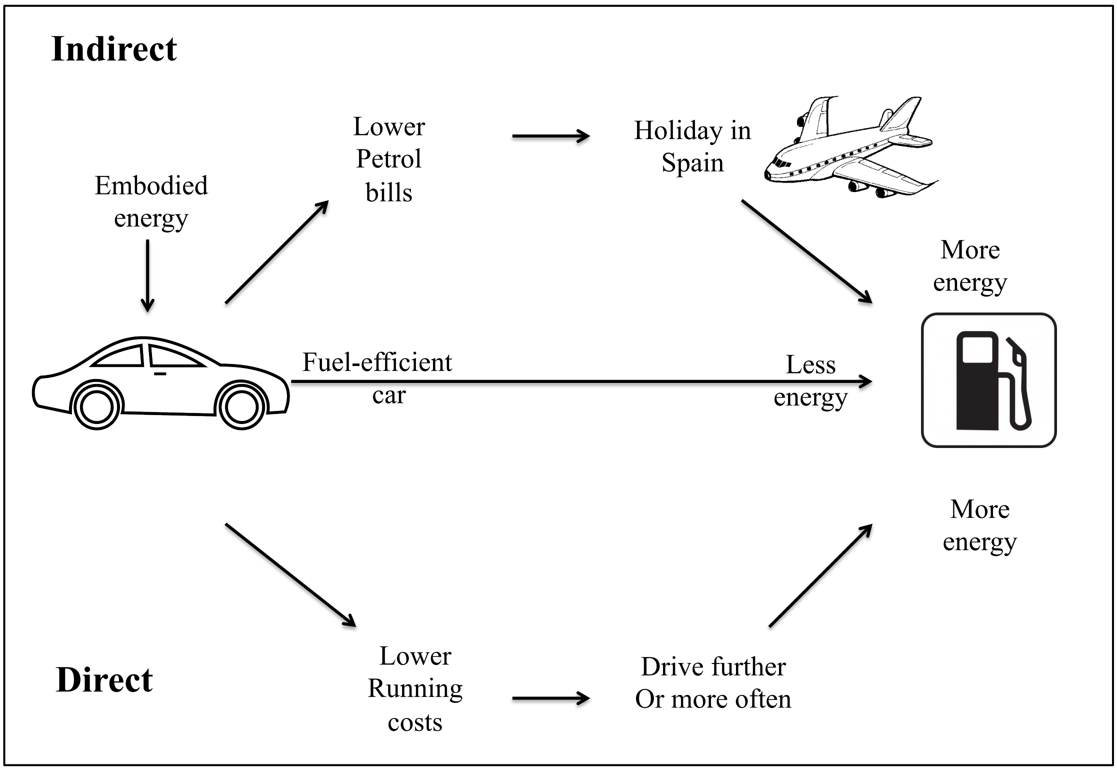
While most of the literature explains rebound effects in various complicated ways, Su (2011b) simplifies the definition as *the price elasticity of travel demand*. Although for transport related rebound effects it is quite a proper definition for expected calculations, the explanations of rebound effects cannot be so simple as the mechanisms lying under are important to understand as well. The rebound effect is a process where new incentives are used to reduce energy demand through technological improvements, where energy efficiency is leading to less energy input for the same output, but where it actually results in an increased energy demand (Solaymani et al., 2015; Sorrell, 2009, 2011; Sorrell & Dimitropoulos, 2008). A typical rebound effect exemplification for consumers would be home heating efficiency (higher indoor temperature, larger houses), lighting technology (more light inside, more garden lighting) and car-fuel efficiency (more cars, higher speed and extended driving length) (Creutzig, McGlynn, Minx, & Edenhofer, 2011).

## 2.3 Classification of rebound effects

Rebound effects as a term implies that some energy that is saved due to how energy efficiency manifests itself in higher energy consumption (Bhattacharyya, 2011, p. 158). Rebound effects can be classified in three separated groups – direct rebound effects, indirect rebound effects and economy wide effects (Greening et al., 2000; Sorrell, 2011; Sorrell & Dimitropoulos, 2008). *Direct rebound effects* are effects resulting directly from energy efficiency improvements. For example, if a household gets installed a more efficient furnace that heats the house using less energy (reduced price for the same amount of heat), they'll choose to heat the household with an even higher temperature and using it more often than before, as well as on times when they usually didn't use heat earlier in order to save money (i.e. during the night or while being absent from their home). *Indirect rebound effects* are secondary effects, affecting other areas from efficiency improvements as a result of saved energy and money. In this case if the consumer chooses to heat the household as they did before, the money they saved is used to go on a holiday and the travel is formerly requiring more energy than the conserved energy from the energy efficient furnace. *Economy wide effects* occur when a decline in the real price of energy services also reduces the price of other intermediate and final goods throughout the economy. As a consequence, a whole sequence of chain reactions develops in form of price and quantity adjustments so that energy-intensive goods and sectors are boosted on the expense of less energy-intensive goods.

Efficiency improvements can also be under-categorized in form of the consumer side versus the producer side rebound effects (Berkhout, Muskens, & Velthuijsen, 2000; Sorrell, 2011). From the consumer side there are *substitution effects* when consumption of the energy service substitutes the consumption of other goods and services while maintaining a constant level of utility and substitution effect. The consumer can also be affected by the *income effect* – higher levels of income leads to higher levels of consumption.

**Figure 2-1 Rebound effects for consumers**

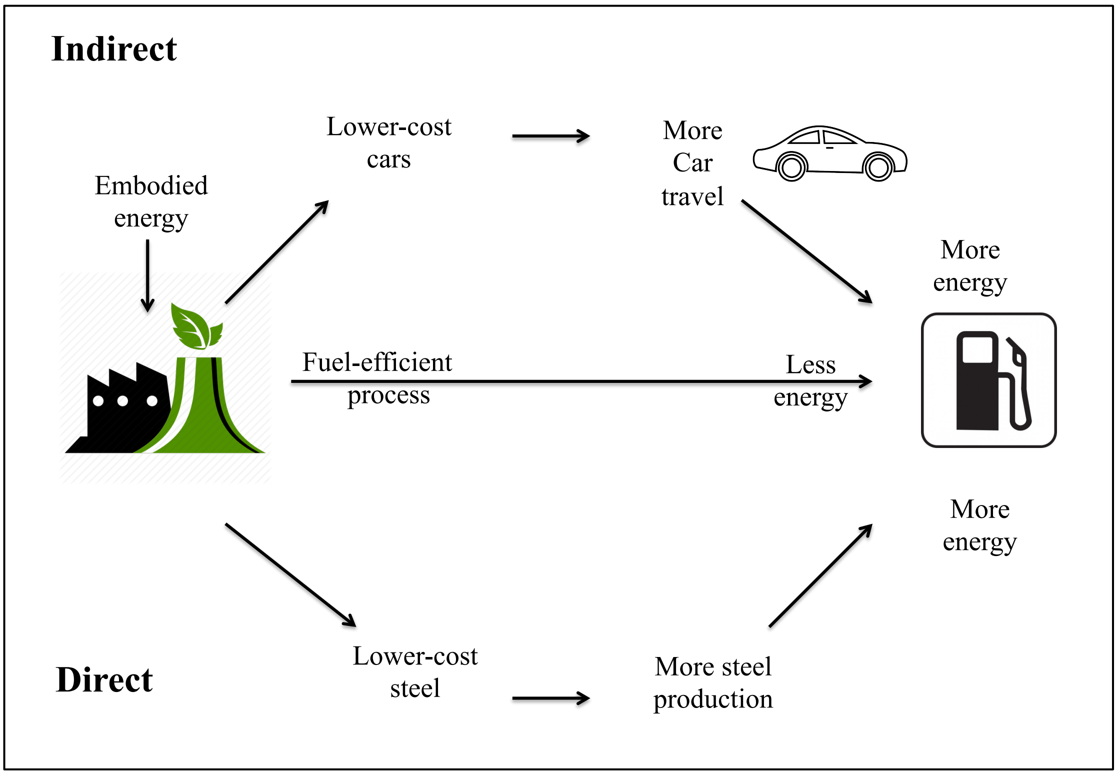



Source: (Sorrell, 2011)

On producer side, there are *substitution effects* in play when cheaper energy service substitutes for the use of capital, labor and other variables keeping production at a constant level of output. For instance, a machine in a fabric that is more efficient would decrease the demand for employees as it would be cheaper for the machine to do the work – this is a classical example of what happened during the industrial revolution in the nineteenth-century and it is a reason for the emerging of the rebound effect as an issue. The mechanism can be explained using a simple production function on a microeconomic view. A producer has a representing amount of production output with inputs of capital and energy. At the point when an energy efficient machine is introduced, less energy (but the same input of capital) is required for the initial output level. However, because of cost-minimization, the producer will change the input mix so that the cheaper energy is now substituting for the capital. Energy inputs are increased, while capital is reduced. In addition, there are *output effects* where cost-saving improvements lead to increased production levels. As producers are focused on profit-maximization and marginalizing costs, the more efficient machine will increase the quantity produced rather than the cost savings.

Indirect rebound effects for producers can be classified as *embodied energy*, which is the energy consumed while achieving the energy efficiency improvements and *secondary effects* as effects that's resulting in other consequences from the energy efficiency improvements.

**Figure 2-2 Rebound effects for producers**

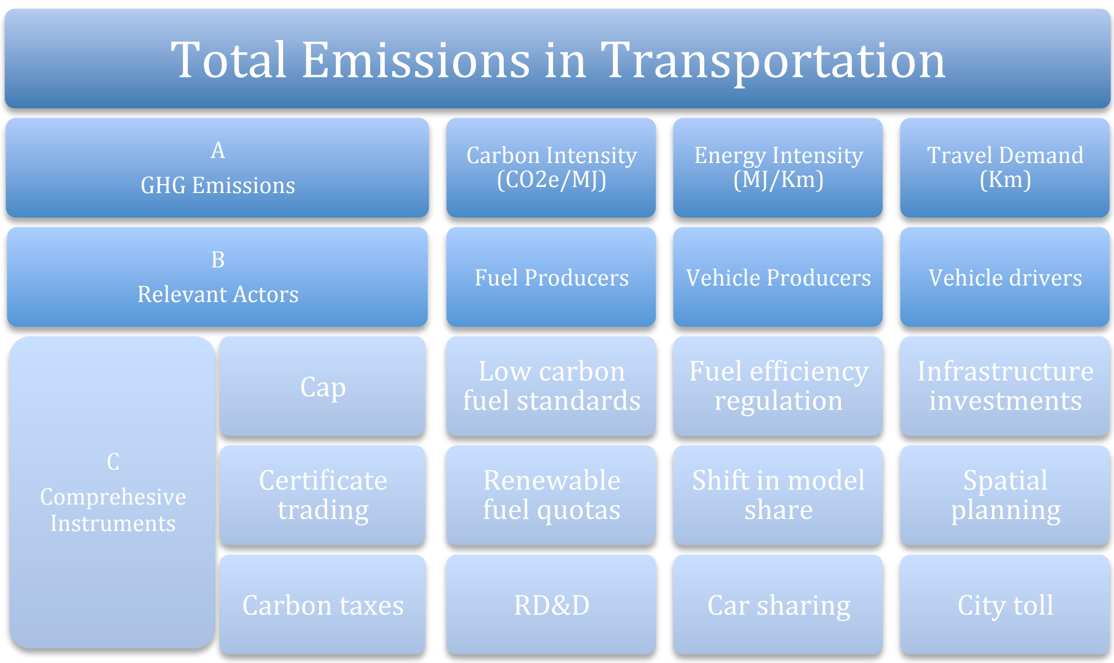



Source: (Sorrell, 2011)

## 2.4 Decomposition of total emissions in transportation

To understand Rebound Effects in the transportation sector and how the regulation policy instruments can be formatted, the GHG-emissions needs to be decomposed into three main categories: carbon intensity, energy intensity and travel demand (Creutzig et al., 2011). Carbon intensity refers to fuel producers and policies that focus on lowering emissions in an upstream lifecycle. This is measured in $gCO_2e/MJ$ (grams of carbon dioxide equivalent to per megajule of fuel energy). Mechanisms that typically are introduced in this area are renewable fuel standards, low carbon fuel standards and emission trading. Energy intensity addresses car manufacturing levels and is measured in MJ/km (megajule of fuel energy per kilometer driven). Typical measures in this area are innovations in more efficient vehicles as well as policy instruments like vehicle taxes and fuel efficiency standards. The third category is the travel demand on the consumer side, which is measured in kilometers. This category is often the most interesting one to analyze, as there are many other factors than price per km that influences consumer behavior in how often and how far we drive. Most people value comfort and vehicle performance as well as fuel efficiency. We can see that the trade-off between different

**Figure 2-3 Decomposition of GHG emissions**




Source: (Creutzig et al., 2011)

factors are playing an important role (Greening et al., 2000). For instance a paper by Poudenx (2008) underlines that most consumers would not switch to public transportation because of an increased quantity of the supply, but rather because of increased quality. Another observation of the trends that could be seen among consumers is that people actually appreciate the congestion as they can escape everyday hectic life while they are waiting alone in their car.

Another reason why GHG-emissions needs to be decomposed is because the upstream factors are often omitted from the transport policies and the emissions are measured only by per-km driven factors and therefore displays the wrong impression of different initiatives (Creutzig et al., 2011; Sorrell, Dimitropoulos, & Sommerville, 2009). Many alternative fuels to fossil fuel are more carbon and energy intensive in the supply chain. An example here is electric vehicle use (and policies that motivates usage of these because of zero tailpipe emissions) in countries that produces electricity by coal causing the upstream emissions to be quite significant in the calculations. In addition, there are emissions related to battery manufacturing and vehicle charging (Michalek et al., 2011).

## 2.5 Transportation related rebound effects

In the consideration of rebound effects in the transportation sector, it is observed that the population reacts to miscellaneous factors in different ways. Various researches in this field show how the income effect in the transport-related analysis is mostly an issue for low-income households. For instance, Murray (2012) concludes his research telling us that cost-effective improvements will be most appealing for low-income households, but at the same time these households will have the highest rebound effects leading to the fewest environmental efficiency improvements when compared to other groups. Also Hymel, Small, and Van Dender (2010), by analyzing induced demand and rebound effects in road transport, find strong negative dependence for rebound effects on real income as the effect decreases aligned to the income magnitude. Among other variables, the analysis results could be justified by time valuation framework – higher hourly wages means higher opportunity cost related to time spent in congestion. Otherwise, the congestion is influencing the rebound effects rather negatively. An examination of the congestion has been evaluated by other scholars (Su, 2010, 2011a, 2011b), and the conclusions are very much similar –

congestion is causing negative consequences such as an increase in household gasoline consumption and per capita vehicle miles traveled.

There is significant magnitude of analytical research for rebound effects in the transportation sector. A case study on microeconomic environmental rebound effects on a macro level for different European transport innovations is making a great contribution to the research area (Vivanco, Kemp, & van der Voet, 2015). They are investigating organizational and normative innovations such as park-and-ride, bicycle-sharing systems, car sharing scheme and high-speed rails as well as catalytic converters, diesel engines and direct fuel injection in passenger cars. The model measures rebound effects comparing the bearing position with or without these innovations. The authors are marking that although these innovations generally introduce better environmental profile comparing to their alternatives, in most of the cases the emissions are increasing as a consequence of these initiatives being introduced. Only park-and-ride, the catalytic converters and direct fuel injections are leading to decreased emissions. Clarifications behind these findings are cost-related – most of the innovations are reducing cost for consumers, leading to more released income and additional consumption of energy related services.

A Norwegian paper investigating a general equilibrium assessment of rebound effects separates the economic sectors and uses the MSG-6 (Multi-sectoral growth) model that is developed by Statistics Norway (Grepperud & Rasmussen, 2004). The key analytical results for transportation tells us that transport-oil efficiency improvements reduce oil-consumption by 15% and that the significant rebound effects are observed mostly in the manufacturing sectors. The authors are admitting that there are several limitations that could explain the contrasting results from other research in the field and that one of the most significant one is the absence of cost-benefit analytical tools.

Governments are implementing various policies to reduce emission amounts. One of the schemes is to motivate for a replacement of old vehicles with newer and more efficient vehicles. Kagawa et al. (2013) is investigating this policy implemented in Japan. The Japanese government was paying a 250,000-yen (3188 US dollars) subsidy to all consumers who decided to scrap their car and buy a standard-sized passenger car that met the emission- and fuel economy standards; the consumers could choose to buy either a hybrid or a gasoline vehicle. Old cars are scrapped and replaced with more efficient vehicles; the intention was to benefit both the economy and the environment. However, the analysis showed that this approach was very costly and also motivated the consumers to replace their cars too early. Even if the new cars were more efficient and environment friendly, the consideration of emissions related to life cycle for manufacturing the new cars resulted in extended estimations for how long these new cars needed to be on the road until the efficiency implemented would actually be reducing the emissions. To decrease emission levels, the estimated time when the new cars could be replaced at earliest was 4,7 years. In addition, the policy was also motivating for more and longer driving as the new vehicles was less costly and there was variation in emissions due to the fact that consumers could choose between hybrid and gasoline vehicles.

More environmentally efficient cars are being incentivized for consumers in several countries and Norway is on top of the list. Because of the enormous increase of Electric Vehicles on Norwegian roads over past few years, Aasness and Odeck (2015) were exploring both incentives and adverse effects that are lying behind this development. Their key findings are that Norwegian government has implemented various financial incentive methods (e.g. discharge from toll, parking fees, access to transit lanes etc.) that make EV purchases and the usage of these less expensive, motivating the population for induced EV consumption. However, they note that the dispensation from toll charges is leading to reduced toll revenues. Also, by giving EV's access to transit lanes, congestion is caused for public transportation. These findings are supported by several other surveys and nevertheless are opposing each other. While Figenbaum, Assum, and Kolbenstvedt (2015) finds these incentives as reliable for reduced emissions and that intentions are met, Holtsmark (2012) argues that because of the consequences from transportation (e.g. accidents, traffic jams, seizure of valuable lands), the government policy should make usage of the roads costly for all types of vehicles and no longer favor EV's by reducing costs. He therefore concludes that electric vehicle owners should pay for using the roads, parking and the energy used just as the fossil car owners do. In addition, he remarks that there is no good reason for why EV's should use the transit lines. However, what all authors agrees on is that electrical vehicle use should not be incentivized by governments in countries that are producing the electricity from fossil sources as GHG emissions are actually higher from EV than from ordinary fuel vehicles.

# 3. THEORETICAL FRAMEWORK

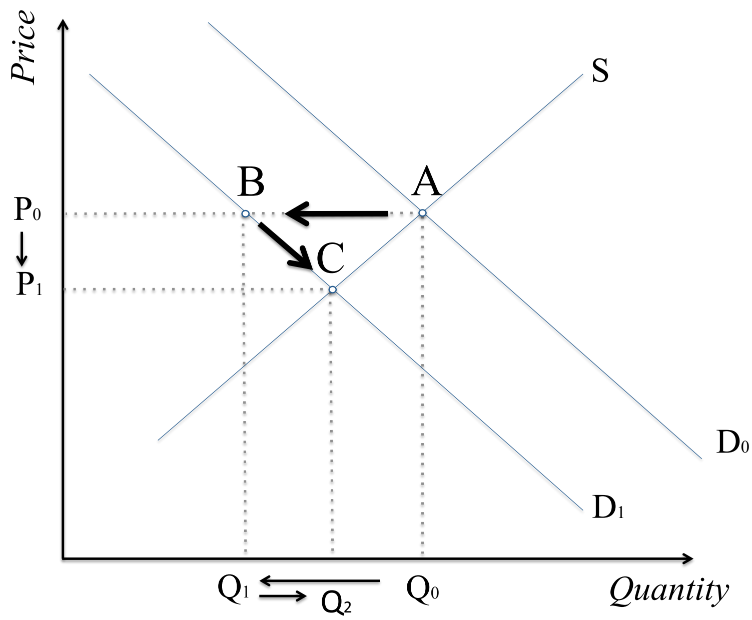
Rebound effects in the transportation sector are driven by energy demand. In order to make any enhancements to climate change policies on the consumer side, the explored and researched fields that need to be held in focus are energy demand, consumption and utility maximization. This chapter is structured by first establishing the rebound effect on a microeconomic view in sub-chapter one, the second sub-chapter explains how the rebound effects are related to utility maximization in the form of income- and substitution effects. The Third part of the chapter initiates the elasticity of Marshallian demand as a background framework for the rebound effect in general. The fourth and fifth sub-chapter explains the rebound effect in the form of energy- and price elasticities and the final sub-chapter describes the rebound effects in the transportation sector.

## 3.1 Energy demand

"*Total primary energy demand* represents domestic demand only and is broken into power generation, other energy sector and total final consumption" (IEA, 2015b). Energy demand is not about demand for oil, gas, electricity etc., but about demand for services and goods that require the use of energy and utility for those services. Energy systems consist of demand and supply side. Previously, the supply side was adjusted in order to satisfy the demand side, but in the 1970´s, researchers, governments and the utilities realized that if the energy problem will be managed appropriately, the demand side couldn't be ignored and needed more focus and resources (Bhattacharyya, 2011, pp. 136-137). Therefore, the concept *Demand-side management* (DSM) of energy was born and it is still used in many industries today. "DSM of energy is the systematic utility and government activities designed to change the amount and/or timing of customer´s use of energy for the overall benefit of the society" (Bhattacharyya, 2011; CRA, 2005). The subject can be categorized into activities like load management, energy conservation, fuel substitution and load building.

In a microeconomic view, the rebound effect is explained in Figure 3-1 as one of the basic movements in an energy supply-demand curve for equilibrium (Gillingham, Rapson, & Wagner, 2015). Because of improvements in energy efficiency, less energy

**Figure 3-1 Rebound effects graphically**



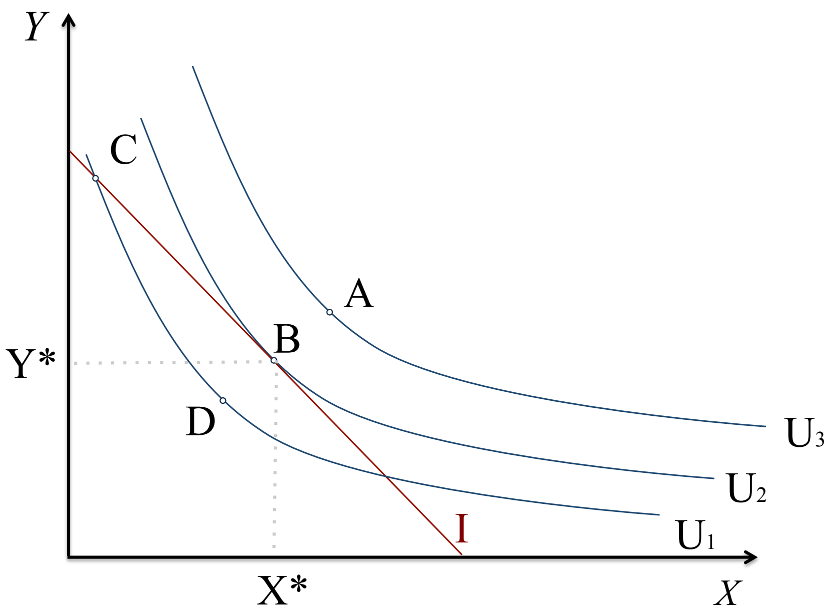

is needed and the demand curve shifts to the left leading to a decrease in quantity demand and a shift from point A to point B. However, the price effect pushes the quantity from point B to C so the equilibrium outcome yields a smaller energy reduction than estimated in a view of the energy efficiency implementation. In this illustration, the rebound effect is the movement between B and C. In a transportation related exemplification, the quantity on the x-axis would be kilometers traveled and the price variable on the y-axis indicates the price per kilometer.

## 3.2 Utility maximization

Whenever we're talking about energy demand, consumer theory is an influential factor and the most essential element that determines the demand of various quantities is consumer utility. *Utility* refers to an overall satisfaction that is affected by a bundle of factors such as consumption, psychological attitudes, personal experience, cultural environment and others (Snyder & Nicholson, 2012, pp. 86-92). To be able to make the analysis of choices manageable, the *ceteris paribus* (other things being equal) assumption is applied in the utility maximization calculations.

In light of consumer theory it is assumed that the consumer will maximize his utility by buying the quantities of the goods that deplete the total income and the trade between the two goods cannot be higher (Snyder & Nicholson, 2012, pp. 109-114). The amount of the total utility is dependent on the budget constraint or the total consumer´s income so it will determine which utility bundle the consumer will maximize his utility by (see Figure 3-2). The budget constraint is represented by the red line marked by the index I. It indicates the amount of money the consumer disposes and will use between the goods X and Y. The maximization point is where the utility curve crosses the budget constraint as the consumer maximizes his utility when the whole budget is used on the goods X and Y. In this graphical illustration the point A on utility $U_3$ is when the consumer does not have enough money while the point D on the utility $U_1$ indicates that the consumer does not use all the money available meaning that there is more utility to maximize. Although both points B and C cross the budget constrain, point B will be preferred as the utility $U_2$ that it crosses, is higher than utility $U_1$ that point C crosses.

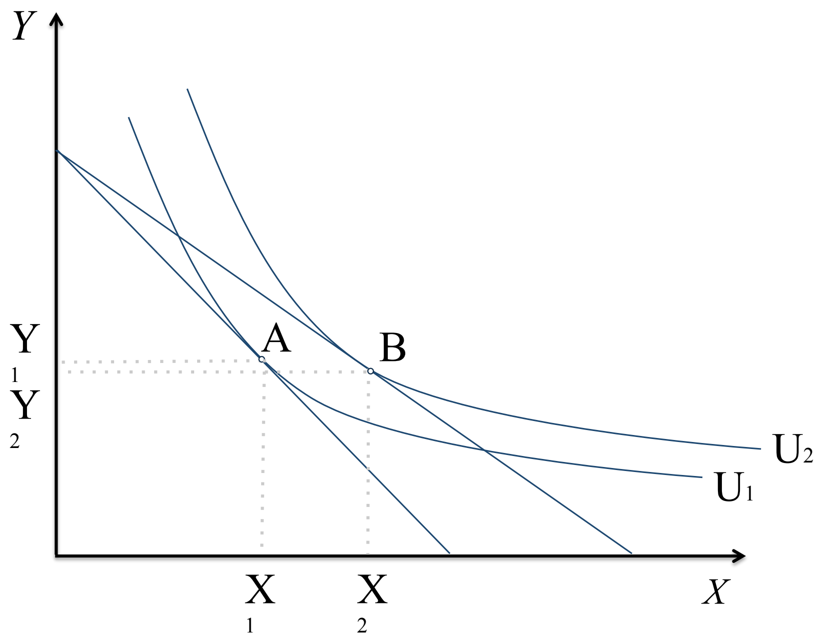
**Figure 3-2 Utility maximization**




The microeconomic foundations as consumer optimization in form of substitution- and income effects are important models to use to understand the rebound effect framework as a concept (Berkhout et al., 2000). For instance – the effect of an energy price drop is causing a substitution effect and consumers switches between the amounts of the goods. An economic model for this mechanism can be observed in Figure 3-3 where a consumer´s budget is facing two goods X and Y with the utility

$U_1$.

**Figure 3-3 Substitution effect for consumer**




In a case where energy efficiency is reducing the price of the good X, the consumer can buy the same amount of the good Y (there is almost no difference between the amounts of $Y_1$ and $Y_2$), but he can now buy higher amounts of the good X using the same budget (note how the price drop affects the increase from $X_1$ to $X_2$). Correspondingly, the budget line rotates anti-clockwise on the vertical axis - the consumer's optimum is shifting from point A to B and the utility level is now increased from $U_1$ to $U_2$. As a consequence of energy efficiency, the available budget for goods X and Y has now increased and the rebound effect in this illustration is the consumption increase in good X. Because of the utility maximization, the consumer increases his consumption for the amounts of the good X, although it was not necessary the purpose of the implementation of the energy efficiency.

## 3.3 Elasticity for Marshallian demand

As already established in the background section, the rebound effects can be identified in a very simple way and basically called the elasticity of either price or some other variable in the calculations. "Elasticity is a percentage change in one variable resulting from a 1-percent increase or decrease in another" (Pindyck & Rubinfeld, 2013, pp. 33-

34) and is a widely used economic model for finding out responsiveness. It basically measures the sensitivity of one variable to another as it is desired to find out how much the quantity of some good will rise (or fall) in either supply or demand and how sensitive the demand is to the price. The categories of the Marshallian demand are own-price elasticity, income elasticity and cross-price elasticity.

The price is a very important instrument in the economics and because the price is easy to adjust according to the market situation in comparison to other variables, one of the most used elasticity models is the price elasticity. So the price elasticity of demand ($E_p$) is calculated by the percentage change in quantity demanded ($\%\Delta Q$) divided to percentage change in the price ($\%\Delta P$). In this case the symbol delta ($\Delta$) indicates a change in the variables.

$$\mathrm{E_p} = (\%\Delta \mathrm{Q})/(\%\Delta \mathrm{P}) \tag{3.1}$$

It can be also written in a little bit more esthetic way so that it is easier to keep track of the order in the variables:

$$\mathrm{E_p} = \frac{\Delta \mathrm{Q}/\mathrm{Q}}{\Delta \mathrm{P}/\mathrm{P}} = \frac{\mathrm{P}\,\Delta \mathrm{Q}}{\mathrm{Q}\,\Delta \mathrm{P}} \tag{3.2}$$

Unless it is a *giffen good*, the price elasticity of demand is a negative figure because while one variable increases, another usually falls (E.g. if the price of some goods increases, the quantity demanded will naturally fall and vice versa). In order to express the magnitude of the elasticity it is commonly said that the demand is either price elastic, price inelastic or unit elastic (Pindyck & Rubinfeld, 2013; Snyder & Nicholson, 2012, p. 152). *Price inelastic demand* refers to a situation where the calculations results in a number greater than 1 as the percentage decline in quantity demanded is greater than the percentage increase in price; it also means that the change in price has a relatively small effect on the change in quantity of the good or service that is demanded. *Price elastic demand* will be referred to when the elasticity calculations results in a number less than 1 in magnitude; it also means that the change in price has a great impact on the change in the quantity demanded. Lastly, *unit elastic demand* will be referred to a situation when the calculated elasticity will be equal to 1. The price elasticity very often depends on the availability of the substitutes as the consumer will buy more of other goods in case of a price increase and the demand will then be expressed as price elastic. In absence of close substitutes, the demand will tend to be price inelastic.

$$E_p < -1 \qquad \text{Elastic demand} \tag{3.3}$$

$$E_p > -1 \qquad \text{Inelastic demand} \tag{3.4}$$

$$E_p = -1 \qquad \text{Unit elastic demand} \tag{3.5}$$

This can be explained using a simple example where a consumer owns a car and he is originally driving 1000 km using 10 liters of fuel; 1 liter of fuel costs 10 kr so he needs 100 kr to drive the total distance. So $Q_0$=1000 and $P_0$=10. Further we establish three different price changes (5, 8 and 15) that could potentially lead to a different quantity change (2000, 500 and 1500). The proportions will then result in different types of elasticities (see Table 3-1). For instance, if a 50% decrease in pricing leads to a 50% increase in kilometers driven, then the price elasticity calculates an elastic demand that is equal to -2. Note, if the kilometers driven stays at the same amount (1000 km), it would lead to a perfectly inelastic demand that is equal to 0 as the price change does not affect the demand of the kilometers driven at all.

**Table 3-1 Examples of elasticities**

| Price | Q=2000 | Q=500 | Q=1500 | Q=1000 |
|---|---|---|---|---|
| 5 | -2 | 1 | -1 | 0 |
| 8 | -5 | 2.5 | -2.5 | 0 |
| 15 | 2 | -1 | 1 | 0 |

Since the rebound effects occur as a result of efficiency improvements, the relevant examples here are when a price is reduced and the quantity is increased. The examples of energy efficiency introduced could be several and the most common is when a new type of vehicle that needs less fuel is supplied. It could also be a reduced fuel tax for the type of fuel that our consumer's vehicle requires. This would happen in a situation where the government wants to motivate consumers to use the exact type of vehicle that the consumer owes so his vehicle will be much cheaper to drive than other types. This price-reduction will lead to different lengths of kilometers driven. The percentage change will then indicate in how elastic the price demand is.

## 3.4 Rebound effects as Energy elasticities

A prevailing econometric approach for direct rebound effect-estimation has been used for secondary data sources (Sorrell, 2011; Sorrell & Dimitropoulos, 2008; Sorrell et al., 2009). This proposition includes information like demand for energy, useful work and/or energy efficiency. Basically the energy efficiency (ε) of an energy assembly can be defined as ε=S/E, where E describes the energy input needed for a unit output of useful work ($P_S$) and $P_S=P_E/\varepsilon$, where $P_E$ express the price of energy. Based on the data that is available for the analysis, estimations of energy efficiency can be determined in two ways:

- Elasticity of energy demand (E) with respect to energy efficiency (ε):

$$\eta_{\varepsilon}(\mathrm{E}) = \frac{\partial \mathrm{E}}{\partial \varepsilon}\frac{\varepsilon}{\mathrm{E}} \qquad (3.6)$$

- Elasticity of demand for useful work (S) with respect to energy efficiency (where S=εE):

$$\eta_{\varepsilon}(\mathrm{S}) = \frac{\partial \mathrm{S}}{\partial \varepsilon}\frac{\varepsilon}{\mathrm{S}} \qquad (3.7)$$

Under certain assumptions, the first elasticity equals the second minus one as E=S/ε can be substituted in the equation for $\eta_{\varepsilon}(E)$:

$$\eta_{\varepsilon}(\mathrm{E}) = \eta_{\varepsilon}(\mathrm{S}) - 1 \qquad \Longrightarrow \qquad \eta_{\varepsilon}(\mathrm{S}) = 1 + \eta_{\varepsilon}(\mathrm{E}) \equiv \mathrm{R} \qquad (3.8)$$

The decomposition of the efficiency elasticity of energy demand can also be formed in other ways and the decisive formation depends on the data availability and measure for useful work (S). For instance, if the energy efficiency corresponds to an increase in the number of energy conversion devices (NO), their average size (CAP), their average utilization (UTIL) and/or their average load factor (LF) and the definition of energy demand elasticity may then be defined as follows:

$$\eta_{\varepsilon}(E) = [\eta_{\varepsilon}(NO) + \eta_{\varepsilon}(CAP) + \eta_{\varepsilon}(UTIL)] - 1 \quad (3.9)$$

## 3.5 Rebound effects as Price elasticities

A great deal of the studies concerning rebound effects are nevertheless using the price elasticities in their estimations rather than energy elasticities (Sorrell et al., 2009). There are three price elasticities that can be used in calculations:

- $\eta_{P_S}(S)$: Elasticity of demand for useful work (S) with respect to the energy cost of useful work ($P_S$):

$$\eta_{P_S}(S) = \frac{\partial S}{\partial P_S}\frac{P_S}{S} \quad (3.10)$$

- $\eta_{P_E}(S)$: Elasticity of demand for useful work (S) with respect to the price of energy ($P_E$):

$$\eta_{P_E}(S) = \frac{\partial S}{\partial P_E}\frac{P_E}{S} \quad (3.11)$$

- $\eta_{P_E}(E)$:Elasticity of demand for energy (E) with respect to the price of energy($P_E$):

$$\eta_{P_E}(E) = \frac{\partial E}{\partial P_E}\frac{P_E}{E} \quad (3.12)$$

Under ceteris paribus assumption that $P_S = P_E/\varepsilon$, increased (or decreased) energy efficiency $\varepsilon$ when energy prices $P_E$ are constant should have the same effect on the energy cost of useful work $P_S$ as decreasing (or increasing) energy prices when energy efficiency is constant (Sorrell & Dimitropoulos, 2008). Under the stated assumptions above, the negative of $\eta_{P_S}(S)$, $\eta_{P_E}(S)$ and $\eta_{P_E}(E)$ can be taken as an approximation to $\eta_{\varepsilon}(S)$ and hence, can be taken as a measure of the direct rebound effect.

$$\eta_{\varepsilon}(E) = -\eta_{P_S}(S) - 1 \tag{3.13}$$

$$\eta_{\varepsilon}(E) = -\eta_{P_E}(E) - 1 \tag{3.14}$$

## 3.6 Rebound effects in the Transportation Sector

Remarkably, the useful work (S) can be measured in a variation of thermodynamic, physical and economic indicators and is a fundamental component of the energy service (Patterson, 1996). In the transportation sector, these indicators can be decomposed in different ways to reveal the significant variables that determines essential contributions to the calculations (Sorrell & Dimitropoulos, 2008). For instance, the variables can be measured in vehicle kilometers, passenger kilometers or tonne kilometers. The decomposing notations are as follows – number of cars (NO), the mean driving distance per car per year (UTIL), the average number of passengers carried per car (LF) and mean (loaded or unloaded) vehicle weight (CAP).

1. Vehicle kilometers

$$S = NO * UTIL \tag{3.15}$$

2. Passenger kilometers

$$S = NO * UTIL * LF \tag{3.16}$$

3. Tonne kilometers

$$S = NO * CAP * UTIL \quad (3.17)$$

When rebound effects are expressed as a percentage, 50% rebound effects mean that half of the efficiency improvement are offset, 100% rebound effects imply that all efficiency improvements are offset and if the rebound effects are higher than 100%, the net savings are negative and efficiency improvements are on *backfire*, meaning that you are worse off after the energy efficiency is implemented. The measurements of the rebound effects should be expressed in physical units by virtue of the errors made when being calculated in monetary units (Berkhout et al., 2000). Saunders (2008) has established a simplified model for explaining calculated rebound (R) conditions. He defines rebound R by using elasticity of fuel use with respect to the efficiency gain.

$$R = 1 + \eta_{\tau}^{F} \quad (3.18)$$

where $$\eta_{\tau}^{F} = \frac{\tau}{F}\frac{\partial F}{\partial \tau} \quad (3.19)$$

Furthermore, the rebound can be explained in a less complicated manner (see equations 3.20 - 3.24). If R equals .60, then the corresponding interpretation will be 60% rebound. Meaning that 60% of the efficiency improvements are offset because of the rebound effect.

| | | |
|---|---|---|
| $R > 1$ | backfire | (3.20) |
| $R = 1$ | full rebound | (3.21) |
| $0 < R < 1$ | partial rebound | (3.22) |
| $R = 0$ | zero rebound | (3.23) |
| $R < 0$ | super-conservation | (3.24) |

# 4. METHODOLOGY

Before the data can be analyzed in light of the research question, it is essential to identify the data and the structure of the methodology. A thesis can be categorized as qualitative research or quantitative research (Wyse, 2011). The first refers to research based on words and descriptions of the research area; the data can be observed but not measured. The second is a research method when it is used, measurable data and calculations that are applied on the basis of the main work area will uncover some statistical patterns. The method used in this thesis is the quantitative research method.

## 4.1 Data

In light of the data description, we often distinguish between primary data and secondary data (Løwendahl & Wenstøp, 2008, pp. 42-47). Primary data is information that you have obtained with regard to your own task, while secondary data is something others have gathered for their purposes, but you still might reuse. Both primary and secondary data can be of qualitative or quantitative nature; primary data is usually collected through questionnaires or interviews, while secondary data will be found in databases. All datasets in this thesis are based on secondary data obtained from other sources. There are various econometric approach-methods for rebound effect-estimations and analysis when using secondary data sources (Sorrell et al., 2009). Significant variables that are needed in the calculations are energy demand, relevant energy service and eventually energy efficiency of that service.

The major part of the data applied in the analysis is pooled cross-sectional data that is based on the Norwegian National Travel Surveys for years 2005, 2009 and 2013/2014, delivered by the Norwegian Social Science Data Services (NSD, Norsk Senter for Forskningsdata). This model is effective to investigate the differences between individual behaviors in different time dimensions and how they react to variable changes such as government policies or prices (Wooldridge, 2009, pp. 5-10). The underlying population must be obtained by random sampling. The amplitude of the survey applies from short trips on daily basis to longer journeys that are less frequent (Denstadli & Hjortol, 2002; Hjorthol, Engebretsen, & Uteng, 2014a, 2014b; Vågane, Brechan, & Hjorthol, 2009; Vågane, Denstadli, Engebretsen, & Hjorthol, 2006). All surveys were collected by telephone-calls as a survey method. The interviews were done on several samples – one part consists of approximately 10-12 thousand persons distributed proportionally and randomly over the Norwegian counties based on the population´s allocation for residents older than 13 years. The other part were supplemented and financed by the Norwegian Public Roads Administration and regional authorities, and consists of several samples.

In addition to the NSD source, data is also collected from several other foundations in order to modify variables that do not contain the dataset:

- For fuel efficiency, data is used from the Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 – 2015 report (EPA, 2015). However, one must be critical to use the calculations, as these values are based on the average fuel efficiency in The United States. The average vehicle motor park in US might differ from the Norwegian one. In addition, the fuel efficiency is based on average numbers, meaning that some vehicles deviate from the real fuel efficiency.

- For fuel prices, data is collected data from Statistics Norway and the prices are adjusted by the average of petrol and diesel for year of NSD surveys (Statistics Norway, 2016).

- For maintenance costs, data is collected from the Norwegian Tax Administration (Skatteetaten) standard rates for distance-based allowances (Skatteetaten, 2016b).

The data applied in the second part of the analysis is primarily from the Information Council for the Road Traffic (OFV/Opplysningsrådet for Veitrafikken AS), however some additional data is applied from Statistics Norway (SSB). OFV data consists of electric vehicle statistics for new and imported used vehicles in Norway. The variables here are which year the vehicle was imported, counties and municipalities. To obtain a describing overview, the data was then combined with population-data and the total amount of vehicles in Norway.

## 4.2 Research design

It is essential to determine and describe the research design in order to develop a correct design model and give a proper description of the thesis. Some of the most well-known designs used in research are exploratory design, case studies, cross-sectional design, descriptive design and causal design (Lynn University, 2016). All three parts of the thesis are based on descriptive research design. This type of design is commonly concerning relationship between two or more variables (Iacobucci & Churchill, 2010, pp. 59-60). The baseline for the thesis is descriptive research design, but some parts could be categorized as exploratory design since it is only establishing the underlying framework and hides a great future potential for further research.

The first part of the data analysis investigates the relationship between a household's vehicle kilometer-demand and different household- and vehicle characteristics, as well as the rebound effects caused by price changes in the Norwegian transportation sector. The model used in the analysis is based on the research done by West (2004) and Goldberg (1998).

The second part of the data analysis shows the present situation of the electric vehicle statistics in Norwegian Vehicle Park nationally. It also establishes some regional descriptive threads in conjunction to the third part. Because the amount of electric vehicles has been growing in significant numbers in the recent years, the research done in this area are still limited. Therefore, this model could also be categorized as an exploratory research design as it establishes a study area for potential future investigations (Iacobucci & Churchill, 2010, pp. 58-59). As an intro to the next part of the thesis, an overview is made showing changes in the relationship between the amount of electric vehicles and gas-fueled vehicles in the Gardemoen-Biri area. This area is interesting to investigate, as there is an almost completed road project where the government has installed several expensive road-tolls. Electric vehicles can pass the tolls free of charge, as opposed to gas-fueled vehicles. It's interesting to see if there is any correlation between toll installments and population behavior in relationship to electric vehicles procurements.

The last part of the analysis is based on a case study for Ryfast sub-sea tunnel project and estimates the price-elasticity based on the same model as in the first part of the analysis but the population is now the affected municipalities by the road project.

# 5. DATA ANALYSIS AND DISCUSSION

This chapter is divided into three parts and each part ends with a discussion of the findings. A quantitative discussion of the findings is held in focus in the discussion of the first part of the analysis. The first part analyzes the rebound effects on a national level and it also has several sub-chapters – the first one describes the model used in the data analysis, the second sub-chapter defines the variables from the model, how these are build and finally gives a brief description of what the variable means for the dataset. The third sub-chapter reveals the data analysis done by the model and the results are discussed.

The second part of the analysis starts by describing the electrical vehicle developments over the past few years in Norway on a national level. The first sub-chapter in the second part of the analysis gives some explanations for the EV-evolvements on a road project-perspective and the second sub-chapter reveals a regression model where variables that indicates if the household disposes an electrical vehicle, hybrid vehicle and el-bicycle are included; the second part ends with a discussion of the findings.

Finally, the third part investigates the Ryfast and Eiganes sub-sea road project impact on the population that is affected by this project. This part will give some background information about the project in first sub-chapter, followed by an analysis and discussion of a regression using the same model as in first part, except that this one will only include the population from the affected municipalities.

## 5.1 Part I: Norwegian Transportation Sector and demand for kilometers

### 5.1.1 Conceptual Model

The model used in the thesis is based on a discrete-continuous conceptualization of kilometers driven by households and it's constructed by a previous research material example done by Goldberg (1998) and West (2004). Firstly, the participants select the number of vehicles at their household's disposal, followed by the type of vehicle and vintage. Furthermore, the participants have to choose the length (in kilometers) to drive as a dependent variable. The model needs to be stated as a functional form for the conditional indirect utility *U* so that it can be derived afterwards and used as estimation for conditional demand for kilometers-equation. The function is defined as follows:

$$U = \left(\alpha_0 + \frac{\alpha_1}{\beta} + \alpha_1 c_t + h'\gamma + \beta y + \eta\right) e^{-\beta p} + \varepsilon \tag{5.1}$$

Here $c_t$ is the operating cost per kilometer and $t$ indexes the year of the observation, $h$ is observed household characteristics, $y$ is households´ annual income, $\eta$ is unobserved household characteristics, $\varepsilon$ is unobserved attributes; $\alpha_0, \alpha_1, \beta$ and the vector $\gamma$ are parameters to be estimated.

Furthermore, the utility equation 5.1 can be derived using Roy´s identity and leads to annual demand for vehicle kilometers (Vehicle kilometers traveled/VKMT):

$$VKMT = q + \alpha_0 + \alpha_1 c_t + h'\gamma + \beta y + \eta \tag{5.2}$$

And lastly, the vehicle kilometers traveled are corrected by moving typical kilometers traveled by bundle to the left side of the equation:

$$VKMT - q = \alpha_0 + \alpha_1 c_t + h'\gamma + \beta y + \eta \tag{5.3}$$

### 5.1.2 Variable descriptives and statistics

Dependent variable VKMT consists of the sum of VKMT for each of the three possible vehicles at the respondent´s disposal. Denotation $V_i$ notes for each possible vehicle at the respondent´s disposal (1, 2 and 3).

$$VKMT = VKMT_{V1} + VKMT_{V2} + VKMT_{V3} \tag{5.4}$$

The operating cost per kilometer $c_t$ consists of a weighted operating cost per kilometer for each of the vehicles the respondent's household has at it's disposal. The weighting is calculated when the operating cost for vehicle $i$ is multiplied to proportional kilometers driven (kilometers traveled by vehicle $i$ divided to kilometers traveled by all vehicles in respondent´s disposal).

$$c_t = c_{V1}\frac{VKMT_{V1}}{VKMT} + c_{V2}\frac{VKMT_{V2}}{VKMT} + c_{V3}\frac{VKMT_{V3}}{VKMT} \tag{5.5}$$

When calculating the operating cost per kilometer for each vehicle, several data inputs are needed. $P$ is the price of fuel (measured in Norwegian krona per liter), $\varepsilon$ is the vehicle´s efficiency (measured in kilometers per liter) and $\omega$ is the maintenance cost (measured in Norwegian krona per kilometer), $i$ denote for vehicle number (1, 2 or 3) and $t$ denote for the year the respondent´s data belongs to (2005, 2009 or 2013/2014). Vehicle´s fuel efficiency is based on the vehicle´s vintage and accounts for kilometers per liter.

$$c_{Vi} = \frac{P_t}{\varepsilon_t} + \omega_t \quad (5.6)$$

There are made some variable constraints in the data analysis. First, the number of vehicles at a household's disposal is limited to a maximum of 3 vehicles. Respondents with one, two or three vehicles accounts for 98.22 percent in the sample, thus the omitted data is disruptive for the estimations made in the analysis. Secondly, because of limitations in the fuel efficiency data availability, only vehicle vintage models from the years 1975 to 2014 are included in the data analysis. Lastly, the type of vehicles is narrowed down to passenger cars. Passenger cars in the Norwegian vehicle park accounts for 75 percent of the total car-park. Thus, other types of vehicles in the sample would not be as representative. The distribution of vehicle types in Norway is displayed in Table 5-1.

**Table 5-1 Vehicle type distribution in Norwegian motor park by 2014**

| Vehicle type | 2014 | Percentage |
|---|---|---|
| Cars | 2555443 | 75% |
| Vans | 441967 | 13% |
| Combined vehicles | 30247 | 1% |
| Trucks | 78668 | 2% |
| Buses | 17111 | 1% |
| Tractors | 263866 | 8% |

Source: Statistics Norway (2015a)

Before the regressions can be presented, analyzed and discussed, the variables used in the regression needs to be described, making it is easier to interpret the results (see

Table 5-2). The data includes both continuous variables where values are different, as well as dummy variables where values are either 1 if the variable satisfies the condition, or 0 if the variable does not satisfy the condition.

For dummy variables, a “D” is put in front of the denotation. In addition to the original model, there’s also regressed a non-linear regression, using logarithmic variables. These are not included in the description table as the only difference is the “Ln” in front of the denotation.

Note that *MedVintageHH*, *Dfemale*, *Dnorth*, *Deduc>15* and *D2005data* are included as baseline variables for the regressions.

**Table 5-2 Description of the variables used in regressions**

| Label | Variable |
|---|---|
| Const | Constant |
| OPC_km | Operating cost per km |
| Age | Respondents age |
| Age^2 | Respondents age squared |
| Cars_HH | Number of personal cars |
| Size_HH | Household size |
| DL_HH | Number of persons with a drivers license |
| IE_HH | Number of income earners in household |
| Income_HH | Households income per year |
| Income_HH^2 | Households income squared |
| DMC | Dummy: Access to MC? |
| Dscooter | Dummy: Access to scooter? |
| Dbicycle | Dummy: Access to bicycle? |
| Dholidayhome | Dummy: Holiday home owner? |
| RetroVintageHH | Number of vehicles vintage 1975-1989 |
| OldVintageHH | Number of vehicles vintage 1990-2005 |
| MedVintageHH | Number of vehicles vintage 2006-2011 |

*The table continues in next page*

| | |
|---|---|
| NewVintageHH | Number of vehicles vintage 2012-2014 |
| Dmale | Dummy: Male respondent |
| Dfemale | Dummy: Female respondent |
| Dnorth | Dummy: Household in North Norway |
| Dwest | Dummy: Household in Western Norway |
| Dsouth | Dummy: Household in South Norway |
| Deast | Dummy: Household in Eastern Norway |
| Dcentral | Dummy: Household in Central Norway |
| Dmetroarea | Dummy: Household in metro area |
| DEduc>10 | Dummy: Respondents education >10 years |
| DEduc>12 | Dummy: Respondents education >12 years |
| DEduc>15 | Dummy: Respondents education >15 years |
| Delbicycle | Dummy: Access to el-bicycle? |
| DEV_HH | Dummy: Is there EV in household? |
| Dgas_HH | Dummy: Is there a gas vehicle in Household? |
| Ddiesel_HH | Dummy: Is there a diesel vehicle in Household? |
| Dhybrid_HH | Dummy: Is there a hybrid in Household? |
| D2013data | Dummy: Respondent belongs to 2013 data |
| D2009data | Dummy: Respondent belongs to 2009 data |
| D2005data | Dummy: Respondent belongs to 2005 data |

In order to find out how much the household expects to drive during a full year, the typical kilometers driven $q$ needs to be estimated by running a regression on the data. West (2004) argues that because of endogeneity issues for variable estimations, true kilometers driven cannot be used in the calculations; the estimations are done by her model. Firstly, the average amount kilometers driven by the number of vehicles at a household's disposal is calculated. Furthermore, there are made some regressive numbers so that the typical kilometers driven varies across the households. Here, the household's income $I_{HH}$ and the number of drivers in household $DL_{HH}$, are used as the independent variables and the result leads to the following estimated equation:

$$q = 9\,545 + .003\,I_{HH} + 3\,422\,DL_{HH} \tag{5.7}$$

Income is classified in 5 possible groups (See Table 5-3) that indicate which of the income ranges the household belongs to. Because it makes more sense if the income is stated as a value, the data has been corrected to an approximate value of the household´s income. Missing values for respondents answering, "I don't know" or "I don't want to specify" are excluded from the regression.

**Table 5-3 Income group description**

| Income group | Income range | Recoded income |
|---|---|---|
| 1 | < 200 000 | 100 000 |
| 2 | 200 000 - 399 999 | 300 000 |
| 3 | 400 000 - 599 999 | 500 000 |
| 4 | 600 000 - 799 999 | 700 000 |
| 5 | > 800 000 | 1 000 000 |

The overall descriptive data is presented in Table 5-4 and presents the share of different household and vehicle characters by the number of personal cars at the household´s disposal. The description reveals some characteristics for what kind of households that dispose one, two or three vehicles. For instance, the size of a household, the number of people with a driver's license and the number of income earners in a household seems to increase gradually to the number of vehicles at a household's disposal. It looks like people living in a metro area where the population is higher than 50 000, choose to have fewer vehicles per household. The reason for this could be city related costs, such as parking, toll and similar. Also, actual kilometers traveled and the total operating costs are increasing proportionally to number of vehicles at a household´s disposal. While gender distribution is somewhat proportional in the sample population, the regional distribution is not as balanced as one could wish. More than half of the respondents represent the east part of the country. As expected, the household´s income is also increasing with the number of personal cars at their disposal; comparatively 751 955 NOK for households disposing one personal vehicle to 883 733 NOK for households disposing two vehicles and 915 821 NOK for households disposing three vehicles. The average household´s income for the whole

**Table 5-4 Comparison of the variable means by number of vehicles**

| Household and vehicle characteristics | Number of vehicles | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | All |
| Households | 19 984 | 9 637 | 819 | 30 440 |
| VKMT | 13 821 | 27 513 | 39 869 | 18 857 |
| OPC_km | 4.60 | 4.76 | 4.87 | 4.66 |
| Age | 51.15 | 47.06 | 45.55 | 49.70 |
| Size_HH | 2.55 | 3.23 | 3.49 | 2.79 |
| DL_HH | 1.78 | 2.15 | 2.61 | 1.92 |
| IE_HH | 0.90 | 1.12 | 1.18 | 0.98 |
| Income_HH | 751 955 | 883 733 | 915 821 | 798 338 |
| DMC | 0.05 | 0.08 | 0.10 | 0.06 |
| Dscooter | 0.05 | 0.07 | 0.14 | 0.06 |
| Dbicycle | 0.80 | 0.86 | 0.86 | 0.82 |
| Dholidayhome | 0.44 | 0.53 | 0.54 | 0.47 |
| RetroVintageHH | 0.04 | 0.11 | 0.24 | 0.07 |
| OldVintageHH | 0.53 | 0.96 | 1.60 | 0.70 |
| MedVintageHH | 0.30 | 0.64 | 0.80 | 0.43 |
| NewVintageHH | 0.13 | 0.29 | 0.36 | 0.18 |
| Dmale | 0.53 | 0.57 | 0.59 | 0.55 |
| Dfemale | 0.47 | 0.43 | 0.41 | 0.45 |
| Dnorth | 0.11 | 0.10 | 0.11 | 0.10 |
| Dcentral | 0.07 | 0.06 | 0.06 | 0.07 |
| Dwest | 0.21 | 0.23 | 0.24 | 0.22 |
| Dsouth | 0.09 | 0.07 | 0.06 | 0.08 |
| Deast | 0.52 | 0.54 | 0.54 | 0.52 |
| Dmetroarea | 0.30 | 0.23 | 0.19 | 0.27 |
| DEduc>10 | 0.87 | 0.90 | 0.92 | 0.88 |
| DEduc>12 | 0.32 | 0.32 | 0.26 | 0.32 |
| DEduc>15 | 0.06 | 0.03 | 0.02 | 0.05 |

sample is somewhere around 798 338 NOK. Access to alternatives such as MC, scooters and bicycles increases in a very small proportion and it is clear that a huge part of the population dispose bicycles. When it comes to education, the proportions are various – the share of people that have at least 10 years of education are increasing with the number of vehicles at a household's disposal while the share of people with more than 12 and 15 year of education decrease with the number of vehicles at a household's disposal. Because of education and income usually being correlated variables, it is expected that both would be either increasing or decreasing depending on the amount of vehicles at a household's disposal. When the results are different from what's expected, it usually means that there are some other unobserved factors that are affecting the variables. For instance, it could be explained that people with higher education levels are more aware of the environment and their personal finances, causing this group to drive less, benefit from car-pooling and use other solutions that makes it less costly to travel.

### 5.1.3 Estimation of vehicle kilometers travelled for the Norwegian population

The linear-regression results for vehicle kilometers traveled (VKMT) and corrected vehicle kilometers traveled (VKMT corrected) are presented in Table 5-5; non-linear regression results for vehicle kilometers traveled (LnVKMT) are presented in Table 5-6. In the models for VKMT, the variable for actual kilometers traveled is used as a dependent variable, while the corrected versions deduct the typical kilometers traveled for vehicle bundles from VKMT. The models for LnVKMT use the same variables, adjusting the dependent variable and continuous independent variables to the logarithmic form. The models with corrected VKMT are not used in the logarithmic models because some VKMT differ from the typical kilometers traveled and leads to negative numbers. The models are divided in three types (1, 2, 3) whereas the first one includes all variables; the second model is simplified using few variables such as price and income; the third model is similar to the first one, except for it's exclusion of dummy variables for the year of the survey. The non-linear models are very similar to the linear models. There are three types (1, 2, 3) – the first one includes all variables, the second one includes only few important variables such as price, income, the number of vehicles at household´s disposition and the dummy variables from the surveyed year. The third model is the same as the second, but it excludes the year variable. Ordinary models and log-log models report the same trends in the results of different variables, the difference is that the logarithmic model expresses a percentage change while as the ordinary model expresses a km change.

All models, as expected, indicates that a higher operation cost per kilometer decreases the amount of kilometers travelled, all else equal the variables are significant at a 1% level. The models indicate that if the price per kilometer increases by one unit, the kilometers traveled will decrease by 6602 km for first model, 9357 km for the second model and 8979 km for the corrected model and 1639 km for the third model. The price variable is the most important and interesting variable of the whole model as it indicates the rebound effects. The elasticity calculations are included at the bottom of the first table while it can be explained straight from the regression for the non-linear regression (coefficient for operating cost per kilometer is the price elasticity for km demand). The interpretation of the elasticities says that the population has an elastic demand for kilometers driven when the price per kilometer changes; the models that excludes the year variable gives inelastic results but the elasticity is substantially high.

The estimated rebound effects are 163% for first model, 231% and 222% for second model and 41% for the third model. These findings somehow differ from previous research, as the rebound effect usually lie somewhere around 20% of partial rebound. When the year variable is removed from the regression, the rebound effect is closer to other research findings, but the values are still much higher. The non-linear models lead to similar results – 245% for the first model, 289% for the second model and 73% for the third model. Rebound effects that are higher than 100% indicate that efficiency implementations leads to backfire – the environment is worse off than before the implementation. A rebound effect of 41 percent indicates that the implementation of the improvements in efficiency only gives 59% of expected improvements in energy usage. The rest is offset as people utilize more output than before – this is because of utility maximization. The budget constraint is still the same so decreased pricing increases the consumption until the budget constraint is met.

An increase in the number of personal cars at a household's disposal increases the kilometers traveled (by around 13,000 km per vehicle in the linear models and by around 70% in non-linear model) and the variable is significant for all models. This is something one could expect, as an additional vehicle at a household's disposal means that the residents of the same household will probably travel separately, thus increasing the total vehicle kilometers travelled for the household in total. The VKMT also increases with a household´s increase in income – because income usually increases with more than one unit and it is categorized in groups (see Table 5-3), additional calculation is necessary to understand these variable results. For instance, if a household's income increases by 200,000 NOK, the amount of kilometers traveled will also increase (800 km in first and third models and 200 km in the corrected versions, 2200 km in the second model and 400 km for the corrected model). However, the variable is significant only for VKMT models (not corrected VKMT). The reason for this is probably income disruptions in correction calculations – income and the number of driver's licenses-variables are used in calculations for typical number of km traveled. Because of these correction calculations, the number of driver's licenses also gives different results in regressions. The variable is significant at a 1% level for all non-linear models and indicates an increase in driving by 5%, 21% and 22% accordingly for models 1, 2 and 3.

Each additional person with a driver's license in a household increases the kilometers in VKMT models, while it decreases in corrected VKMT models. However, the variable is significant in all models meaning that it is relocated when calculating the correction in VKMT. The first model indicates that an additional person with a driver's license will lead to an increase by 781 km and a decrease by 2641 km for the corrected model. The second model excludes this variable while the third model gives us similar results as the first one. The non-linear model reports that one extra person will lead to a 7.5% increase in the amount of kilometers travelled.

All else equal, the owners of holiday-homes also drives more during the year, probably because they choose to drive to their respective holiday homes instead of staying at home and not driving (or driving less in their local area). The results indicate that households disposing holiday-homes will drive somewhere around 800 or 900 km more during a year than households who do not dispose a holiday-home.

For people living in a metro area where the population is higher than 50,000, the VKMT will decrease – by 1547 km in linear models and by 10.3% in the non-linear model. City-cost related issues might explain this relationship or it might be because of congestions, causing the population to choose public transportation rather than using personal vehicles. Or it could simply be because of the fact that many people who are not living in the city still work there, requiring them to travel more during the working days.

If the vehicle vintage is retro (1975-1989 models) compared to the vehicle being medium (2006-2011), the household will drive around 5000 km less (28% in the non-linear model) – it is natural that people owning old-fashioned vehicles use them less frequently, probably in order to spare the vehicle's condition and because they often use these vehicles as a hobby-vehicles during the weekend or on special occasions. People will also drive less for old and new vintage models (1300-1600 km and 300-900 km respectively; the non-linear model reports 10% decrease for both groups), but the reduction is substantially smaller. These findings indicate that the newer the vehicle is, the smaller the reduction will be. People might maximize utilities more when a vehicle is newer, as it usually is more comfortable and has less noise. It also could be some prestige related issues as it might be imposing to *show-off* when using a newer vehicle.

The respondent's gender is also positive and significant if the respondent is male compared to the female respondents – it reports approximately 300 km increase (3% for non-linear model). This makes sense, as it is usual that the male in the household will drive the vehicle if the family is traveling together.

The geographical location is also increasing the vehicle kilometers traveled. The variables here are compared due to respondents located in the north of the country, and it looks like people living in west- and central-Norway drives less. However, the west variable is not significant.

Access to MC, scooters and bicycles seems not to be significant for most of the models; the non-linear regression imposes some significance on 5% and 10% levels for respondents disposing a bicycle and scooter. The unexpected results are that these variables are increasing the VKMT – one would initially expect that these are substitutes for a vehicle and would therefore decrease the amount of vehicle kilometers traveled. The explanation for this phenomenon might be unobserved attitude, training and leisure variables. Education doesn't seem to affect the VKMT that much; the variables are neither significant.

## Table 5-5 Regression for vehicle kilometers traveled

| Variable | VKMT 1 | VKMT 1 corrected | VKMT 2 | VKMT 2 corrected | VKMT 3 | VKMT 3 corrected |
|---|---|---|---|---|---|---|
| Const | 20863.401 *** | 11318.401 * | 32003.507 *** | 18622.271 *** | 2520.942 * | -7024.058 *** |
| | (6660.239) | (6660.239) | (4183.920) | (4189.948) | (1333.521) | (1333.521) |
| OPC_km | -6602.015 *** | -6602.015 *** | -9357.406 *** | -8978.836 *** | -1639.152 *** | -1639.152 *** |
| | (1782.779) | (1782.779) | (1113.90) | (1115.504) | (217.454) | (217.454) |
| Age | 101.351 *** | 101.351 *** | - | - | 101.154 *** | 101.154 *** |
| | (30.651) | (30.651) | | | (30.651) | (30.651) |
| Age^2 | -1.626 *** | -1.626 *** | - | - | -1.623 *** | -1.623 *** |
| | (.318) | (.318) | | | (.318) | (.318) |
| Cars_HH | 13632.498 *** | 13632.498 *** | 13285.716 *** | 12207.138 *** | 13748.534 *** | 13748.534 *** |
| | (223.348) | (223.348) | (166.880) | (167.120) | (219.398) | (219.398) |
| Size_HH | 81.223 | 81.223 | - | - | 80.263 | 80.263 |
| | (90.705) | (90.705) | | | (90.670) | (90.670) |
| DL_HH | 780.641 *** | -2641.359 *** | - | - | 793.125 *** | -2628.875 *** |
| | (175.778) | (175.778) | | | (175.738) | (175.738) |
| IE_HH | 1269.718 *** | 1269.718 *** | - | - | 1247.467 *** | 1247.467 *** |
| | (182.451) | (182.451) | | | (181.813) | (181.813) |
| Income_HH | .004 * | .001 | .011 *** | .002 | .004 * | .001 |
| | (.002) | (.002) | (.002) | (.002) | (.002) | (.002) |
| Income_HH^2 | -2.036E-09 | -2.036E-09 | -5.443E-09 *** | -2.691E-09 * | -2.177E-09 | -2.177E-09 |
| | (1.52E-09) | (1.52E-09) | (1.49E-09) | (1,49E-09) | (1.52E-09) | (1.52E-09) |
| DMC | 58.865 | 58.865 | - | - | 49.573 | 49.573 |
| | (364.669) | (364.669) | | | (364.689) | (364.6889) |
| Dscooter | -233.018 | -233.018 | - | - | -241.680 | -241.680 |
| | (371.269) | (371.269) | | | (371.291) | (371.291) |
| Dbicycle | -273.666 | -273.666 | - | - | -273.082 | -273.082 |
| | (232.125) | (232.125) | | | (232.090) | (232.090) |
| Dholidayhome | 898.640 *** | 898.640 *** | - | - | 926.706 *** | 926.706 *** |
| | (181.531) | (181.531) | | | (178.435) | (178.435) |
| RetroVintageHH | -4803.497 *** | -4803.497 *** | - | - | -5114.068 *** | -5114.068 *** |
| | (396.098) | (396.098) | | | (378.425) | (378.425) |
| OldVintageHH | -1349.842 *** | -1349.842 *** | - | - | -1665.218 *** | -1665.218 *** |
| | (214.845) | (214.845) | | | (182.825) | (182.825) |
| NewVintageHH | -902.631 *** | -902.631 *** | - | - | -353.245 | -353.245 |
| | (306.807) | (306.807) | | | (237.916) | (237.916) |
| Dmale | 376.156 ** | 376.156 ** | - | - | 374.943 ** | 374.943 ** |
| | (174.629) | (174.629) | | | (174.606) | (174.606) |
| Dwest | 414.508 | 414.508 | - | - | 407.232 | 407.232 |
| | (325.613) | (325.613) | | | (325.627) | (325.627) |
| Dsouth | 2840.847 *** | 2840.847 *** | - | - | 2824.095 *** | 2824.095 *** |
| | (407.968) | (407.968) | | | (407.963) | (407.963) |
| Deast | 2453.061 *** | 2453.061 *** | - | - | 2442.551 *** | 2442.551 *** |
| | (295.833) | (295.833) | | | (295.760) | (295.760) |
| Dcentral | 1356.086 *** | 1356.086 *** | - | - | 1354.150 *** | 1354.150 *** |
| | (429.542) | (429.542) | | | (429.585) | (429.585) |
| Dmetroarea | -1547.360 *** | -1547.360 *** | - | - | -1547.911 *** | -1547.911 *** |
| | (202.161) | (202.161) | | | (202.174) | (202.174) |
| DEduc>10 | -149.739 | -149.739 | - | - | -132.336 | -132.336 |
| | (303.103) | (303.103) | | | (302.764) | (302.764) |
| DEduc>12 | -122.321 | -122.321 | - | - | -138.245 | -138.245 |
| | (196.549) | (196.549) | | | (196.348) | (196.348) |
| D2013data | 7060.563 *** | 7060.563 *** | 10094.085 *** | 9770.101 *** | - | - |
| | (2515.817) | (2515.817) | (1507.640) | (1509.812) | | |
| D2009data | 2903.567 ** | 2903.567 ** | 4341.334 *** | 4331.909 *** | - | - |
| | (1199.824) | (1199.824) | (802.598) | (803.755) | | |
| | | | | | - | - |
| Elasticity | -1.63 | -1.63 | -2.31 | -2.22 | -0.41 | -0.41 |
| Adjusted R^2 | .209 | .176 | .190 | .153 | .209 | .175 |
| N | 30439.000 | 30439 | 30443 | 30443 | 30439.000 | 30439 |

Denotation for significance levels: *** for 1%level, ** for 5% level and * for 10% level; standard errors in parentheses.

**Table 5-6 Regression for vehicle kilometers traveled, log-log model**

| Variable | LnVKMT 1 | LnVKMT 2 | LnVKMT 3 |
|---|---|---|---|
| Const | 11.004 *** | 9.755 *** | 6.758 *** |
| | (.635) | (.381) | (.113) |
| LnOPC_km | -2.349 *** | -2.893 *** | -.728 *** |
| | (.461) | (.266) | (.036) |
| LnAge | -.006 | - | - |
| | (.015) | | |
| Cars_HH | .726 *** | .698 *** | .696 *** |
| | (.011) | (.008) | (.008) |
| LnSize_HH | .062 *** | - | - |
| | (.013) | | |
| LnDL_HH | .075 *** | - | - |
| | (.019) | | |
| LnIE_HH | .029 | - | - |
| | (.020) | | |
| LnIncome_HH | .054 *** | .209 *** | .221 *** |
| | (.014) | (.010) | .010 |
| DMC | .016 | - | - |
| | (.018) | | |
| Dscooter | .016 | - | - |
| | (.018) | | |
| Dbicycle | .024 * | - | - |
| | (.013) | | |
| Dholidayhome | .060 *** | - | - |
| | (.009) | | |
| RetroVintageHH | -.282 *** | - | - |
| | (.020) | | |
| OldVintageHH | -.102 *** | - | - |
| | (.011) | | |
| NewVintageHH | -.112 *** | - | - |
| | (.015) | | |
| Dmale | .030 *** | - | - |
| | (.009) | | |
| Dwest | .063 *** | - | - |
| | (.017) | | |
| Dsouth | .171 *** | - | - |
| | (.021) | | |
| Deast | .133 *** | - | - |
| | (.015) | | |
| Dcentral | .081 *** | - | - |
| | (.022) | | |
| Dmetroarea | -.103 *** | - | - |
| | (.010) | | |
| DEduc>10 | .016 | - | - |
| | (.017) | | |
| DEduc>12 | .014 | - | - |
| | (.010) | | |
| D2013data | .527 *** | .674 *** | - |
| | (.148) | (.082) | |
| D2009data | .237 *** | .323 *** | - |
| | .075 | .045 | |
| | | | |
| Adjusted R^2 | .249 | .231 | .249 |
| N | 23946.000 | 30443 | 23946 |

Denotation for significance levels: *** for 1%level, ** for 5% level and * for 10% level; standard errors in parentheses.

### 5.1.4 Regressions by geographical areas

There are also made regression analysis based to regional delineation. Dependent variables are therefore called VKMTwest, VKMTnorth, VKMTsouth, VKMTeast and VKMTcentral, indicating which Norwegian area the population belongs to (see Table 5-7). There are several reasons for this modeling. Results from this kind of analysis can be used in a decision making for transportation policies and it helps decide which factors the population will react to. Because the population might have different behavior in different areas, it is beneficial to separate the geographical allocations so that the interpretations of the population´s behavior aren't provided on false backgrounds.

The west, north and east models have similarities in the results and the elasticity lie in the same trend. However, the price variable for the north is not significant, therefore it's value should not be interpreted too much and the data should be investigated more. The price variable for the south is actually positive but it is not significant either, as there could be some other disturbances leading to these results. In many ways, the most unexpected results are for central Norway – indicating a 441% of rebound effect. It is more than twice that of the other areas and the price variable is also significant on a 1% level. This high rebound effect-value means that the price-based policies gives great potential for the government to affect the population's behavior in order to decrease emissions. One should otherwise be cautious with the interpretation of these findings as such a high level of the rebound effect is not an ordinary finding and it differs from other research made on this field.

Owners of holyday-homes are traveling more than those not owning a holiday home. It is a natural and expected result, as people have to travel to their holiday homes. Inhabitants in central Norway seems to travel the most if they own a holiday home, while inhabitants in the west of Norway are the least affected (the north and south are insignificant, leading to the results not being included in the comparison). The reasons for these results might not be based on a behavior exclusive to the inhabitants of the affected areas; it might simply be caused by greater distances to the closest holiday home-areas.

As seen earlier, more vehicles in household increase the number vehicle kilometers traveled. The number of people with driver's licenses, as well as income earners in a household are increasing the VKMT as well and the variables are significant. The vehicle vintage variables show the same trends as before. Retro vehicle owners will drive the least, but the new vintage vehicle variable is not significant.

**Table 5-7 Regression for vehicle kilometers traveled by geographical areas**

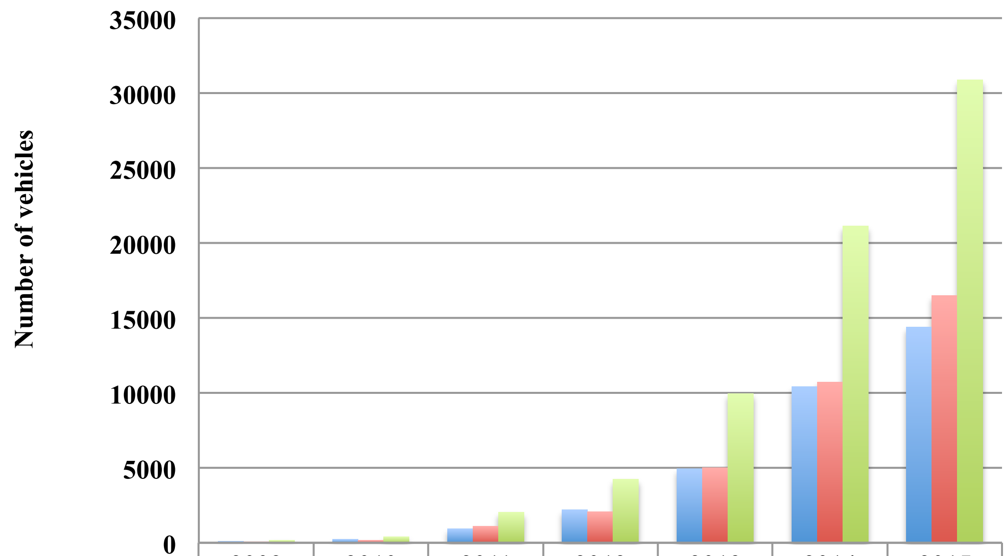
| Variable | VKMTwest | VKMTnorth | VKMTsouth | VKMTeast | VKMTcentral |
|---|---|---|---|---|---|
| Const | 23223.764 ** | 16608.289 | -20547.187 | 24060.614 ** | 58290.546 *** |
| | (10185.295) | (17182.761) | (30651.099) | (10257.039) | (22005.893) |
| OPC_km | -6358.004 ** | -5678.951 | 4591.873 | -6668.694 ** | -16646.679 *** |
| | (2725169) | (4595.329) | (8254.022) | (2747.851) | (5901.399) |
| Age | 72.536 | 181.713 ** | 197.973 * | 65.075 | 150.566 |
| | (50.175) | (83.667) | (111.276) | (46.888) | (102.036) |
| Age^2 | -1.219 ** | -2.216 *** | -2.958 *** | -1.318 *** | -2.072 * |
| | (.525) | (.870) | (1.147) | (.483) | (1.083) |
| Cars_HH | 12434.383 *** | 11742.775 *** | 14221.334 *** | 14466.474 *** | 13290.035 *** |
| | (337.623) | (605.190) | (1008.486) | (343.262) | (733.713) |
| Size_HH | 70.339 | 449.682 * | 168.372 | 72.079 | -433.473 |
| | (141.904) | (240.147) | (294.083) | (146.186) | (297.445) |
| DL_HH | 627.091 ** | 931.740 ** | 1663.478 ** | 657.999 ** | 950.779 * |
| | (267.765) | (470.194) | (693.804) | (275.022) | (579.270) |
| IE_HH | 1136.856 *** | 696.912 | 1144.745 * | 1278.393 *** | 1719.541 *** |
| | (302.357) | (503.633) | (650.761) | (277.559) | (630.942) |
| Income_HH | .003 | .008 | .003 | .002 | .006 |
| | (.004) | (.006) | (.007) | (.003) | (.007) |
| Income_HH^2 | -2.018E-09 | -4.578E-09 | -3.221E-09 | -2.795E-10 | -3.194E-09 |
| | (2.72E-09) | (4.42E-09) | (5.39E-09) | (2.28E-09) | (5.11E-09) |
| DMC | 202.448 | -94.643 | -783.807 | -179.100 | 2122.050 * |
| | (585.491) | (908.010) | (1436.786) | (566.206) | (1160.716) |
| Dscooter | -147.839 | 312.474 | -1962.212 | -64.806 | 440.952 |
| | (638.203) | (769.713) | (1414.221) | (608.181) | (1046.665) |
| Dbicycle | 195.002 | -812.008 | 327.040 | -502.260 | 253.129 |
| | (350.653) | (589.017) | (899.745) | (367.416) | (792.245) |
| Dholidayhome | 917.377 *** | 445.653 | -426.366 | 1002.206 *** | 1856.104 *** |
| | (290.303) | (474.003) | (717.302) | (278.965) | (591.387) |
| RetroVintageHH | -2494.179 *** | -2444.542 ** | -6892.260 *** | -5724.399 *** | -5049.788 *** |
| | (696.917) | (1043.085) | (1482.546) | (599.193) | (1263.507) |
| OldVintageHH | -1142.137 *** | -1112.716 ** | -1905.760 ** | -1419.709 *** | -1200.578 * |
| | (332.875) | (549.300) | (987.726) | (330.228) | (703.987) |
| NewVintageHH | -710.096 | -1644.776 * | -577.317 | -699.715 | -2637.844 *** |
| | (457.916) | (879.877) | (1432.911) | (467.181) | (1014.784) |
| Dmale | 39.081 | 334.208 | 2137.534 *** | 216.699 | 382.935 |
| | (280.384) | (460.003) | (682.527) | (267.926) | (564.277) |
| Dmetroarea | -1817.775 *** | 463.159 | -1719.477 ** | -1467.597 *** | -2532.721 *** |
| | (296.019) | (512.877) | (731.031) | (340.494) | (605.082) |
| DEduc>10 | -597.995 | 15.287 | -1860.295 * | 139.740 | 960.780 |
| | (503.303) | (811.242) | (1088.939) | (460.062) | (1062.799) |
| DEduc>12 | 332.491 | -1456.568 *** | 859.010 | -16.148 | -1351.901 ** |
| | (323.569) | (515.287) | (737.387) | (301.484) | (626.487) |
| D2013data | 6845.778 * | 4493.816 | -6162.952 | 6983.366 * | 19323.539 ** |
| | (3861.589) | (6531.987) | (11547.533) | (3872.766) | (833.649) |
| D2009data | 2177.986 | 2908.403 | -2200.719 | 2604.352 | 10780.390 *** |
| | (1906.179) | (3257.863) | (5349.363) | (1828.752) | (4098.156) |
| Elasticity | -1.70 | -1.65 | 1.02 | -1.56 | -4.41 |
| Adjusted R^2 | .281 | .203 | .178 | .193 | .256 |
| N | 6707 | 3155 | 2551 | 15965 | 2049 |

Denotation for significance levels: *** for 1%level, ** for 5% level and * for 10% level; standard errors in parentheses.

## 5.2 Part II: Electric vehicles in Norwegian vehicle park

Import of electric vehicles in the Norwegian Vehicle Park has exploded over the past few years and there is no wondering why Norway has been recognized as an EV-capital on an international level (AVERE, 2012). Until 2010, the levels of el-vehicles were insignificant, but since 2011 the number of el-vehicles has increased by substantial amounts (see Figure 5-1). These are registrations of both new and imported electrical vehicles in the Norwegian market for the years 2009 to 2015 and the data shows that the numbers has doubled yearly for the past few years. The data also separates metro areas with a population of more than 50 000, beyond metro areas and the total amount for the entire country. It can be perceived that the amounts of electric vehicles people consume are approximately equal both within and outside metro areas, but the overview might be different if the country is divided into separate parts. This part of the thesis will investigate the indicators that might affect these changes and it will also introduce the regression model where alternative transport for fossil fuel vehicles is included as a variable.

**Figure 5-1 First time registrations of el-vehicles in Norway**




| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|
| Metro area | 120 | 234 | 925 | 2197 | 4941 | 10415 | 14403 |
| Not Metro area | 60 | 172 | 1104 | 2062 | 5027 | 10738 | 16498 |
| Total | 180 | 406 | 2029 | 4259 | 9968 | 21153 | 30901 |

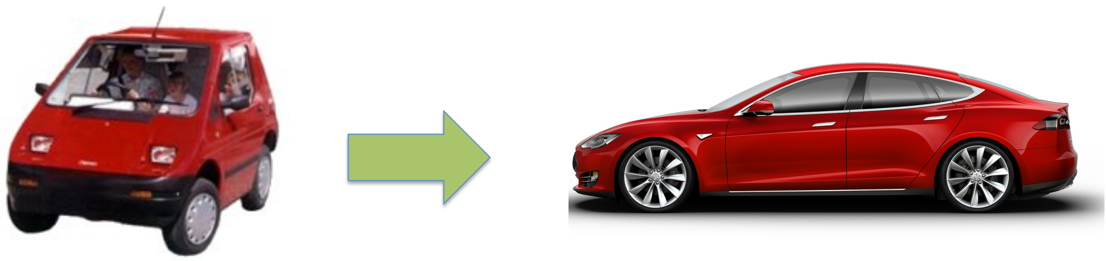
Source: OFV (2015), Statistics Norway (2012).

**What could be the reasons for the recent growth in electric vehicles?**

The Norwegian government is actively incentivizing the use of electric vehicles for the population giving us several reasons for why the share of electric vehicles is increasing so rapidly (Mirani, 2013, 2015). There are several developments that might be a reason for the booming in electrical vehicle purchases over past few years.

**More comfort and better esthetics** – vehicles have changed over past years in their looks, comfort and space. The newer versions of el-vehicles very often look just like any other ordinary vehicle in the market, while older el-vehicles were small in size and usually intended for only one or two persons. For instance, the luxurious electrical vehicles of the brand Tesla started to arrive Norway by the end of 2013 and has earned a role as a very trendy car in the Norwegian society (Petroff, 2014; Skogstad, 2013).

**Figure 5-2 Electric vehicle changes over time**



Source: (DELK, 2009; TESLA, 2016).

**Subsidized reductions in costs** – free parking at most municipal parking spaces; free passage in all the tolls and exemption from congestion charge; the annual fee is only 445 NOK versus 3 135 or 3 655 NOK for regular cars in 2016. Free charging at most public charging stations is offered for EV-owners, and the purchase of electric cars are exempt from the one-time fee (*engangsavgift*) and VAT. There is given a 50% discount on company-car taxation, free transport of electric vehicles on highway ferries (the driver must pay for the passenger ticket), and government regulations provides an extra supplement (10 øre in 2015) on the kilometer allowance (Norsk elbilforening, 2016; Skatteetaten, 2016a). These are substantial cost reliefs that motivate the population for an electrical vehicle purchase.

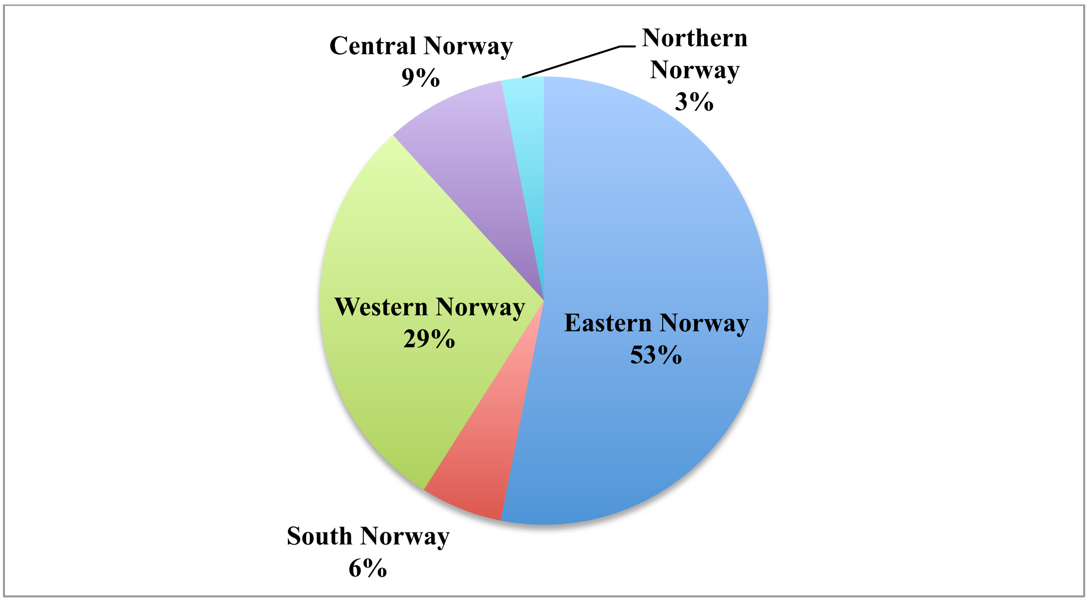
**Expanded range** – the fact that the length of the distance for what an el-vehicle can drive has increased rapidly over past few years, makes it more attractive for consumers and many electrical vehicles can now drive up to 430 km before it requires charging (Schaal, 2015). People are often dependent to drive longer distances either because of holidays or long distances to work and other destinations where they have to go. Improved ranges for how far an electrical vehicle can drive is therefore an important factor in many vehicle purchase decisions.

**Saved time** – free admission to drive in collective road-lanes might be another reason for electric vehicles being seen as more attractive (NPRA, 2015). Passing the congestion during rush-hours saves the electric vehicle-owners time and the time-valuation could be an important factor in the decision making when a consumer is choosing which vehicle to buy. Because of the expanding amounts of electrical vehicles, there are some counties that has started to limit the admission to drive in collective road-lanes for EVs that are carrying one or more passengers in addition to the driver (Marcussen, 2015). Even if that might be a turn-off for the incentives the governments are trying to achieve in order to motivate for environment-friendly vehicle consumption, it is a fine limitation to implement in order to avoid having too many vehicles driving in the collective road-lanes, disrupting it´s purpose for public transit.

**Improved efficiency** – on average, the cost of the electricity needed to drive an electric vehicle is around 15-20 øre per kilometer; an electric motor has far fewer moving parts and require far less costly maintenance and there is almost no noise from the electric vehicles at all (Norsk elbilforening, 2016). All of these features make consumers desire the purchase of an electrical vehicle even more.

It is important to keep in mind that this part of the thesis is on a very descriptive and exploratory nature, meaning that there could be completely other reasons like a booming economy, trends and other factors that are affecting the growing number of EV-purchases. The distribution of el-vehicles can be presented in several ways. The Figure 5-3 displays the distribution of electric vehicles by the following regions: East, North, Central, West and South parts of Norway. Here it can be observed that East and West parts of Norway accounts for more than 80% of the total el-vehicles imports for the years 2006 to 2015; Central Norway has a share of 9 percent, South holds a share of 6 percent and North holds a 3 percent share.

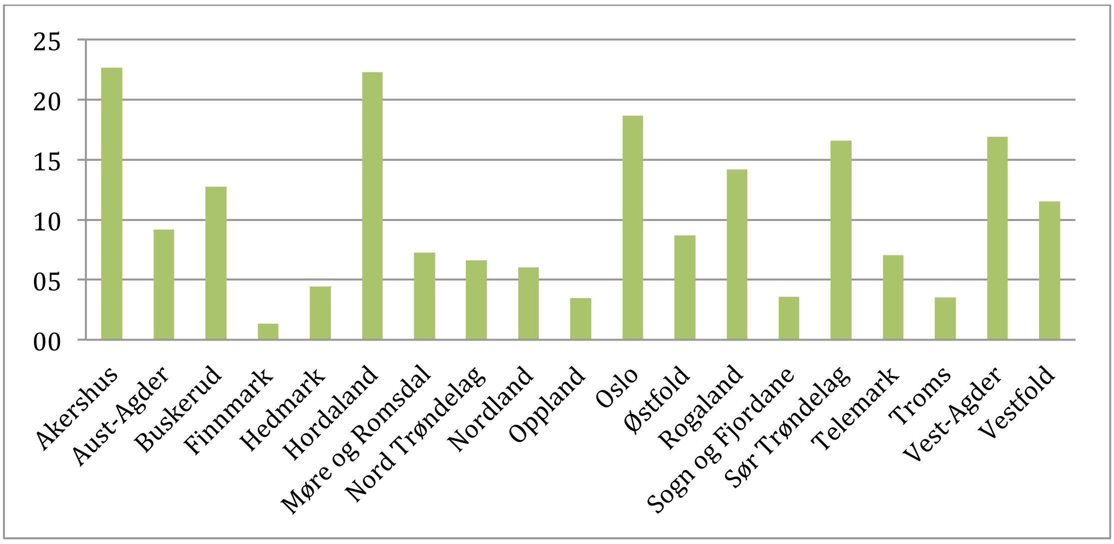
**Figure 5-3 Distribution of el-vehicles in Norway by region (2006-2015 data)**




Source: OFV (2015).

Furthermore, Figure 5-4 shows statistics for the number of electric vehicles per 1000 inhabitants distributed by county. The counties with highest proportions are Akershus, Hordaland, Oslo, Sør Trøndelag and Vest-Agder with more than 15 vehicles per 1000 inhabitants. The medium group with more than 10 vehicles per 1000 inhabitants accounts for the counties Buskerud, Rogaland and Vestfold.

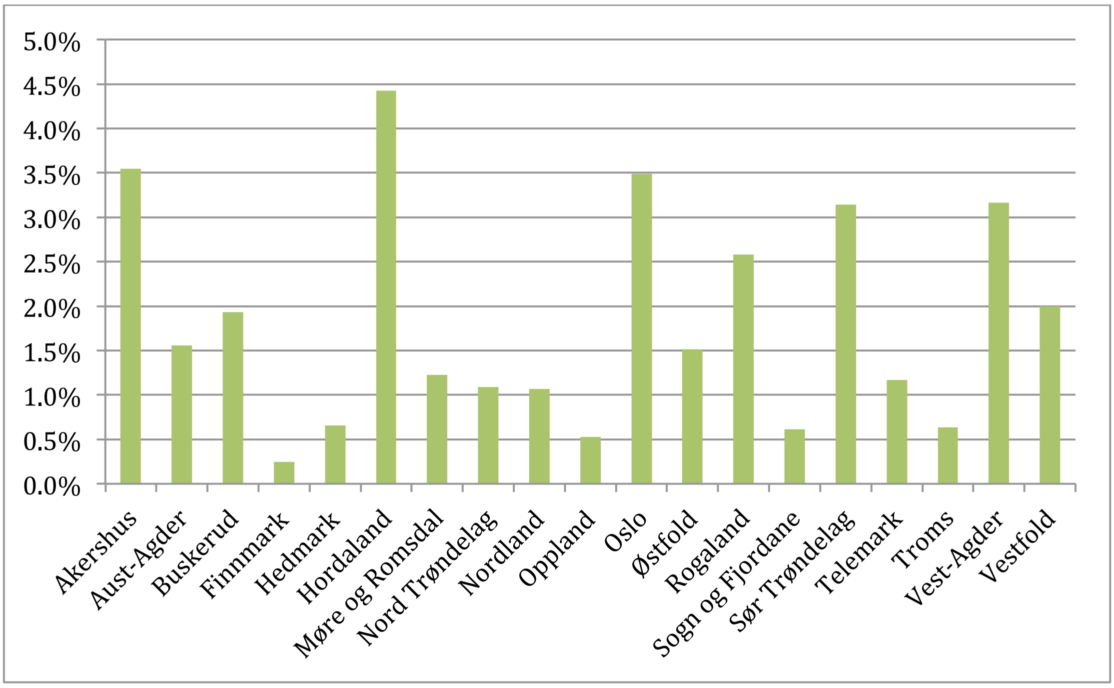
**Figure 5-4 Number of el-vehicles per 1000 inhabitants**




Source: OFV (2015), Statistics Norway (2015b).

Because some counties might be incentivizing alternative transportation more actively, the general behavior in car driving might also explain the increase in the amounts of electric vehicles. Figure 5-5 might allow for some further explanations as it displays the percentage of electric vehicle distribution by county in the total vehicle park. It looks like the electric vehicle share of the whole motor park is in equal proportions as the inhabitant shares, so there is no reason to think that amounts of electric vehicles have increased more rapidly because of county incentive systems.

**Figure 5-5 New el-vehicles share of the total motor park in Norway**



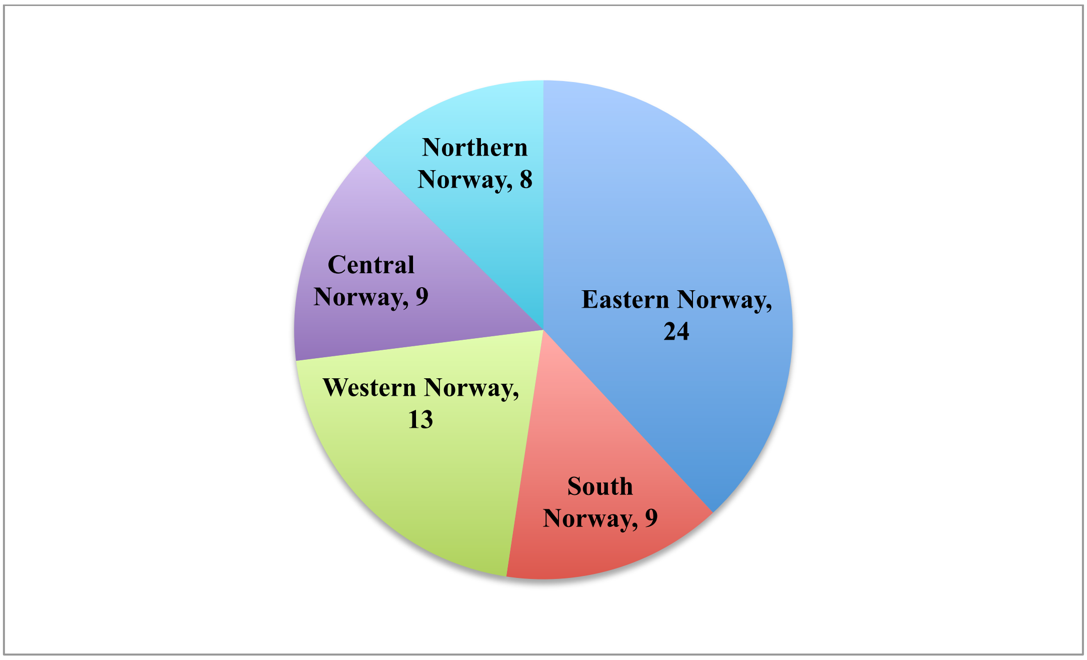

Source: OFV (2015), Statistics Norway (2015a).

### 5.2.1 Road project impacts on EV demand

The reason for the increase in the use of electric vehicles might also be explained by consequences of changes in infrastructure on a geographical basis. For instance, completion of some specific road project that opens a new highway or a tunnel that has high tolls might be enough of a reason for more inhabitants to choose to buy electric vehicles. Because of the Norwegian Government subsidizing electric vehicles in tolls, it is free of charge to pass for these, and the high prices (elastic price elasticity) might just be a reason in itself.

The Norwegian Public Roads Administration (NPRA) is continuously working with different road projects in order to further improve the Norwegian infrastructure. However, improved infrastructure needs to be financed by someone and one of the most common approaches for doing so is implementation of road tolls in areas where road improvements has been completed. Figure 5-6 displays the number of road projects by region in the years 2014 – 2017 that's either planned or completed during this time period (NPRA, 2016e). Comparing this chart to the chart displayed in Figure 5-3, it shows us that there are distinct similarities in each region, which might mean that the amounts of new electric vehicles are correlated to road projects.

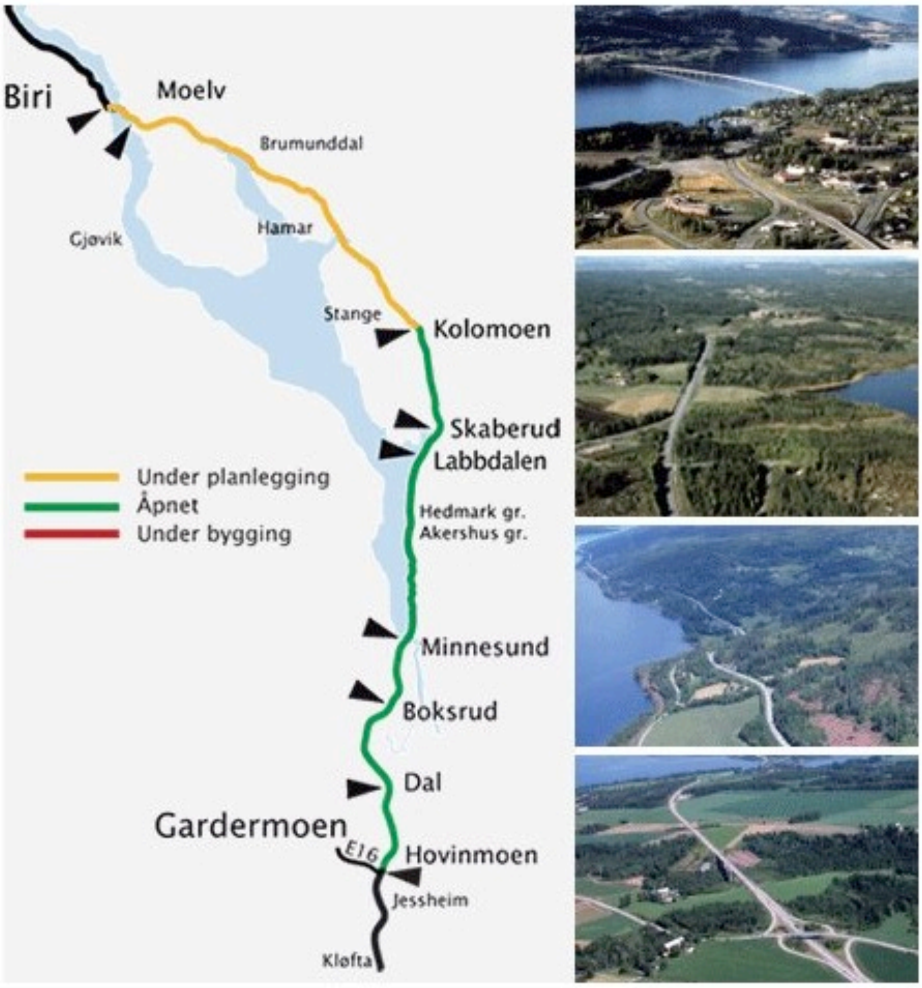
**Figure 5-6 Road projects 2014 - 2017 by region**




Source: NPRA (2016e).

E6 in Norway goes from Svinesund to Kirkenes and is the main connection between the south and the north of Norway; E6 Gardemoen-Biri is a part of this compound. Commissioned by the Norwegian Parliament, NPRA started to expand this route to a four-lane road with a central reservation in December 2007 (NPRA, 2016c). The Figure 5-7 displays the details for the route as it is divided in several shorter distances. Most of the road sections are completed already - Kolomoen-Skaberud and Dal-Hovinmoen were completed in 2009, Skaberud-Labdalen in 2010, Minesund-Boksrud and Boksrud-Dal in 2011 and Labdalen-Minesund in 2015 and the projects total cost of about 8.350 billion NOK is financed by the state and 6 different tolls. The installation of the tolls starts immediately after each section is completed, which might lead to a reaction from the population living in the affected areas. The municipalities that are involved in this project are Eidvoll, Hamar, Ringsaker, Stange and Ullensaker. Because electric vehicles are passing the toll free of charge, it is interesting to investigate and figure out if the road projects and toll implementation has some effect to the electric vehicle consumption in the area.

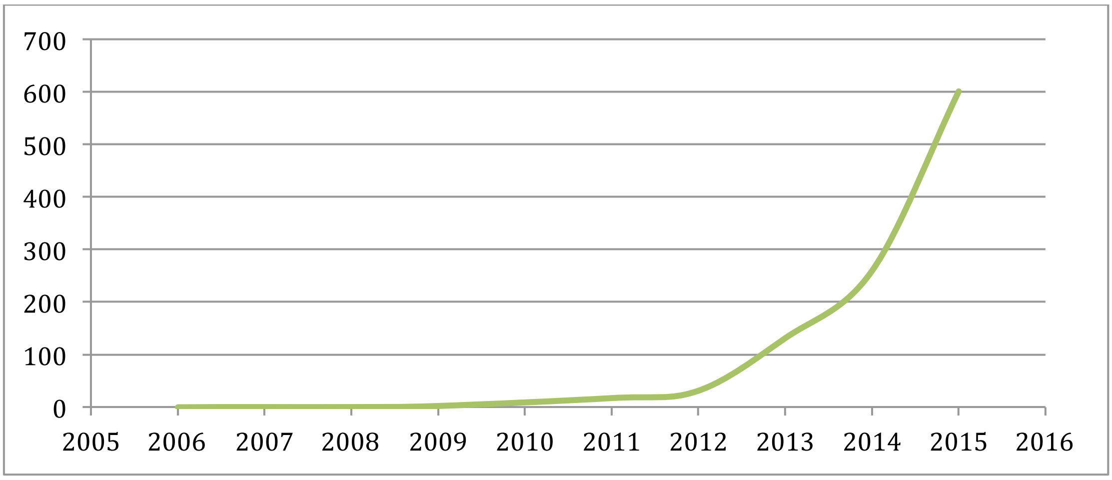
**Figure 5-7 E6 Gardemoen - Biri project**




*Yellow line = planning phase, green line = road open/project completed, red line = construction phase*
Source: NPRA (2016c).

The Figure 5-8 displays the amounts of new electric vehicles in the affected area of the Gardemoen – Biri project for the years 2006 to 2015. The graph confirms the established expectation as numbers of new electric vehicles increases substantially after most of the projects are completed. However, it is important to note that this descriptive analysis does not include several variables such as vehicle characteristics that might be the real reason for these increases.

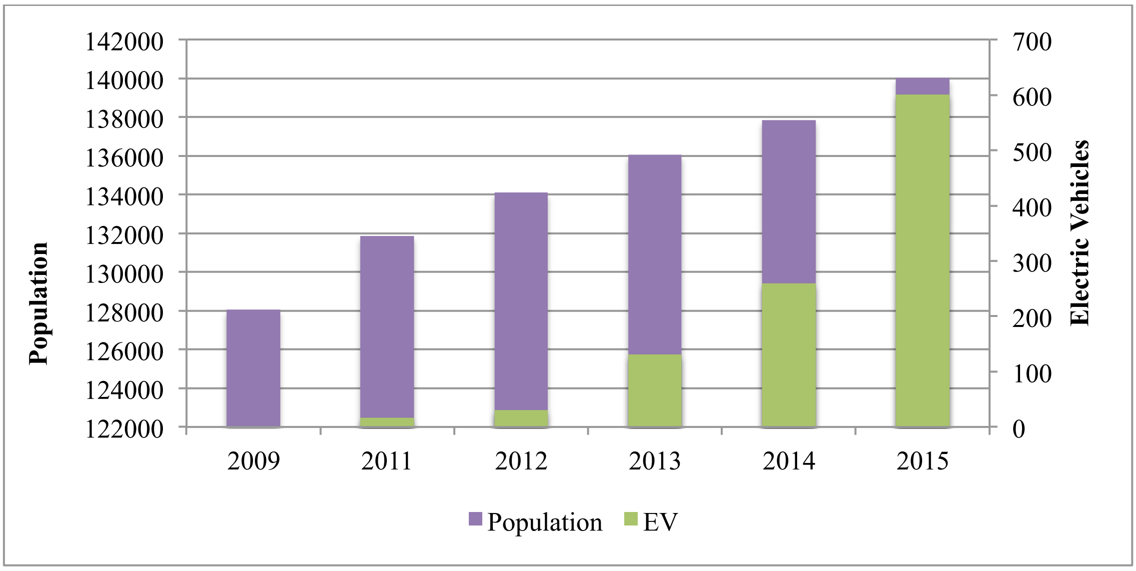
**Figure 5-8 New electric vehicles by year in Gardemoen-Biri project area**




Source: OFV (2015).

To make sure that the increase in electric vehicle-usage in this area is not caused by a sudden population increase, the Figure 5-9 displays both population changes and new electrical vehicles for each year in the area. While the population is increasing gradually, the amounts of electrical vehicles have been doubling in past few years, meaning that there is no evidence for a correlation between these two variables.

**Figure 5-9 New EVs VS Population increase by year**




Source: OFV (2015), Statistics Norway (2015b).

### 5.2.2 Estimations for vehicle kilometers traveled by the Norwegian population in 2013

Regressions in first part of the analysis can be extended including factors that indicates if the household disposes electrical and hybrid vehicles, as well as electrical bicycle (see Table 5-8 and Table 5-9). Because only survey in 2013-2014 data asked questions related to vehicle fuel, the other data sets are excluded from this analysis. The model is very similar to model presented in a previous part – some variables are now excluded and some are added. For instance, vehicle vintage is now excluded as most of the electrical vehicles are relatively new and inclusion of these variables would disrupt the regression. On the other hand, additional variables that indicate if a household disposes electrical bicycle, electrical vehicle or hybrid vehicle are now included in the regression results.

Rebound effects are now even higher than before indicating that people are even more elastic to the price changes. The values lie between 250 and 260 percent (the non-linear model reports even higher values – 249, 314 and 284 percent), indicating that people in 2013 are more elastic. Over the past few years, the awareness of the costs has increased significantly in society and this could explain the results. This means that as long as the population is this elastic, the timing is perfect to implement new government policies that could decrease driving. However, there might be some model disruption that leads to wrongly impression of the present situation. One needs to be very cautious, when interpreting these results.

The new variables are really interesting to interpret in this regression analysis. If a household disposes an electrical or hybrid vehicle, as well as an el-bicycle, the kilometers traveled will decrease (respectively by 3,000 to 3,600 km, 626 to 1,148 km and 1,310 to 1,695 km in linear models 1, 2, 3 and 19-22%, 4-14% and 10% for non-linear models). The hybrid-vehicle variable is not significant (but it is 1% significant in LnVKMT5 model), while the electrical-vehicle variable is significant on 1% level and the el-bicycle is significant on either 1-, 5- or 10%-levels. These results give a great deal of background on the rebound effect-matters as it contradicts the arguments that implementation of an efficient vehicle will increase travel demand. This could mean that that cost-relieve policies for electrical vehicles should be supported.

**Table 5-8 Regression for Vehicles kilometers traveled by 2013 data**

| Variable | VKMT 4 (2013) | VKMT 4 corrected (2013) | VKMT 5 (2013) | VKMT 5 corrected (2013) |
|---|---|---|---|---|
| Const | 44576.721 *** | 35031.721 *** | 49426.970 *** | 33996.778 *** |
| | (6046.556) | (6046.556) | (5946.536) | (5957.599) |
| OPC_km | -9882.662 *** | -9882.662 *** | -9930.949 *** | -9575.746 *** |
| | (1140.469) | (1140.469) | (1143.540) | (1145.668) |
| Age | 93.503 ** | 93.503 ** | - | - |
| | (39.279) | (39.279) | | |
| Age^2 | -1.269 *** | -1.269 *** | - | - |
| | (.406) | (.406) | | |
| Cars_HH | 12090.351 *** | 12090.351 *** | 12988.049 *** | 11995.033 *** |
| | (199.466) | (199.466) | (191.316) | (191.672) |
| Size_HH | 256.411 ** | 256.411 ** | - | - |
| | (112.662) | (112.662) | | |
| DL_HH | 792.899 *** | -2629.101 *** | - | - |
| | (204.622) | (204.622) | | |
| IE_HH | 1778.360 *** | 1778.360 *** | - | - |
| | (267.781) | (267.781) | | |
| Income_HH | -.001 | -.004 | -.003 | -.006 |
| | (.004) | (.004) | (.004) | (.004) |
| Income_HH^2 | 1.624E-09 | 1.624E-09 | 5.482E-09 ** | 3.627E-09 |
| | (2.67E-09) | (2.67E-09) | (2.67E-09) | (2.68E-09) |
| DMC | -92.117 | -92.117 | - | - |
| | (416.451) | (416.451) | | |
| Dscooter | 226.569 | 226.569 | - | - |
| | (417.861) | (417.861) | | |
| Dbicycle | -264.808 | -264.808 | - | - |
| | (282.960) | (282.960) | | |
| Dholidayhome | 788.467 *** | 788.467 *** | - | - |
| | (210.730) | (210.730) | | |
| Dmale | 214.415 | 214.415 | - | - |
| | (208.403) | (208.403) | | |
| Dwest | 694.188 ** | 694.188 ** | - | - |
| | (358.719) | (358.719) | | |
| Dsouth | 4018.732 *** | 4018.732 *** | - | - |
| | (542.188) | (542.188) | | |
| Deast | 2975.421 *** | 2975.421 *** | - | - |
| | (329.594) | (329.594) | | |
| Dcentral | 1364.105 *** | 1364.105 *** | - | - |
| | (485.104) | (485.104) | | |
| Dmetroarea | -1801.648 *** | -1801.648 *** | - | - |
| | (237.272) | (237.272) | | |
| DEduc>10 | 36.128 | 36.128 | - | - |
| | (423.147) | (423.147) | | |
| DEduc>12 | -438.264 * | -438.264 * | - | - |
| | (239.263) | (239.263) | | |
| Delbicycle | -1309.587 * | -1309.587 * | -1599.730 ** | -1695.039 ** |
| | (806.871) | (806.871) | (812-316) | (813.827) |
| DEV_HH | -3606.482 *** | -3606.482 *** | -3312.738 *** | -3007.777 *** |
| | (724.075) | (724.075) | (728-241) | (729.596) |
| Dhybrid_HH | -626.536 | -626.536 | -1148.847 | -979.405 |
| | (798.869) | (798.869) | (805.891) | (807.390) |
| | | | | |
| Elasticity | -2.58 | -2.58 | -2.60 | -2.50 |
| Adjusted R^2 | .215 | .184 | .199 | .164 |
| N | 20854 | 20854 | 20858 | 20858 |

Denotation for significance levels: *** for 1%level, ** for 5% level and * for 10% level; standard errors in parentheses.

**Table 5-9 Regression for vehicles kilometers traveled by 2013 data, log-log model**

| Variable | LnVKMT 4 (2013) | LnVKMT 5 (2013) | LnVKMT 6 (2013) |
|---|---|---|---|
| Const | 10.291 *** | 10.195 *** | 9.741 *** |
| | (.657) | (.552) | (.548) |
| LnOPC_km | -2.488 *** | -3.138 *** | -2.843 *** |
| | (.323) | (.295) | (.292) |
| LnAge | .058 *** | - | - |
| | (.023) | | |
| Cars_HH | .636 *** | .705 *** | .698 *** |
| | (.011) | (.010) | (.010) |
| LnSize_HH | .088 *** | - | - |
| | (.017) | | |
| LnDL_HH | .069 *** | - | - |
| | (.024) | | |
| LnIE_HH | .038 | - | - |
| | (.046) | | |
| LnIncome_HH | .145 *** | .255 *** | .254 *** |
| | (.025) | (.017) | (.017) |
| DMC | .012 | - | - |
| | (.022) | | |
| Dscooter | .037 * | - | - |
| | (.022) | | |
| Dbicycle | .034 ** | - | - |
| | (.017) | | |
| Dholidayhome | .066 *** | - | - |
| | (.012) | | |
| Dmale | .027 ** | - | - |
| | (.012) | | |
| Dwest | .096 *** | - | - |
| | (.020) | | |
| Dsouth | .218 *** | - | - |
| | (.030) | | |
| Deast | .167 *** | - | - |
| | (.018) | | |
| Dcentral | .089 *** | - | - |
| | (.027) | | |
| Dmetroarea | -.109 *** | - | - |
| | (.013) | | |
| DEduc>10 | -.023 | - | - |
| | (.027) | | |
| DEduc>12 | -.008 | - | - |
| | (.013) | | |
| Delbicycle | -.104 ** | -.109 *** | - |
| | (.044) | (.042) | |
| DEV_HH | -.220 *** | -.194 *** | - |
| | (.037) | (.037) | |
| Dhybrid_HH | -.041 | -.139 *** | - |
| | (.045) | (.041) | |
| Adjusted R^2 | .239 | .227 | .239 |
| N | 16524 | 20858 | 16524 |

Denotation for significance levels: *** for 1%level, ** for 5% level and * for 10% level; standard errors in parentheses.

## 5.3 Part III: Ryfast case

### 5.3.1 Background

The Ryfast-road project has been discussed and analyzed for a long time now and the project has been finally initiated fully and is to be delivered by 2019 (NPRA, 2016a). There are currently two ferry services between Ryfylke and North Jæren: Stavanger – Tau and Lauvvik – Oanes. The ferries bind Ryfylkes municipalities Suldal, Hjelmeland, Strand and Forsand, with its 19,500 inhabitants in total, together with the regional center of Stavanger and the rest of North-Jæren. They are also the region's main liaison to the national transport network: E39 Coastal Stamford Road, Stavanger Airport Sola and Risavika harbor. Stavanger – Tau is a connection with heavy traffic. In 2010 an average of 2,192 persons traveled daily by this route and approximately 1,580 vehicles utilized it. Lauvvik – Oanes route have roughly the same traffic as Stavanger – Tau, with an average annual daily traffic of 1,573 travelers in 2009 and 1,300 travelers daily in 2010. Ryfast is a typical ferry replacement project where connection problems vanish when the project is finished. Because the ferry is docked in the Stavanger centrum, there is additional traffic pressure on the road network.

The traffic from Hundvåg and the other islands around it must travel over the bridge and through downtown to reach Stavanger. The capacity is currently overwhelmed and there is a lot of congestion during the rush hours. The Ryfast projects second main purpose is to provide the inhabitants and businesses in Hundvåg/Buøy with a new connection to the mainland in order to facilitate development, settlement and businesses on the islands. In addition, there is currently tremendous traffic in the Tasta/Eiganes area. Adding the Eiganes tunnel to the project, the traffic, which amount to about 35,000 vehicles, will be moved to a better and safer road. The construction of the Eiganes tunnel will relieve local roads for transit traffic. The goal of the project is to lead to environmental improvements along the current road and fewer car accidents. The emerge of the roads will be better, because E39-Eiganes tunnel provides much greater capacity and shorter travel time for drivers. It will also give better conditions for public transportation.

The price of Ryfast is calculated to be 6.4 billion NOK (2014 million) and the Eiganes tunnel is calculated to cost 2.9 billion NOK (2014 million) (NPRA, 2016d). Some of the money comes from state-allocated funding, Stavanger municipality contributes with 200 million NOK, Rogaland County contributes with 103 million NOK, Ryfylke

**Figure 5-10 Ryfast and Eiganes tunnel project**


Source: (NPRA, 2016b)

municipalities funds with 30 million NOK and the Stavanger industry-association gives 30 million NOK. However, these projects will mainly be financed through road tolls so the population´s price elasticity plays an important role here. Because the current government policies are giving free passage to electrical vehicles, there is a high probability that a large portion of the Ryfast population will acquire electrical vehicles in order to escape the toll related costs. Because most of the project funding is planned to come from road tolls, this could extend the financing period significantly. The road toll pricing needs to be reconsidered in a clever and cautious way in order to be effective.

### 5.3.2 Estimated vehicle kilometers traveled in the Ryfast and Eiganes areas

Table 5-10 displays regression results using the same model as in the first part of the data analysis. The difference here is that the population is only the affected municipalities by Ryfast and Eiganes road projects – Strand, Forsand, Hjelmeland, Stavanger, Sandnes, Sola and Gjesdal. Because the price variable in models VKMT 6 and the VKMT 6 corrected are not significant, only the results from models VKMT 7 and 8 are held in focus in this discussion. Only significant variables are discussed as well.

The underlying rebound effect lies between 36 and 40 percent indicating an inelastic population, however the people in this area are still relatively affected by price changes. This could mean that people might seek out for substitutes such as electrical vehicles and hybrids – on the bright side it decreases emissions but it also extends the toll-funding period. Conversely, the values are still significantly higher than other research reports, so one might want to be cautious to draw any conclusions until more data is available and investigated.

The number of cars at a household's disposal is still a significant variable, but it seems to affect approximately 2,000 km less than in the national-based analysis. This means that people in this area already travels less when looking at the number of vehicles as opposed to the rest of the Norwegian population.

Variables for people with driver's licenses in a household again give us a different result (both are significant). Corrected VKMT gives a negative result as it is already interacted in correction measures.

Owners of holiday-homes will travel more than those not owning a holiday home. Vehicle vintage seems to continue the same trends as in the original model – retro model owners will travel the least.

The interesting finding is that the metro area-variable is not significant. This could either mean that city related costs and congestions are not that affecting as in other country areas or substitution transportation such as public transportation is not provided well enough, causing people living in the city to still seek out travel by personal cars rather than using public transport.

Finally, if a person has had an education for more than 10 years (compared to 15 years), they travel less. Even if the income is not significant in this analysis and because lower education often means lower income, the results could indicate that it is a proxy for low income households.

## Table 5-10 Regression for vehicle kilometers traveled by affected municipalities from Ryfast road project

| Variable | VKMT 6 | VKMT 6 corrected | VKMT 7 | VKMT 7 corrected | VKMT 8 | VKMT 8 corrected |
|---|---|---|---|---|---|---|
| Const | 18853.261 | 9308.261 | 8102.910 ** | -1442.090 | 5740.891 * | -7425.036 ** |
| | (17511.93) | (17511.93) | (3852.556) | (3852.556) | (3210.280) | (3224.879) |
| OPC_km | -4219.822 | -4219.822 | -1350.945 ** | -1350.945 ** | -1331.439 ** | -1207.084 ** |
| | (4683.589) | (4683.589) | (655.636) | (655.636) | (584.476) | (587.134) |
| Age | 56.296 | 56.296 | 55.530 | 55.530 | - | - |
| | (80.833) | (80.833) | (80.763) | (80.763) | | |
| Age^2 | -1.215 | -1.215 | -1.207 | -1.207 | - | - |
| | (.858) | (.858) | (.857) | (.857) | | |
| Cars_HH | 11086.218 *** | 11086.218 *** | 11117.920 *** | 11117.920 *** | 10592.562 *** | 9585.883 *** |
| | (517.528) | (517.528) | (514.615) | (514.615) | (422.126) | (424.046) |
| Size_HH | -2.715 | -2.715 | 3.085 | 3.085 | - | - |
| | (216.903) | (216.903) | (216.539) | (216.539) | | |
| DL_HH | 1214.496 *** | -2207.504 *** | 1223.401 *** | -2198.599 *** | - | - |
| | (414.858) | (414.858) | (414.180) | (414.180) | | |
| IE_HH | 551.791 | 551.791 | 537.388 | 537.388 | - | - |
| | (494.715) | (494.715) | (494.002) | (494.002) | | |
| Income_HH | -.005 | -.008 | -.004 | -.007 | -4.645E-05 | -.006 |
| | (.007) | (.007) | (.007) | (.007) | (.007) | (.007) |
| Income_HH^2 | 3.263E-09 | 3.263E-09 | 2.874E-09 | 2.874E-09 | 3.075E-09 | 3.190E-09 |
| | (5.06E-09) | (5.06E-09) | (5.02E-09) | (5.02E-09) | (5.02E-09) | (5.04E-09) |
| DMC | 169.823 | 169.823 | 166.593 | 166.593 | - | - |
| | (950.319) | (950.319) | (949.824) | (949.824) | | |
| Dscooter | -1196.461 | -1196.461 | -1208.617 | -1208.617 | - | - |
| | (1199.711) | (1199.711) | (1198.960) | (1198.960) | | |
| Dbicycle | 597.504 | 597.504 | 573.861 | 573.861 | - | - |
| | (583.010) | (583.010) | (581.794) | (581.794) | | |
| Dholidayhome | 1721.350 *** | 1721.350 *** | 1749.087 *** | 1749.087 *** | - | - |
| | (455.126) | (455.126) | (450.209) | (450.209) | | |
| RetroVintageHH | -4850.106 *** | -4850.106 *** | -4957.382 *** | -4957.382 *** | - | - |
| | (1222.831) | (1222.831) | (1202.165) | (1202.165) | | |
| OldVintageHH | -1560.478 *** | -1560.478 *** | -1761.566 *** | -1761.566 *** | - | - |
| | (534.023) | (534.023) | (431.040) | (431.040) | | |
| NewVintageHH | -1618.395 ** | -1618.395 ** | -1318.876 *** | -1318.876 *** | - | - |
| | (705.735) | (705.735) | (520.019) | (520.019) | | |
| Dmale | 376.270 | 376.270 | 384.455 | 384.455 | - | - |
| | (441.196) | (441.196) | (440.775) | (440.775) | | |
| Dmetroarea | -834.581 | -834.581 | -830.581 | -830.581 | - | - |
| | (567.591) | (567.591) | (567.244) | (567.244) | | |
| DEduc>10 | -1667.676 ** | -1667.676 ** | -1644.670 ** | -1644.670 ** | - | - |
| | (822.037) | (822.037) | (817.950) | (817.950) | | |
| DEduc>12 | 497.974 | 497.974 | 475.724 | 475.724 | - | - |
| | (493.955) | (493.955) | (492.492) | (492.492) | | |
| D2013data | 4071.223 | 4071.223 | - | - | - | - |
| | (6608.285) | (6608.285) | | | | |
| D2009data | 1236.612 | 1236.612 | - | - | - | - |
| | (3303.894) | (3303.894) | | | | |
| Elasticity | -1.24 | -1.24 | -.40 | -.40 | -.39 | -.36 |
| Adjusted R^2 | .354 | .301 | .355 | .302 | .322 | .260 |
| N | 1463 | 1463 | 1463 | 1463 | 1463 | 1463 |

Denotation for significance levels: *** for 1%level, ** for 5% level and * for 10% level; standard errors in parentheses.

# 6. CONCLUSIONS

By analyzing the Norwegian National Travel Survey data for years 2005 – 2014, this thesis has been investigating the underlying rebound effects for the Norwegian population as well as household- and vehicle characteristics that affect travel demand for kilometers. The purpose of the thesis is to answer the underlying research questions and set a perspective for potential future research accumulation.

The rebound effect is an estimation that calculates if an implementation of either technological improvements or some specific government policies lead to the expected decrease in energy demand (and therefore decrease in greenhouse gas emissions) or if the environment is actually worse off after the implementations. These calculations can be based on direct, indirect or economy wide effects, as well as on consumer versus producer side rebound effects. The thesis has been investigating consumer side direct rebound effects in the transportation sector.

The model used in the data analysis is based on a research paper done by Sarah West (2004), but some adjustments are made due to data availability. The regression models are formed in either linear-regression format or in non-linear form (ln-ln). The dependent variable is vehicle kilometers traveled and some models correct the variable by deducting the typical amount of kilometers traveled by the household type. The difference between regression models are otherwise determined by how many and which variables are included or excluded from the model as it is the main factor for why the results differ in a significant manner. Some of the key findings deviate from a previous research on a level that makes one to be suspicious if there are some irregularities in either model or in the dataset. These findings are still not excluded from the thesis, as it could be interesting to investigate the reasons for these differing results as well as leaving the reader to judge the findings themself.

RQ1: What are the rebound effects in the transportation sector of Norway?

Rebound effects lie between 41% and 222% for the Norwegian transportation sector on a personal car-basis and most of the results indicate a very elastic population. It also indicates that the rebound effect is either on partial rebound (some of the improvements are offset) or even on backfire (energy efficiency implementations make the environment worse off than before). The results are very different from other research materials as rebound effects usually are found to be approximately 20% - partial rebound and therefore indicating that only some of the improvements are offset. If the year variables are excluded from the regression, the rebound effect is 41% partial rebound indicating for an unelastic population, but these findings are still much higher than other research papers usually report. Ln – Ln model estimates the rebound effect to lie between 72.8 and 280 percent. Such high numbers is a concerning finding.

RQ2: What is the overall and regional electric vehicle share in Norway?

The second part of the analysis indicates that the amount of new and imported electrical vehicles have increased significantly over past few years and that the Norwegian policies incentivizing electrical vehicle use might be the reason behind these numbers. There is some evidence that high costs related to toll roads has had an impact on the decision making-process for consumers to switch to electrical vehicles from fossil fuel vehicles, but the results aren't conclusive and need to be investigated further more. The regression model including the vehicle fuel type leads to rebound effects that lie between 250% and 260%. The Ln – Ln models reports a rebound effect that is 314%. These are extreme backfire results that do not correspond to other research on this subject and one need to be cautious when interpreting these findings. There might as well be something wrong with the model or data so it is essential to investigate these findings further.

RQ3: What are the rebound effects in the Ryfast and Eiganes case?

For the Ryfast and Eiganes case, the regression results again lead to different results depending if the year variables are included or not. However, because of the price variable that is used in the elasticity calculations is not significant for regression with the year variable, the models without the year variables are presumed as the key findings. The regressions report a rebound effect between 36 and 40 percent. This indicates an inelastic population, but still a much higher rebound effect than other research papers report.

All of these results imply that the government policies need to be considered and evaluated very carefully when decisions are being made, as the results indicate that the population is very sensitive to price changes. For instance, if toll roads are made too expensive, many people will switch to electrical vehicles as they pass free of charge. It is very good for the environment, but the funding of the road will be extended dramatically and the congestion will probably also worsen. In addition, the government will have to pull most of the incentivizing policies if majority of the population switches to electrical vehicles.

However, rebound effects are a very complicated matter. Because of complicated structure issues, it is difficult to estimate a complete rebound effect that shows the correct bearing setting of the matter. For instance, electrical vehicles are presumed to have zero tailpipe emissions in government policies. This is very unfortunate assumption because of the fact that electrical vehicles are carbon and energy intensive both in the supply chain as well as at the end of the vehicles life cycle. This sets a perspective for future research on the topic of rebound effects. Firstly, because it is hard to measure indirect rebound effects, it is essential to work further on this matter in order to find a proper way to estimate the issue. Secondly – rebound effects on the producer side should be compiled to the consumer side effects when government policies are considered.

Another potential further analysis that could be both interesting and useful to investigate is metro area-estimations for vehicle kilometers-demand. Congestions are most often forming in cities and the policies targeting driving would have a use for more investigation mapping out the population´s behavior and elasticity. The findings in this thesis shows that people living in metro areas already drive less compared to those who do not. However, this makes sense because of people not living in the city might still be working in the city and the way to work is therefore longer for them – ergo they travel more kilometers during the year. However, another probable reason could be the city-cost and congestion related issues – already implemented city policies might be working and fulfilling its purposes and mitigate the vehicle kilometers demand. The variable mean table confirms this as people in the city also disposes fewer vehicles than those who live outside of the city. It is therefore interesting to find out which of the initiatives are working best in a potential future analysis.

Another notification is the holiday-home variable. This thesis has been investigating direct rebound effect, but this variable could be taken as a proxy for holiday travel in general and might be interpreted as an indirect rebound effect. Meaning that the saved money might be used on a journey to Spain or Thailand that again requires travel by an airplane, leading to enormous GHG emissions in comparison to the saved emissions by EV travel. This could be evidence for an indirect rebound effect presence but supplementary research needs to be in place for any more justified discussion.

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