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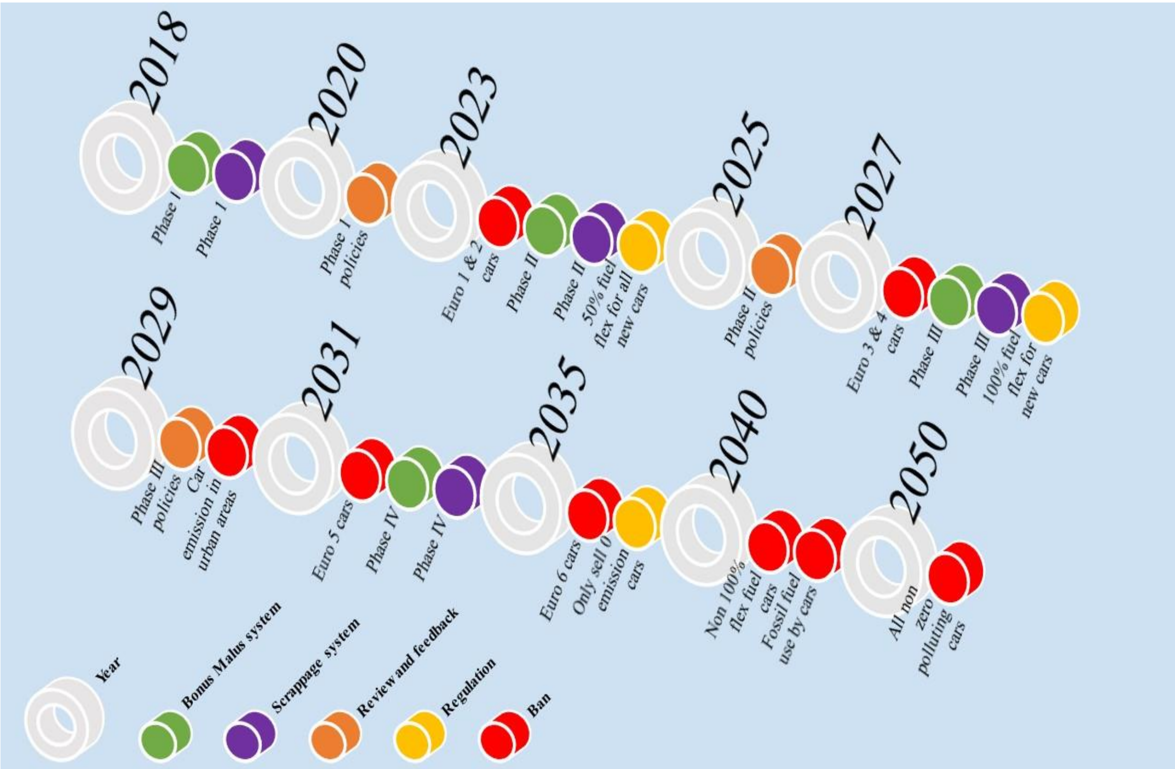

Analysis and application of policy incentives for a fossil free personal transport system in Sweden by 2050

A fossil fuel freedom roadmap for the personal vehicle sector

Master's Thesis within the Sustainable Energy Systems programme

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CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER’S THESIS

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Cover:
Diagram depicting the policy implementation strategy for a fossil free personal transport sector in Sweden by 2050.

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Gothenburg, Sweden

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ABSTRACT

Sweden's political leadership has fully committed to their vision for a clean, safe and efficient transport system, completely free of fossil fuels. In 2008, an ambitious plan was put forward by the Swedish government– To be entirely fossil free, as a nation, by 2050. As a prelude to this vision, an intermediate target was given to the transport sector – To be fossil fuel independent by 2030. However, this commitment has not yet been effectively translated, into a wholesome transition strategy. With time running out, a clear action plan with a robust policy system is to be formulated and implemented. The objectives of this thesis are to study these visions using a planning methodology called backcasting, with the scope being the Swedish personal vehicle sector. Using this methodology, a wholesome vision for the personal mobility is proposed and the impact of current initiatives by the government to reach these visions are studied. Next, a market based policy framework which could achieve the visions in the most sustainable manner, is proposed. Finally, a roadmap for the implementation of the policy framework is also proposed, designed to meet the twin visions for 2030 and 2050.

Key words: Personal vehicle, Fossilfree, Transition, Policy, Strategy.

Contents

Preface

This document is a thesis report of Masters of Science in Sustainable Energy Systems, a 120 credits program offered by the Department of Energy and Environment, from Chalmers University of Technology. The period of study was February 2016 to July 2016. The thesis was conducted at SWECO AB, at their office in Göteborg, Sweden. Supervision was provided by both SWECO and from the Department of Energy and Environment at Chalmers, through the division of Physical Resource Theory.

Göteborg August 2016

Siddharth Radhakrishnan

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Thanks to all the teachers and mentors who inspired and influenced me, culminating on the chosen topic for my thesis. You have challenged and shattered my notions and presumptions, and for that, I am a better human being. Thank you.

To all my colleagues and dearest friends; you provided me with the light, whenever the mind was cold and dark. Thank you.

This work is dedicated to my family – my mother Renuka, my sister Mrinalini and my brother-in-law Jordin – for the unconditional love and support, helping me chase my dreams. Thank you.

Göteborg August 2016

Siddharth Radhakrishnan

Acronyms

EEA – European Environment Agency

ETS – European Trading Scheme

EU – European Union

GHG – Greenhouse gases

ICCT – International Council on Clean Transportation

IPCC – Inter-governmental Panel on Climate Change

ITE – Institute of Transport Economics

ITS – Intelligent Traffic Systems

SEA – Swedish Energy Agency

STA – Swedish Transport Agency

TWh – Tera Watt hours

1 Introduction

1.1 Background

In late November 2015, a week before the crunch talks at the Paris climate negotiation table were to commence, Sweden had an announcement - The climate and environment minister, Åsa Romson, declared that Sweden would soon be a fossil fuel free welfare state [Fossil Free Sweden Initiative, 2015]. Earlier in September of the same year, in the state budget announcement, the government had announced that it plans to invest 4.5 billion kronor in climate protection measures, towards this goal. Although there has been no fixed timeline to achieve this aim, 2050 has been suggested to be the date of realization.

How much of a challenge is this? A quick look at current statistics might give us an idea. For the year 2013, the total energy supplied within Sweden is 565 TWh [Energy in Sweden, 2015]. Fossil fuel energy's contribution to this is 167 TWh, which amounts to 30% of total supply. Crude oil and petroleum contributes to 140 TWh of the supply, meaning roughly 82% of fossil fuel supply is from oil. Thus, if Sweden wants to be fossil fuel free, then current use of oil products is by far the biggest problem to be solved.

Out of the total final use of 96 TWh of oil products, 13 TWh is in the residential sector, 10 TWh in the industrial sector and 2-3 TWh in the electricity sector [Energy in Sweden, 2015]. The remaining 71 TWh, that is roughly 74% of all oil use, is in the transport sector. With 93% of domestic transport usage being road transport, it is clear that the number one challenge in making Sweden fossil fuel free is to phase out the usage of oil in road transport.

So is it possible to phase out oil products from an entire sector dependent on it, within a relatively short span of 35 years? Fortunately, history itself provides the answer to this. In 1971, the oil usage in the residential sector was 110 TWh, amounting to roughly 70% of total energy usage in the sector [Energy in Sweden, 2015]. By 2007, this had reduced to 15 TWh, a whopping 86% in reduction. This was the result of a combination of many market and technology related factors; High oil prices caused due to the oil crisis in 1973, the government introducing a carbon tax and the rise of biomass CHPs and heat pumps, shifted the demand away from oil towards cheaper electricity.

So is the same approach to the transport sector applicable in current times as well? This time around, the global economy is sluggish and oil prices are at record lows. With the advent of self-driving cars, car sharing, electric bikes etc., the future of the transport system is dynamic and unpredictable. It is very clear that the government needs to be proactive and quick to implement a wholesome strategy for a fossil fuel free transport sector.

The government from their part, has recognized the importance of shifting the transport sector to a fossil free one and placed a target of a fossil fuel independent transport fleet in Sweden by 2030. This was included in the bill passed in 2009, where the Swedish parliament determined Sweden to have a net zero GHG emitting energy system by 2050 (Bills 2008/09:162 & 163). To develop a strategy for the same, a commission was appointed and their report came out in Dec 2013 (SOU 2013:84 - Fossilfrihet på väg).

The 2050 goal for achieving fossil fuel freedom from all sectors have been studied and a roadmap strategy to achieve the same have been proposed by Swedish Environment Agency, supported by the Swedish Energy Agency. The study takes a forecasting approach, using estimated emission trajectories of different sectors and assumptions regarding existing nuclear power and application of CCS technologies [International Energy Agency – Sweden Review, 2013]. Overall the roadmap suggests the following actions:

- Significant reductions in domestic emissions;
- Increase net uptake of carbon in forests and fields;
- Purchase emission allowances from the international market;
- Increased investments in research and innovation, and for the transport sector in particular, increased investments in research and infrastructure.

The 2030 target of having a fossil fuel independent vehicle fleet have been interpreted in two different ways :

- Have a fleet where fossil fuels could be replaced by other fuels in practice;
- Achieve 80% reduction (from 2007 levels) in fossil fuel usage in the transport sector.

It is all the more clear that, to achieve such a large reduction in fossil fuel usage by 2030, in a relatively short span of 15 years, would be no mean feat and would require clear market incentives in the short term; through cleaner technology, or taxing the polluter or a combination of both. It is also clear that for the complete net decarbonisation of the transport sector by 2050, long term policy initiatives and regulations would be necessary.

1.2 Thesis objectives

The thesis objectives are three folded:

- To study the current policies in place, and the future policy proposals from the Swedish government for the required transition to a fossil free transport sector and analyse the gaps, if any.
- Analyse and identify the policy ecosystem components required to enable this transition and meet the targets for 2030 and 2050.
- Propose a long term implementation strategy for the policy eco-system, with clear timelines and achievement milestones, such that targets are met for 2030 and 2050.

The planning tool of Backcasting is used as an overarching methodology to achieve the said objectives. The following study/analysis are conducted as part of this methodology, such that the thesis objectives are achieved:

- Analysis and establishing a sustainability development framework, where the economic, social and environmental challenges of the required transition is mapped.
- A discussion on the various stakeholders of a vehicle during its entire lifetime; manufacturers, customers, service providers etc., focusing on their perspectives on sustainable growth, within the proposed sustainability framework.
- Creation of an overarching vision which acts as a guiding principle for solution design.
- A literature review on the current state of the strategy and the recommended solutions from the government side, directed to help realize the two targets. The study would revolve around the report (SOU 2013:84 - Fossilfrihet på väg), which will be summarized and the implementation status of the recommendations reported. The review would also include the policy framework implemented by Norway and France, who have both tried to reduce the usage of fossil fuel usage in the transport sector, by use of market based policies. Gaps in the current strategy to achieve the declared vision is then realised and discussed.
- Formulation of a policy ecosystem, consisting of market and legislative measures which will steer the personal vehicle sector from the current state to the vision state. Research based on all parameters which connect vehicles to the environment will be considered and their relative impact will be studied.
- Creating a long term implementation strategy for the new policy ecosystem so as to stimulate and shift the market towards the overall vision, in such a manner that government targets are met, sustainable growth for the stakeholders is maintained, all the while societal cost for the transition is kept to a minimum. Reasoning behind regulations and emission milestones would be discussed, along with a study on the impact of different policy initiatives on fleet emissions.

Thus a roadmap for decarbonisation of personal transport, with the vision as the destination, with milestones of progress and with a timeline of the policy injections will be a desired output from the study. The results of the study would be presented and discussed with experts in a workshop, which acts as a review and authentication of the thesis.

1.3 Thesis scope

Transition of transport sector as a whole is a highly complex multi-sectoral problem involving multiple stakeholders and decision makers. For the purpose of reducing this complexity, the scope of the thesis has been reduced to personal mobility only. Thus in the backcasting process we look at the future of personal transport at 2050, and develop the vision for personal mobility in Sweden. The policy framework and implementation strategy would then be made in such a way to reach the twin targets of 2030 and 2050 in the personal transport sector, while keeping the vision as guide and map.

2 Methods

The main method used for answering the thesis objectives is Backcasting. A literature review is also used as a method, and this is included in the Backcasting process. A workshop with experts is also conducted at the end of the thesis, to verify and discuss the results of the backcasting process.

2.1 Backcasting

For any future oriented study, one can opt for a predictive methodology or a normative one. Forecasting is the most typical predictive study, where current trends are studied and their status predicted in the future. It has been, and still is, an effective tool for decision making.

Backcasting however, goes for a normative style of study. It can be defined as a method to develop normative scenarios in order to explore the feasibility and implications of achieving certain end points [Robinson, 2003]. Backcasting was made popular in energy studies by Lovins in 1977, where the oil crisis forced a new look at planning where energy demand could be calculated way ahead in the future.

Backcasting is an excellent planning method when the problem looked at has the following characteristics [Dreborg, 1996]:

- Extremely complex, spanning sectors and multi levels in the society.
- Major change is needed; when the current trends and their projections are not enough to achieve them.
- Dominant trends are part of the problem.
- Problem to a great extent is a matter of externalities, which the market doesn't efficiently cover.
- Time horizon is long enough to allow the scope for deliberate choice.

In Sweden, backcasting has been implemented as a planning methodology from the 70s for energy future studies. According to The Natural Step, backcasting is more effective than forecasting, which might result in a more limited range of options, hence stifling creativity. Also, forecasting relies on what is known today; but that knowledge is always imperfect and things change over time. Backcasting comes with its disadvantages as well; it is difficult to develop a successful sustainability strategy which is agreed upon by all stakeholders. The process if often long and tedious, and often detailed plans may need to be changed due to technical difficulties/development. [Beloff,Lines & Tanzil, 2005]

The backcasting approach would be the backbone of the thesis, providing the path to effectively plan and design the policy framework which would then be used to formulate the implementation strategy to achieve the goals.

2.2 Literature Review

To achieve the thesis objectives, it is imperative to study and discuss what Sweden and other prominent European countries have planned and devised to achieve their respective decarbonisation goals in the personal transport sector. For this purpose, a literature review is conducted on Swedish government's studies on the topic, focusing on the reports 'Fossilfrihet på väg' and 'Ett bonus-malus-system för nya lätta fordon', released in December 2013 and April 2016 respectively.

For comparative purposes, a literature review is also conducted on the policies made by France and Norway, to decarbonise their personal transport fleet.

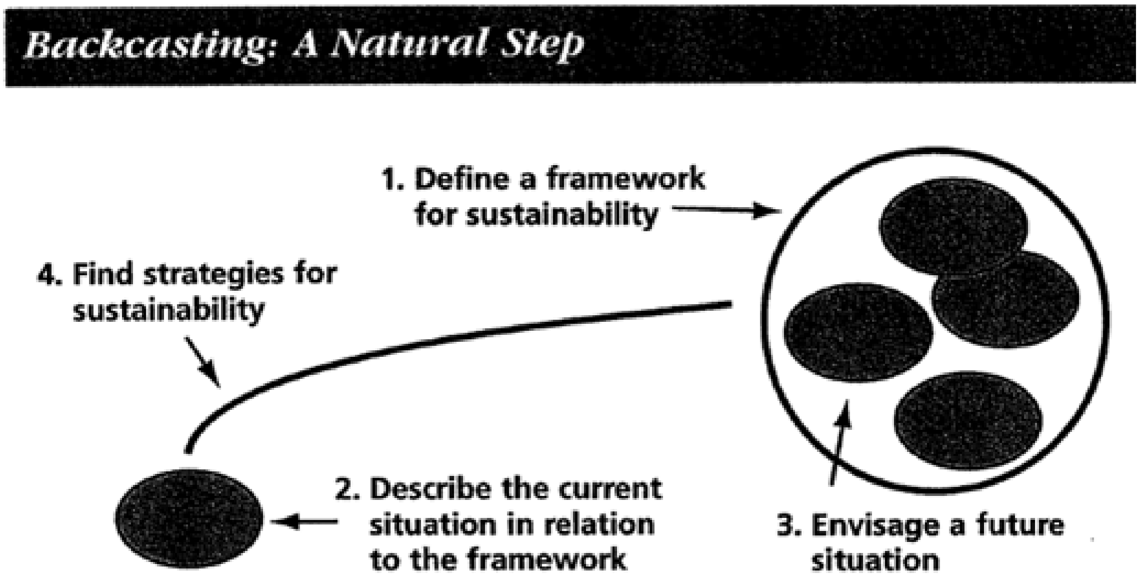
2.3 Expert Workshop

The final implementation strategy is presented to experts in the field for their review and comments. This is seen as a method of validation from highly experienced peers. The review is conducted as a workshop, where the results of the thesis are presented and a discussion is followed regarding the topic. The details of the review is provided right before the conclusion of this report.

3 Backcasting for strategic planning

The backcasting methodology is a planning tool used for devising any sustainable transition, and it is the back bone on which this thesis has been constructed. The process can be explained using the figure below:

Figure 1: Backcasting flow diagram [Holmberg, 1998]



As can be seen from the figure, the first step of the backcasting process is to define the framework for sustainability. This step help define the boundary conditions which is needed for the future, so that the target meant to be achieved is within these boundaries. The boundary conditions are such that they ensure that the future state is a sustainable one for all of humanity. In this thesis, the social, economic and environmental limitations for the year 2050 is studied and why it may not be affordable, not to have a transition to a fossil free state. Special focus is made on personal mobility in Sweden.

In the second step of backcasting, the current situation in relation to the framework is studied in detail. Here the current state of personal mobility in Sweden is looked at in detail, with a special focus on personal vehicles. In order to get the complete picture, a literature review is conducted on the Swedish government's efforts to induce changes is also discussed and summarized. The review would also include governmental efforts to curb fossil fuel usage in personal transport from 2 other major countries in Europe.

In the third step, the focus is on visualizing an ideal future for personal mobility in Sweden at 2050. Using the framework constraints and the details of the current situation, a vision is framed which is meant to be a guide for systems thinking and decision making. As before, a special focus is made on the thesis topic, personal vehicle sector in Sweden, and a discussion on the stakeholders and their possible interpretation of the vision is summarized.

After this step, we take a view at the governmental goals for 2030 and 2050 and assess whether current (and proposed for the future) policies would be able to achieve these goals or not. For this the data gathered in step two will be taken into consideration. After the need of a new solutions for transitions is established, step four of backcasting is begun. As the thesis focus on personal vehicle transition, market policy solutions for its transition to meet the government goals, while staying true to the vision, would be designed. Other solution ideas shall be briefly discussed in the discussion section, at the end of the report. The backcasting process for this thesis is concluded with the formation of a policy framework, where different policies can be 'switched on or off' according to the need and target.

4 Backcasting Step 1 – Setting the boundary conditions

4.1 Introduction

The backcasting process begins with setting up the boundary conditions for the future world we live in. The question to be studied here is - ‘What are the conditions to be met by a society such that its future generations are not adversely affected by its activities?’ In other words – ‘How can a society be sustainable in its activities, in the long run?’ To answer this question, the thesis looks deeper into sustainability and its principles.

Sustainability can be described using its dimensions and principles. The three interrelated dimensions have been described as ‘the three pillars of sustainability’ or ‘the triple bottom line’ (Elkington, 1997) and they are:

- Ecological
- Economic
- Social

The dimensions affirm that for a process or behaviour to be sustainable, it needs to be ecologically, economically and socially sustainable. This can be translated as judicial and efficient use of natural resources, in a healthy economy, results in the wellbeing of the society.

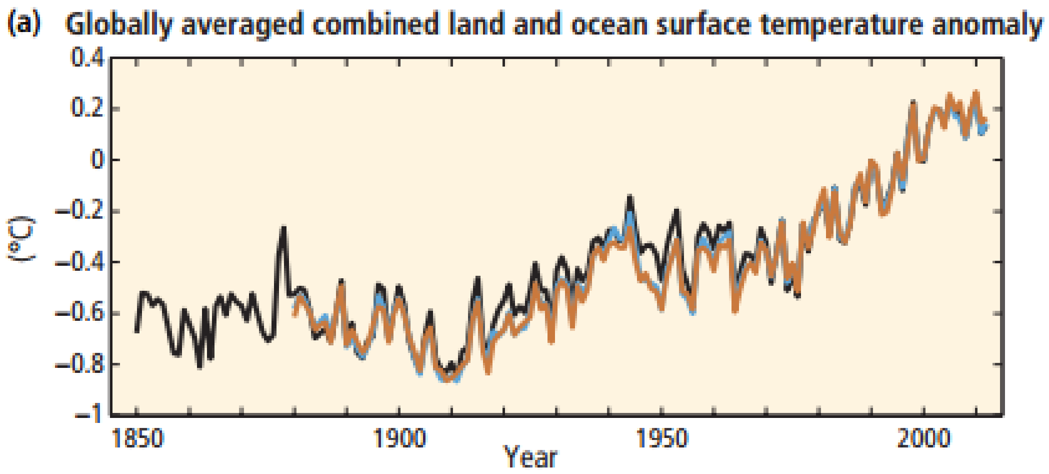
In order for a society to be sustainable, certain principles or system conditions need to be met [Holmberg & Robert, 2000], which are:

- Concentration of substances extracted from the Earth’s crust should not adversely affect nature’s functions and diversity;
- Concentration of substances produced by society should not adversely affect nature’s functions and diversity;
- Natural resources are not impoverished by over-harvesting or other forms of ecosystem manipulation;
- Natural resources are used fairly and efficiently in order to meet basic human needs worldwide.

It is apparent that in the pursuit of the fourth system condition, which is the need to attain social sustainability for mankind, we constantly push the threshold of the other three system conditions, which incidentally pertain to ecological sustainability. Society as we see today, have broken the system thresholds of ecological sustainability, and the perfect example of an after effect, one which is relevant for this thesis, is climate change.

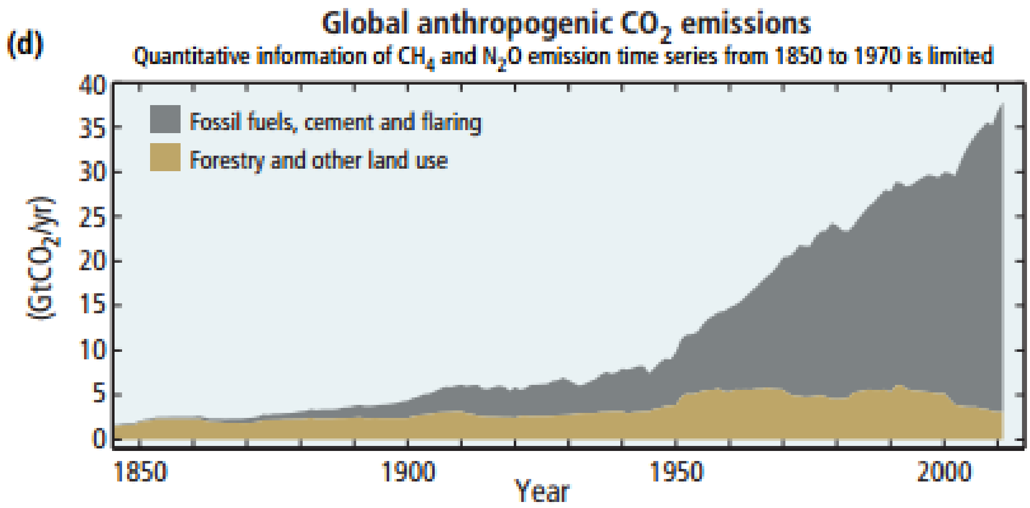
Climate change is highly linked to the phenomenon of global warming. Global warming is described as an increase in the earth’s average temperature and it has been a steadily increasing phenomenon since the 1950s, as can be seen below from the chart.

Figure 2: Avg. global temperature [IPCC Assessment report, 2014]



This rise in temperature co-relates almost identically with the rise in greenhouse gas emissions in the world. From the chart below, it is evident that CO_2 emissions from burning of fossil fuels is the main contributor to global warming from the 1950s.

Figure 3: Global anthropogenic CO_2 emissions [IPCC assessment report, 2014]



The IPCC panel of climate change experts testifies this data, and states the following [IPCC Assessment report Page 64 Section 2.3, 2014] –

‘Continued high emissions would lead to negative impacts for biodiversity, ecosystem services and economic development and amplify risks to livelihoods and for food and human security.’

The science makes it clear that to have a sustainable society in place, the world must reduce and eventually stop the burning of fossil fuels. With these arguments in place, the thesis testifies the Swedish government’s target to be a fossil fuel free state to be upheld.

4.2 Sustainability framework for the personal vehicle sector

The personal vehicle sector in Sweden has therefore, the tough task to transition away from fossil fuelled vehicles to cleaner vehicles. This transition could be achieved by shifting the demand to other cleaner transport systems, and also by using alternative vehicle technologies and/or alternative fuels. The system conditions for a sustainable society, discussed in the previous section, can be used to study the effects of such a transition.

4.2.1 Material extraction affecting nature's functions

Most energy sectors around the world and in particular, transport, require oil based petroleum products. By current estimates, the Reserves to Production ratio (R/P) of the use of oil is at 52 years [BP statistical review, 2015]. Technologies such as fracking, and explorations at sensitive areas such as the arctic may increase this ratio but pose a much greater risk to the local environment. Alternative bio-based fuels are already in the market that are technically renewable, even though their production is bound by system boundaries such as tillable land and freshwater use. Such fuels also compete for land with food production and other more valuable crops to society. Materials required for making of vehicles also need to be considered, where mines all over the world cater to their production and affect the local environment. For the scope of this thesis, discussion shall be limited to fossil fuel uptake.

4.2.2 Material use affecting nature's functions

Transport sectors all around the globe are highly dependent on oil and its refined products, and Sweden is of no exception. In 2014, out of all new personal vehicle registrations in Sweden only 1.3% didn't need any kind of fossil fuel to run [ICCT pocketbook, 2015]. In addition to global warming through CO_2, burning of oil causes local pollution, dust and noise which in an urban setting upsets social and ecological balances. Use of carbon neutral alternative fuels would reduce contribution towards global warming to a great deal, but not local urban pollution.

4.2.3 Resource impoverishment through over harvesting

Limited land is available for agriculture, in which intensive food and fuel crop production create reduced fertility in soil. Currently, the most popular non fossil fuel based propulsion system are Lithium based batteries. Under current trend, R/P of Lithium is set around 330 years [Tahil, 2007], but this could drastically reduce if the technology takes off during the transition phase. Reusing and recycling would be even more important in this case.

4.2.4 Unfair and inefficient use of natural resources

As oil becomes scarcer and more concentrated in a few countries in the future, the burden of transition would become heavier on the future generations. It is unfair to pass on an economy built on fossil fuel usage to the next generations who would not be able to do the same. That oil as an energy source is inefficiently used is also a major concern. In automobiles, only 20%-30% of the energy content in oil is being converted into meaningful work. Currently, other propulsion technologies exist in the market which are oil free and more efficient, and these would be important during the required transition.

4.2.5 Framework description

Thus, a brief description of a sustainability framework for the personal transport sector in Sweden is given below:

- Use of oil as a transport fuel must be reduced and eventually phased out, as its use contributes highly to the twin effects of global warming and local pollution.
- Use of alternative fuels which are carbon neutral may still cause local pollution and need the use of fertile land and clean water, which then cause unwanted secondary effects. Thus its use must be highly regulated.
- Use of technology which does not need fossil fuels has to be nurtured and supported. This support needs to be made in such a way that economic sustainability of the stakeholders involved is maintained.
- Use of transport needs to be made as efficient as possible. This might mean supporting all measures which reduces travel needs and/or make travel choices as sustainable as possible.

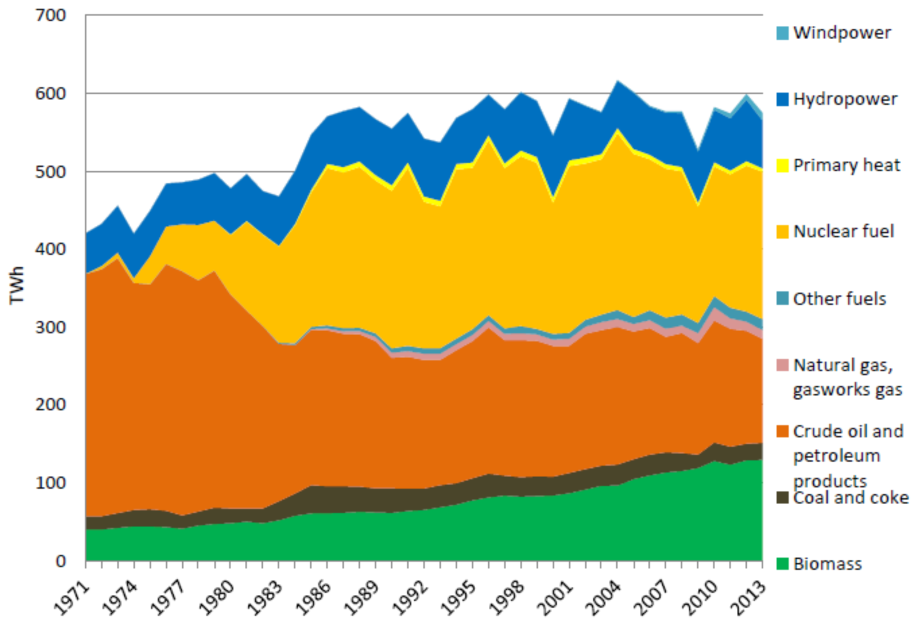
5 Backcasting Step 2 - Studying current situation

5.1 Introduction

Now that the framework for sustainability is established, the next step is to study the current situation in relation to the framework. The focus is on personal mobility in Sweden, in particular the personal vehicle segment and the approach would be to study the current market and policies which dictate the market and during the lifetime of a vehicle.

It is already established in the previous section that in order to have a sustainable society, there is a need to reduce fossil fuel usage, eventually phasing them out. Fossil fuel supply in Sweden, as a share of total energy supplied, can be seen in the figure below:

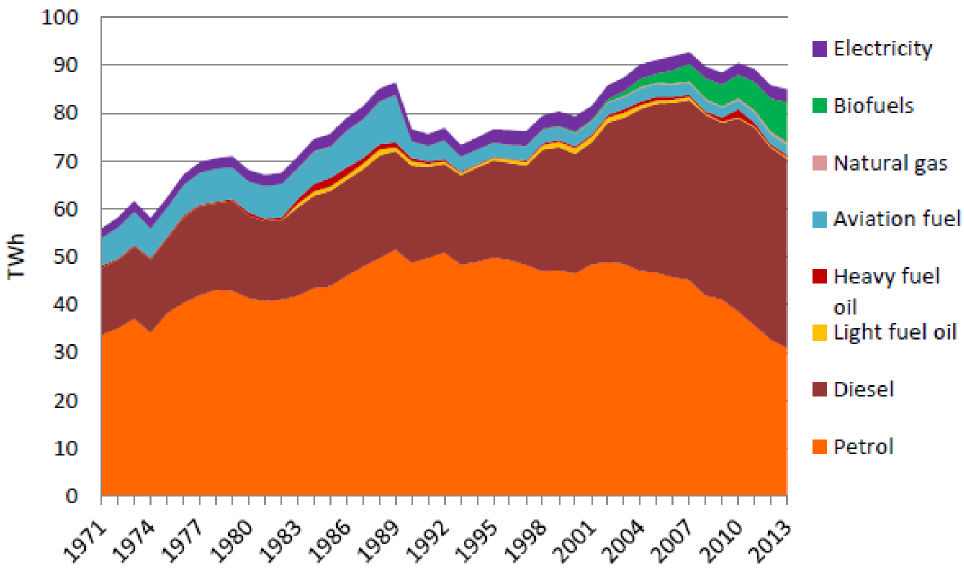
Figure 4: Total energy supplied in Sweden [SEA and Statistics Sweden, 2015]



It can be seen that total energy supply has increased from around 415 TWh in 1971 to 565 TWh in 2013 – an increase of 150 TWh in 42 years. In the same period, the contribution of fossil fuels towards energy supply has reduced from 77% to 30%. Thus we can see that Sweden has succeeded in some degree to drastically reduce its fossil fuel usage in a generation. The reason for this reduction can be attributed to the rise of cheaper alternative energy sources such as nuclear and biomass, technologies such as heat pumps, and market based polices by the government, where this study will focus on.

With 75% of fossil fuel usage seen in transport sector, it is clear where the focus needs to be. And from the following figure, it can be said that the transport sector is highly coupled with fossil fuel usage, and has been for decades:

Figure 5: Total energy consumption in transport sector in Sweden [STA and Statistics Sweden, 2015]



It can be seen that the use of fossil fuels, petrol and diesel have been steadily rising from 1971 till the early 90s. Use of petrol peaked in the 90s, and since the turn of the century, use of diesel has been more than substantial. The great recession in 2008 affected the industry a lot; however, since 2013, the automobile market in Sweden has revived immensely; May 2016 was the twenty-ninth consecutive month of increasing registrations of new cars and 2016 is set to break the record for most car sales in a year [BILSweden, 2016].

5.2 Stakeholder introduction

The personal vehicle sector in Sweden has a number of stakeholders who are pivotal during the lifetime of a personal vehicle in Sweden. They are listed below:

- Vehicle Manufacturers
- Vehicle Owners
- Vehicle Users
- Government – Transport Authority
- Government – Energy Authority
- Fuel(Energy) suppliers & Infrastructure
- Vehicle Dealers
- Vehicle Repair & Infrastructure
- Insurance companies
- Banks

Most of these are for profit business practitioners and crucially, all of them are part of the economy and society as well. Their perceptions and future perspectives will be discussed in the next step of backcasting.

5.3 Initiatives to curb fossil fuel usage

The success in reducing overall usage of fossil fuel usage in Sweden have been primarily due to energy tax initiatives by the government from the early 70s. The oil crisis in the seventies triggered a policy change to focus on oil substitution as a means of reducing oil usage. In 1991, the Swedish energy taxation system was reformed; a carbon tax was introduced (together with other emission taxes such as SOx tax and NOx tax) on fossil fuel usage, with the exception of electricity generation and a 50% exemption to industry [Johansson 2000]. Thus the shift focused from oil substitution to emission reduction, as the government decided to focus on the looming climate targets. Biofuels were exempted from taxation and its use have steadily increased henceforth. All these measures have been instrumental in reducing the carbon emissions from fossil fuel usage, to the tune of 18.3% from oil and 13.8% from coal, during the period from 1990 till 2010 [IEA Sweden, 2013]

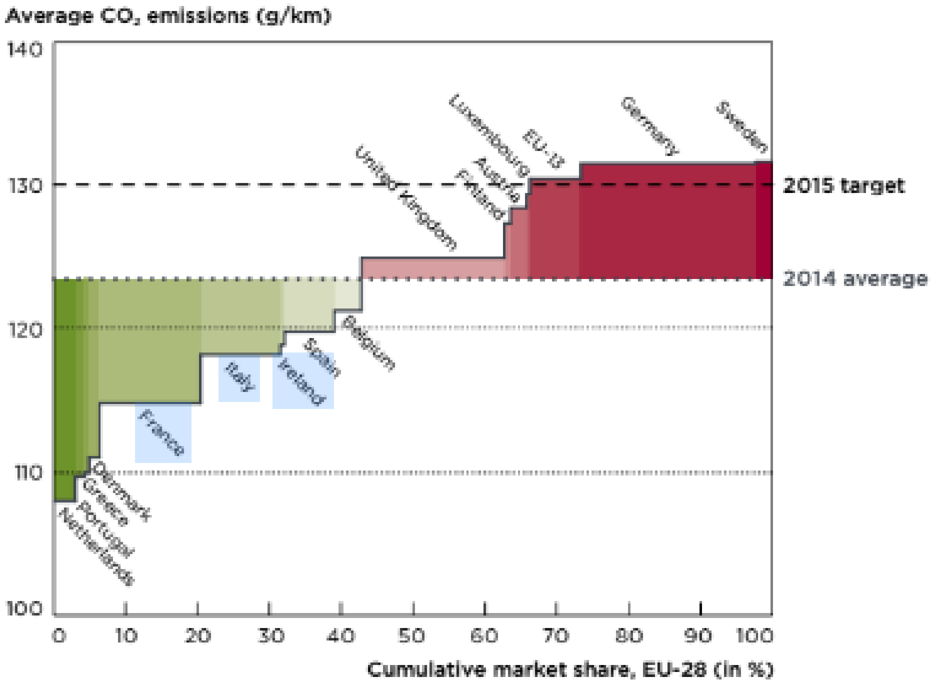
Meanwhile the EU were also working on their policies for reducing GHG emissions. After the adaptation of the Kyoto protocol in December 1997, the EU committed itself to reducing GHG emissions by 8 percent during the period 2008 – 2012, compared to 1990 levels [Marklund, 2011]. The responsibility of mitigation was then redistributed among the member countries, in what is known to be as the Burden Sharing Agreement (BSA) in 1998. The EU's approach to use the market for reducing GHG emissions resulted in the launch of the cap and trade, emission trading system (ETS) in 2005. The ETS system is in its 3rd development phase now, (2013 – 2020) and covers around 45% of total GHG emissions from the EU. However the ETS system has largely avoided the transport sector; the targeted sectors have been industry and energy production mainly. Civil aviation has been included under ETS since 2013 [European Commission, 2013].

In the transport sector, the main EU policy has been to restrict the toxic air pollutants from vehicles, and for this the Euro emission standards were initiated in 1992. Starting from Euro 1, and now at Euro 6, these include progressively tighter limits for vehicle pollutants such as CO, NOx, HC and PM. For GHG emissions, measures includes voluntary agreements from vehicle manufacturers to reduce CO_2, and average minimum fleet emission directives such as 130g CO_2/km by 2015 and 95g CO_2/km by 2020, for personal vehicles.

Coming back to Sweden, it's the same parameter, the average fleet emission of fleet, which has been a major focus point for local policymakers. The figure below (Figure 7) explains why. Sweden has the highest average CO_2 emissions (g/km) in personal vehicle fleet among all the members of the EU. Not only do they emit more than the EU average, they are also bigger and heavier, and this has been the case traditionally. The following reasons could be attributed to this [Sprei & Wickelgren, 2010]

- Sparsely populated country with a lot of distance to cover;
- Two popular domestic manufacturers, Volvo & SAAB (The latter is inactive now) who traditionally focused on making big powerful cars;
- Traditionally strong market for roomy, powerful cars for the whole family and for all four seasons;
- Use of trailers is common, which need powerful vehicles;

Figure 6: Average CO_2 emissions (g/km) of vehicle fleet [European Vehicle Market Statistics, 2015]



The government has tried to shift this disparity in the fleet with certain policies. The annual vehicle tax system was differentiated on the basis of CO_2 emissions per km, from 2006 onwards. The factor of differentiation now stands at 22 SEK per gm of CO_2 per km, beyond 111 g CO_2/km at mixed driving. Since 2012, a super green car rebate was introduced for vehicles which emits only 50 gCO_2 per km or below. The maximum rebate stood at 40000 SEK. There was also tax exemption on ‘environment friendly’ (EFV) cars, during the first five years after its purchase from 2006. The definition of an EFV car has undergone changes over time, and from 2013 the highest approved emission from a gasoline or diesel car is 95 gCO_2/km, for an average weight of 1372 kilos [Naturvårdsverket, 2015].

The Swedish government has also tried to discourage the use of fossil fuels by subsidizing renewable ones in the transport sector. Together with increasing the energy tax on diesel and gasoline, pure renewable fuels like ethanol and biogas has both carbon and energy tax exemption [Naturvårdsverket, 2015]. There has also been a directive to have a mandatory requirement of renewable fuel in gas stations which sell beyond a specific amount of gasoline. This legislation came into effect in 2006 and has resulted in an increase in E85 pump installations.

The increasing evidence of the effects of manmade global warming and the 2008 global economic recession proved the trigger for the Swedish government to plan for a fossil free future. In 2009, this resulted in the announcement of an integrated climate and energy strategy by the parliament. The end goal of the strategy was to have zero net emissions of GHG from Sweden by 2050. The strategy included an emission target of 40 percent reduction from 1990 levels by 2020, an increase in use of renewable energy to 50 per cent by 2020, and energy efficiency targets. For the transport sector, the goal was to have a fossil fuel independent vehicle fleet by 2030. This target will be a major milestone included in the strategy proposed by this thesis. At the same the EU target for the same time period is to reduce GHG emissions to below 20% of 2008 levels by 2030, and to below 60% of 2008 levels by 2050. As can be seen, Sweden's targeted emission reduction is much more ambitious than EU targets for the same period.

As of 2016, we have the following policy instruments which affect the personal vehicle market and the usage of a personal vehicle:

- Emission performance standards for new vehicles (Applicable for all EU members);
- Vehicle fuel taxes;
    - Energy Tax
    - CO_2 Tax
    - Value – added tax
- Tax reduction for biofuels;
- Mandatory biofuel/renewable supply at gas stations;
- CO_2 differentiated annual vehicle tax;
- Tax reduction for 'environment friendly cars';
- Super green car rebate;

It is clear that these current policies would not be adequate enough to force transition and meet the targets in the transport sector. The government being well aware of this, appointed a commission in 2009 to study the different alternatives and come up with a policy strategy which can help achieve the mitigation targets. The report by the commission came out in December 2013, named as – 'Fossilfrihet på väg', translating to 'fossil freedom on the road'. One of the proposed policy measure – A bonus – malus system, was further called for in depth study by the government, and its report was released in April 2016.

These two documents would be reviewed for the relevant scope and summarized in the literature review, presented in the next chapter. A study on the transition policies made by two other countries, Norway and France, would also be included in the review.

6 Literature review

6.1 'Fossilfrihet på väg' – December 2013

The commission appointed by the Swedish government to strategize the path to fossil freedom for road transport, released their report titled 'Fossilfrihet på väg' – translated to 'Fossil freedom on road' in December 2013. The directive given to the commission by the government was the following:

'To investigate general instruments which put a price on GHGs, complemented by targeted instruments for technical development, to be implemented in stages and at such a rate that, 2030 and 2050 targets are realized.'

The resulting report was divided into two parts, and together comprised of more than 1000 pages of comprehensive study and analysis on the current policies for all vehicles on the road. The focus for the review was on extracting information regarding proposals for future policies which could lead to reduction in emissions from the personal vehicle sector. The proposals can be summarized as below:

- Fuel Taxation
    - Raise energy tax on Diesel in 3 steps by 2020 – such that its carbon and energy tax component would be similar to gasoline.
        - Increase by 25 öre in 2015, 25 öre in 2017 and the rest by 2020.
    - If the proposed new EU energy directive is favorable, move towards an energy tax based on energy volume.
    - In the long run, move towards a km run, usage based tax system.
    - Carbon tax to be adjusted to reflect the actual amount of carbon in the fuel.
    - Biofuels to receive continued tax exemption up to the year 2030.
- Energy efficiency (Reduction in emissions)
    - 1st proposed option
        - A registration tax plus Bonus – Malus environmental performance system, with or without weight differentiation, effective from 2015. Super green car rebate and CO_2 emission differentiated vehicle tax taken off.
    - 2nd proposed option
        - Development of present day's super green car rebate and CO_2 emission differentiated vehicle tax system as a combined Bonus – Malus system.
    - Either of the options to be implemented by 2015, effects evaluated by 2018 and changes made accordingly.
    - Overall tangible target – Average CO_2 emissions of new cars in Sweden shall not exceed 95 g/km by 2020.

    - Improved communication of information on energy efficiency and CO_2 emissions presented on all new vehicles.
- Other measures
    - Fuel flexible vehicles to receive an additional premium.
    - Energy efficient variant(less emission per km) of a vehicle to be incentivized for purchase through selected price modelling.
    - Incentive model to be analysed to see whether an efficiency based approach (kWH/km) would be more appropriate than emission based one (gCO_2/km)
    - Congestion taxing zones to be extended in Stockholm and fees to be increased. Fully electric cars pay zero, while PHEV pay half of the fees, till 2021.

There were a few restrictions in the report, some mentioned in the report itself:

- No mandate on proposing measures to compensate the fiscal deficit in the treasury, caused by the decline in revenues of fuel taxes.
- Regarding energy efficiency measures, the report admits that analysis were made only on 2 of the possible 6 combination of proposals mentioned.

6.2 ‘Ett bonus – malus system för nya lätta fordon – April 2016

After the report in December 2013, the Swedish government took particular interest in the proposals, and in the particular the proposed Bonus – Malus system. Another commission was duly appointed to study this system and propose a viable way which could work in the Swedish context. This report came out in April 2016, in the latter part of this thesis and is a valuable work on what could be the next step in transition policies in the Swedish transport sector. The intricate points of the proposed system, to be applied for new vehicle registrations from 2018, are given below:

- A Bonus – Malus system, with the bonus being a ‘super green car’ bonus and the malus included as a tax component in the existing annual vehicle tax system;
- Bonus component determined by emissions;
  - Upto 60000 kr for zero emission vehicles;
  - Upto 45000 kr for vehicles emitting less than 35 gCO_2 per km;
  - Upto 35000 kr for vehicles emitting more than 35 gCO_2 per km, but less than 50 gCO_2 per km;
- Malus component determined by emissions as well;
  - 80 kr per gCO_2 per km higher than 95 gCO_2 per km annually for 3 years, to be included in the annual vehicle tax;
  - After 3 years, taxation amount reduced to 22 kr per gCO_2 per km;
- Weight differentiation
  - Below 1392 kg kerb weight, bonus – malus system same as proposed above (without weight differentiation);
  - Above 1392 kg kerb weight, the CO_2 component in the vehicle tax is to be adjusted;

6.3 Policies by European countries for reducing fossil fuel usage in personal transport

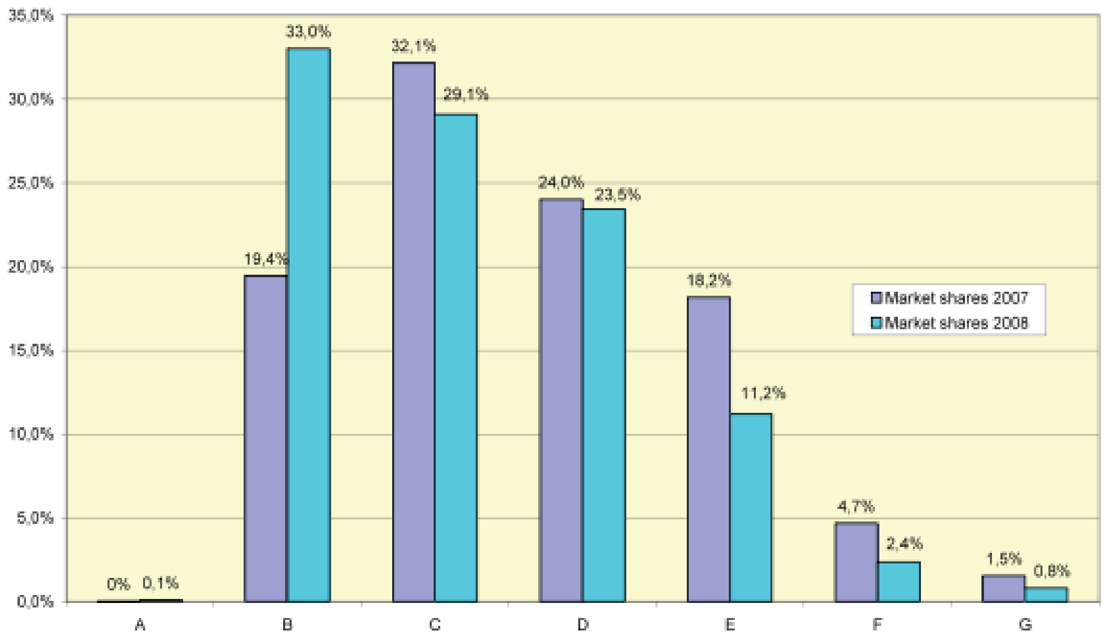
6.3.1 France

The French government setup a bonus-malus system for new light vehicle sales in 2008. According to the system, a bonus would be paid for any vehicle which emits less than 130 gCO_2/km. The amount of bonus is varied, and it is according to the CO_2 emission of the said vehicle, as explained below [ADEME, 2009]:

- Any vehicle which emits less than 100 gCO_2/km would be paid a bonus of 1000 Euros.
- Any vehicle which emits between 120 and 130 gCO_2/km would be paid a bonus of 200 Euros.
- Vehicles which emits more than 160 gCO_2/km, would have to pay a sales tax (Malus) on top of the retail price of the vehicle.
- For vehicles emitting more than 250 gCO_2/km, the amount of malus was 2600 Euros.

At the same time as the policy implementation took place in 2008, the oil price saw a sharp rise, and together, these two factors caused a change in the automobile market in France, as can be seen in the figure below:

Figure 7: Effects of Bonus – Malus on market share of energy class [ADEME, 2009]



As can be seen from the figure, there was a remarkable shift in the markets within a short span of one year. The B segment cars emit less than 130 gCO_2/km, and hence they were entitled for a bonus, and their sales increased from 19.4% to 33%. In all other segments, from C to G, which have progressively more powerful and more emitting cars, the market went down.

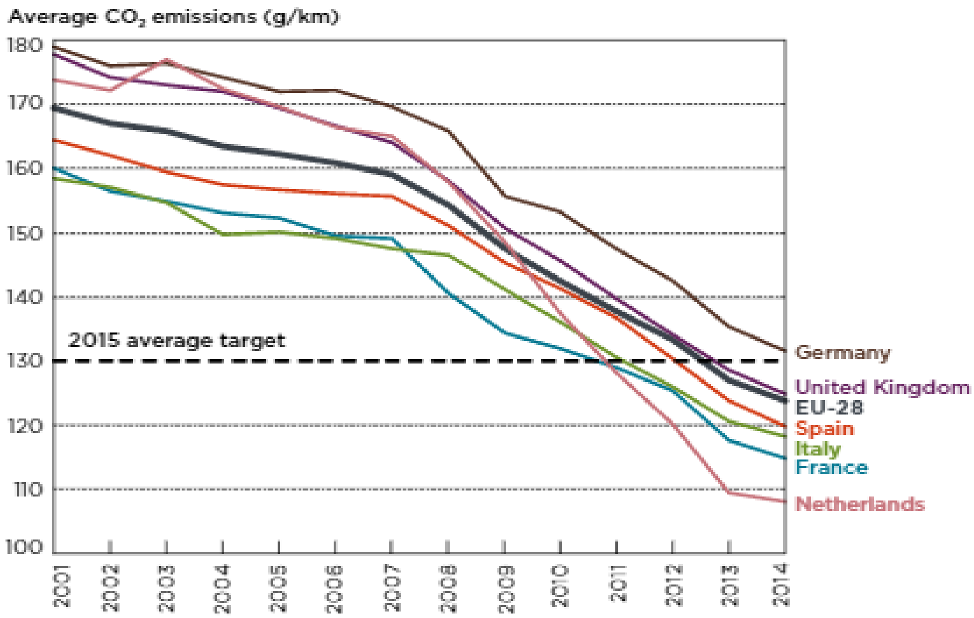
Studies show that the CO_2 emissions of new cars in France fell 6% in one year, from 148 gCO_2/km to 139 gCO_2/km, while having a positive effect on the French automobile market, with sales increasing by 3.5% in the same period [ADEME, 2009].

As of 2016, the French bonus – malus system has the following structure [ADEME, 2016]:

- New vehicles having emissions between 0 to 20 gCO_2/km; receive bonus of 6300 €.
- For emissions from 21 to 60 gCO_2/km; receive a bonus of 1000 €.
- No bonus or malus for vehicles emitting between 61 to 130 gCO_2/km.
- Beyond 130 gCO_2/km, a malus needs to be paid. The malus brackets are segmented for (mostly) every five point increase in emissions;
    - Between 131 gCO_2/km to 135 gCO_2/km, pay malus of 150 €.
    - Between 135 gCO_2/km to 140 gCO_2/km, pay malus of 250 €.
    - Between 141 gCO_2/km to 145 gCO_2/km, pay malus of 500 €, and so on.
    - The last malus bracket is emissions of 201 gCO_2/km and beyond, and the customers pay a malus of 8000 €.

The result of these policies on the average emission of newly registered cars in France has been profound and can be visualized in the figure below:

Figure 8: Average CO_2 emissions of new registered vehicles by country [European Vehicle Market Statistics, 2015]



From the figure, it can be seen that there is a general downward trend towards low emissions, which can be attributed towards increased efficiency of cars and EU level policies. For France in particular, it can be seen that there is a sharp decline from 2007 onwards, coinciding with the bonus – malus system, and this has resulted in France having one of the lowest average CO_2 emissions in Europe, with 115 gCO_2/km in 2014.

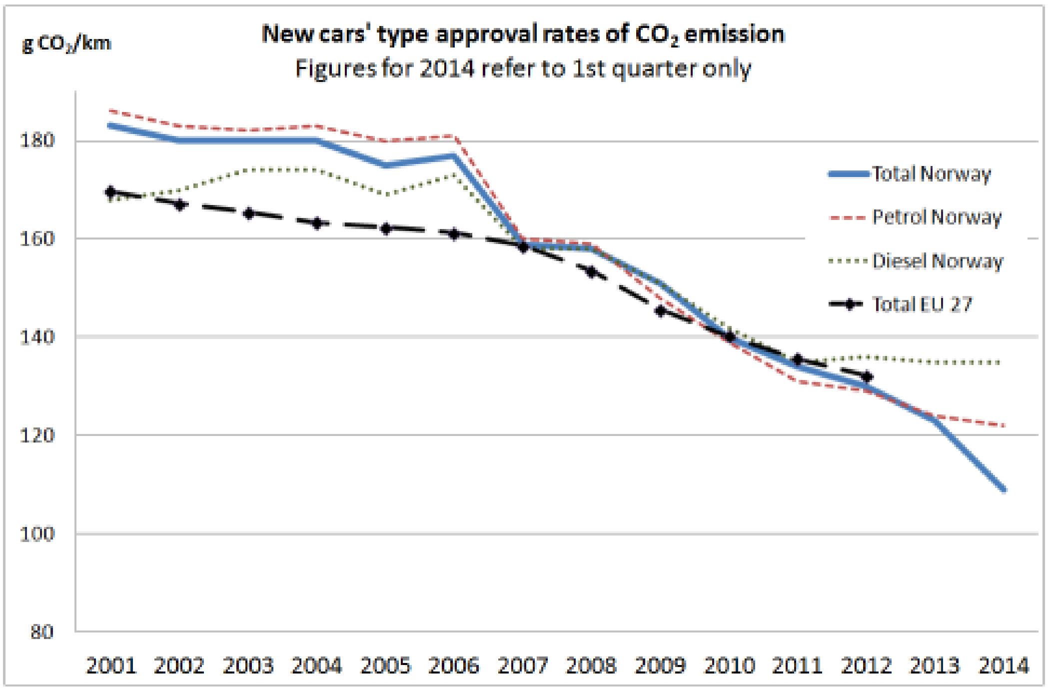
6.3.2 Norway

Norway has a system of heavy taxation on both the usage of personal vehicles, in the form of fuel tax and the purchase of a new vehicle, in the form of purchase tax, and this is much higher than in most countries. The purchase tax is made up by four components [ITE, 2014]:

- Curb weight of the vehicle (kg)
- Power of the engine (kW)
- CO_2 emission (g/km)
- NOx emission (mg/km)

From 2007 onwards, increasing weightage has been given to the CO_2 component of the purchase tax, to incentivize the sale of lesser emitting vehicles. In addition to high taxes for high emitting vehicles, low emitting vehicles such as plug in hybrids were provided tax reliefs for further incentives. Such initiatives resulted in a great reduction in average emissions from new car sales in Norway, as can be seen in the figure below:

Figure 9: Average CO_2 emission from personal vehicles in Norway [ITE, 2014]



In 2009, the government of Norway set up a target of having 50,000 EVs registered in the country as a climate change mitigation initiative in the transport sector. To make

EVs more attractive, the following tax and infrastructure incentives were provided [WSDOT, 2011]:

- Exemption from annual vehicle tax
- Exemption from purchase (sales) tax
- Exemption from annual road tax
- Exemption from VAT
- Exemption from company car benefit tax
- Exemption from toll fees
- Free parking wherever there is public parking
- Permission to ride in bus and taxi lanes
- Free battery charging from publically funded charging stations

These incentives, together with very high purchase taxes for fossil fuel based vehicles, made EVs extremely competitive in the market; in 2014, the highly popular EV model Nissan Leaf was priced, after all the exemptions, at 240,690 NOK and in the same size class, the 1.3 liter Volkswagen Golf was priced at 238,000 NOK. As a result of these incentives, Norway reached its target of 50,000 EVs on the road in 2015, 2.5 years before the target year of 2018. Due to this aggressive policy measures, Norway has the highest EV vehicle fleet per capita in the world and has by far the highest penetration rate in the new vehicle market, with almost one third of new sales being EVs or plug in hybrids.

But these rewards do come at a price for the Norwegian government. In 2014 alone, the tax exemptions have caused a revenue loss of up to 4 billion NOK for the government. Studies have also shown that there are rebound effects to the policies, such as [Holtsmark & Skonhoft, 2014]:

- Motivate high income families to buy an EV vehicle as their second car, which then misses the point of carbon mitigation;
- Opportunity lost by not investing in emission rights from EU and keeping them unused, which would
    - Reduce the quota supply
    - Drive up the carbon price, making clean investments feasible
    - Keep Norway carbon neutral

The Norway government has recognized that continued tax incentives for EV may harm their treasury and has decided to phase out some of the current incentives from 2018. From 2018, EV owners would be required to pay half of the road tax and from 2020, the full amount. The VAT exemption for EV vehicles is set to end in 2018 and is set to be replaced by a subsidy scheme, which may reduce as technology improves. Also parking for EV vehicles may or may not be free, and the decision would rest with local authorities.

7 Backcasting Step 3 – Visualizing 2030 & 2050

7.1 Introduction

The next step in the backcasting process is to visualize the transition to a fossil free transport sector in Sweden. For this a simple approach is taken; with the sustainability framework as a guiding path, a future journey from one point to another is visualized. From the result, an overall vision statement for personal mobility is written. The thesis then takes up two of the main governmental targets; fossil fuel independence by 2030 and fossil fuel freedom by 2050, and dive into more details, categorizing them into the following:

- Social
- Economic
- Environmental
- Technology/Infrastructure
- Policy

The vision step is wrapped up with a discussion on possible stakeholder impacts of the vision.

7.2 Y to Z – A journey in the future

Consider person 'M' wants to travel from Y to Z, in the distant future. The person's need for travel could be for many different reasons, but let's consider the simple scenario where M travels to Z (downtown) from Y (home), spend some time there and comes back in a similar fashion.

- According to the framework designed, mobility needs to be as efficient as possible. To be most efficient, the need for mobility itself is studied. Was it necessary for M to travel from Y to Z in the first place? Could this be replaced by a service instead? For example, if M was supposed to visit a bank to sign a few documents and come back, could it have been done at home, by using a service in the bank's website instead? Or if it was to buy food/groceries, could it be ordered online and be delivered at home by a sustainable mobility system (say biking)? These examples are of services which currently exist which eliminated the need for travel altogether. In the future, we could see more and more of these services replacing or minimizing the need for transport.
- As no service can replace this particular trip, M has now decided to travel from Y to Z. Now M has to choose the option which is the easiest / fastest / cheapest, according to M's criteria for the hour. To make this trip as clean and sustainable as possible, the challenge is to match these criteria with the most clean transport solution applicable. For example, can M's need be fulfilled by walking from Y to Z? If not, could biking be a good alternative? Are there biking paths and bikes present to fulfil that need? If not, would public transport options be feasible? The idea here is that, in order to promote sustainable mobility, those options should as feasible, or more, than unclean transport options, and match M's criteria for transport.

With these ideas, the vision for personal mobility in the future can be stated as thus:

"*Personal mobility, as a need, is minimized*

&

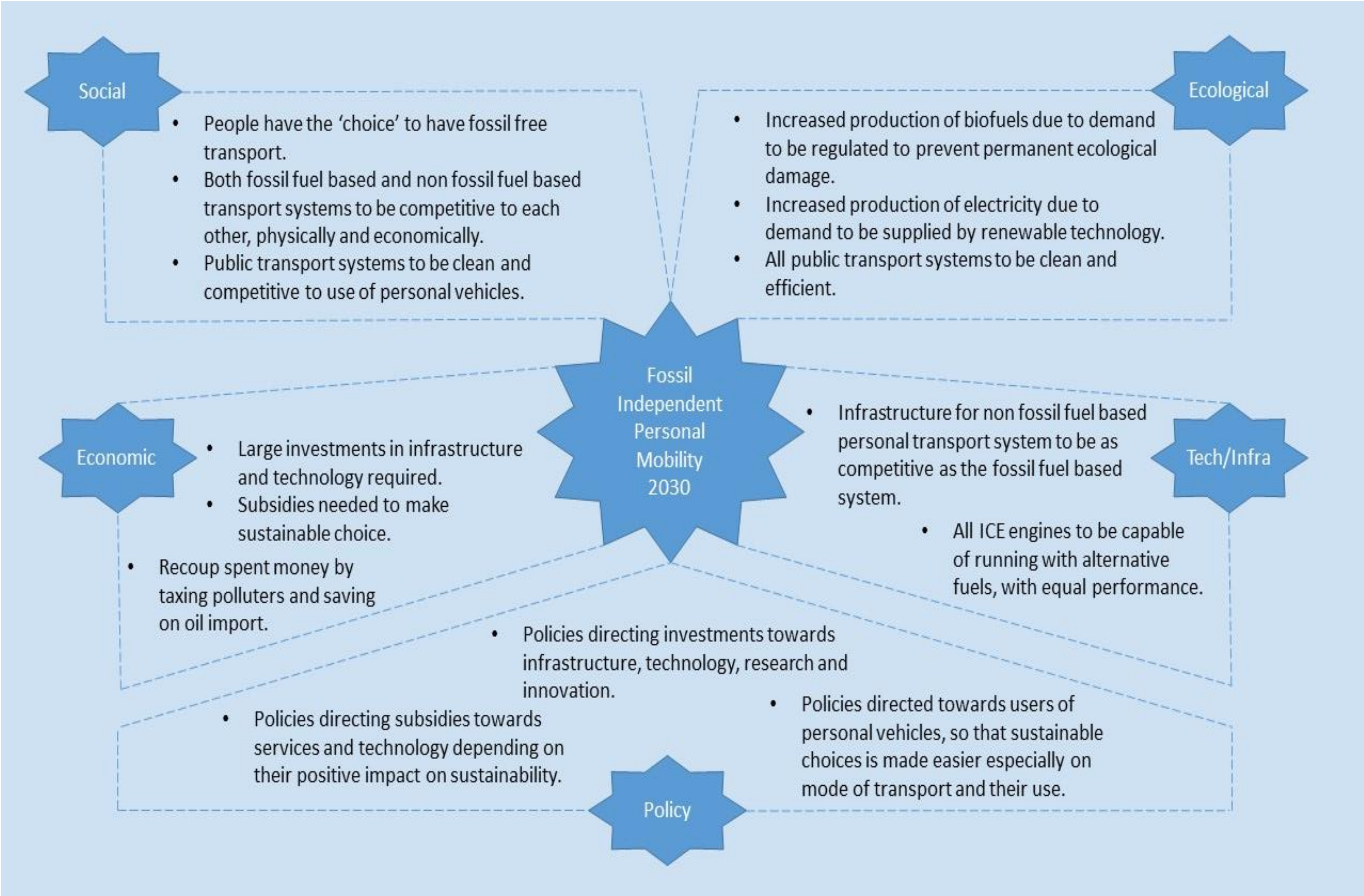
Personal mobility, as a choice, is clean, efficient and easily accessible"

7.3 Visualization map for target 2030 – Fossil fuel independence in Swedish personal transport sector

The figure below (Figure 10) illustrates the thinking behind a fossil fuel independent personal mobility sector for 2030. Some of the main points here are discussed below:

- Fossil fuel independence is a term which can have broad interpretations, and that's been the case ever since the government has come forward with the target. As of today, two broad interpretations remain; one more objective interpretation where all personal vehicles could be run on alternative, non-fossil based fuels and without a drop in performance, and the other more statistical interpretation where if fossil fuels are to be banned from tomorrow, at least 80 percent of mobility systems in the country should be able to work. In this thesis, both these ideas are evaluated in the design for solutions.
- At 2030, the systems to be designed are already in place so that anyone's need for mobility could be achieved by different means. The idea is that to be truly fossil independent, mobility systems which are not dependent on fossil fuels need to be competitive with systems that are not, in terms of ease of access, affordability, safety, speed etc. This would mean users/customers can choose a transport means which is independent of fossil fuels, without sacrificing their time or money.
- This competitiveness would obviously need substantial investments and subsidies in sustainable mobility infrastructure and technology, respectively. The competitiveness could also be achieved by making fossil fuel based mobility systems more expensive, i.e. the polluter pays principle.
- The transition away from fossil fuels would inevitably result in an increased demand for alternative, cleaner fuels. The visualization for 2030 presents a system level goal oriented approach, such that recommendations for investments, taxes and subsidies would be purely based on the sustainability framework discussed in the previous section. This would mean that certain alternative fuel/technology would be supported better than another alternative fuel/technology, e.g. Hybrid vehicles over biogas vehicles in an urban setting, as the latter contribute more to local emissions and noise.

Figure 10: Visualization map for a fossil free independentl vehicle sector in Sweden by 2030

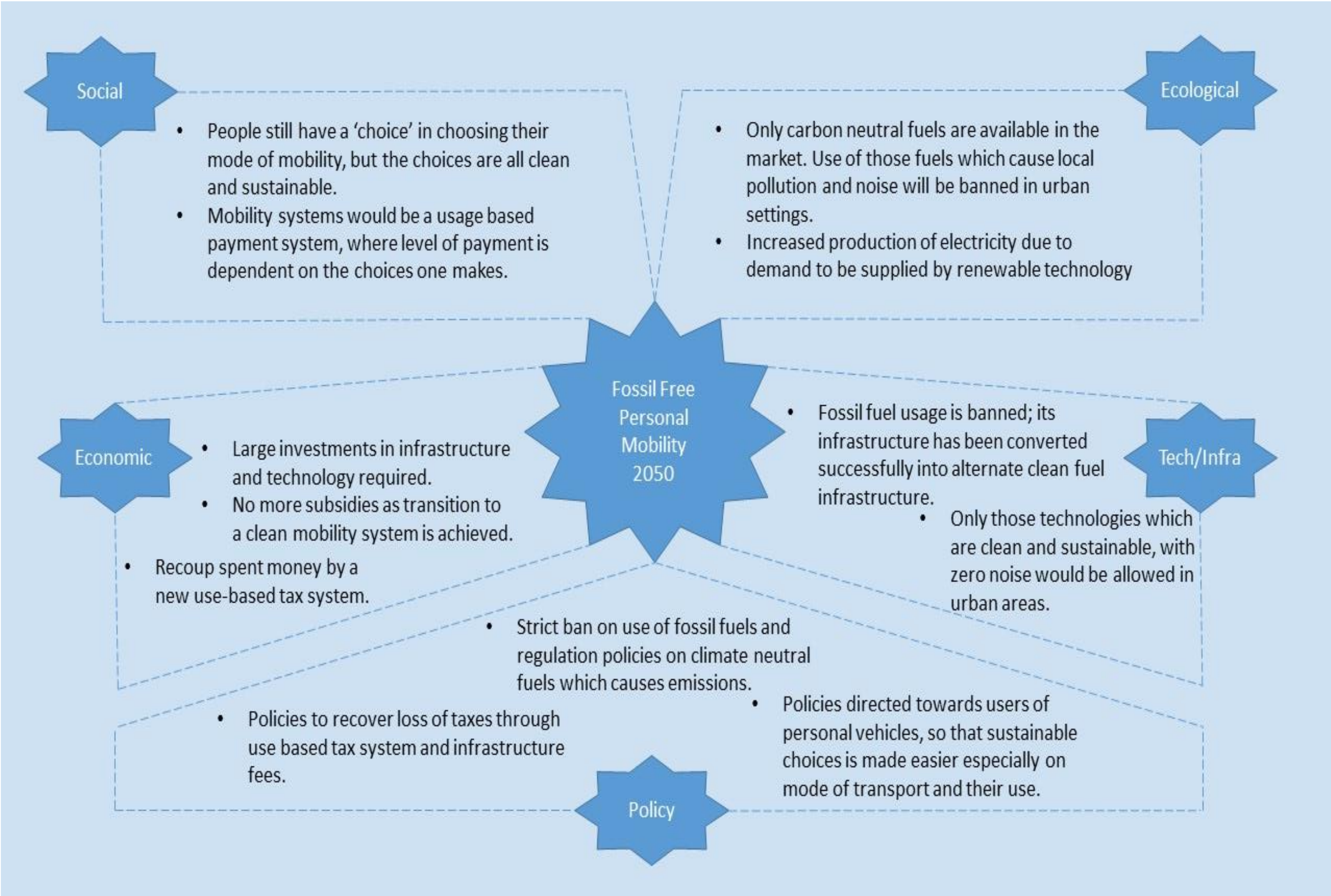


7.4 Visualization map for target 2050 – Fossil fuel freedom in Swedish personal transport sector

The figure below (Figure 11) illustrates the thinking behind a fossil fuel free personal mobility sector for 2050. Some of the main points here are discussed below:

- At 2050, the choices for personal mobility have all been successfully converted to clean and sustainable. Fossil fuels will be banned (from 2050) and only climate neutral/pure renewable fuels are available. The transition will be long and gradual, and its economic impact on the government will be substantial. Together with infrastructure costs and subsidies, a major loss of tax revenue will be seen as fossil fuels are gradually phased out. New tax systems such as a road usage based one would have to be carefully designed to replace the losses. The detail study of such a system is outside the scope here, as this thesis would be concentrating on the fossil fuel phase out transition.
- Both fueling and road infrastructure would need to be built up substantially if the transition is to be complete. The fossil fuel infrastructure which is already well placed will be in risk of going defunct, and it would be ideal if they can be converted to future fuel/recharge stations instead.
- Urban areas will allow only clean and noiseless vehicles to run and use the infrastructure. This would mean that hybrid vehicles, for example, running on electricity and biofuel, would have to drive in ‘only electricity’ mode when it enters the urban area and allowed to use the biofuel engine, once it’s out of the area. This ensures that urban areas are pollution and noise free, but also caters to long distance travelers who wants to more power in the highways.

Figure 11: Visualization map for a fossil free personal vehicle sector in Sweden by 2050



7.5 Stakeholder interpretation

How will the stakeholders for the lifetime of a vehicle, introduced in the section before, interpret this vision? Would their current strategy/business model work in the required transition or would they need to adapt to survive? The table below (Table 1) describe their present situation and their possible needs in order to adapt and grow with the overall vision and governmental targets for 2030 and 2050.

7.6 Gap analysis – Comparing Step 2 & 3 results

Now that the current situation and future vision for personal mobility in Sweden has been described, it will be interesting to compare both and identify the main gaps between the two. Here, the analysis is categorized via the sustainability dimensions (social, ecological and economic), as seen in the table below (Table 2):

It is clear from the table that the main gaps are in proactive policies, which are required urgently if the targets of a fossil fuel independent transport system at 2030, and a fossil fuel free transport system at 2050, are to be achieved. In the backcasting process, the next step – Step four – are design of solutions which would close the gaps mentioned. Since an analysis and discussion of all possible solutions and their interactions with each other is outside the scope of this thesis, the next sections will be concentrating on how an ideal policy and legislation system can be derived and implemented, exclusively for converting the current fleet of personal vehicles in Sweden to a zero net emission vehicle fleet in the span of 34 years, and achieve the twin targets for 2030 and 2050.

Table 1: Description of stakeholder needs and their requirements for adapting to the transition

Stakeholder	Present Situation	Policy/market needs so as to adapt to the transition
Vehicle Manufacturers	• Manufacturing governed by market and EU regulations • Demand is for fossil fuel based, efficient cars in certain categories • EU regulations look at efficiency in terms of gCO_2/km	• Shift in market; Policies which direct demand for alternative fueled vehicles • Investments in research and innovation • Slow gradual transition so that companies can adapt while profits are sustained
Vehicle Owners	• Choice governed by price and class of vehicle (Small, Sedan, SUV) • Market highly favorable to fossil fuel based cars • Price of alternate fuels and alternate fueled vehicles not competitive to fossil fuel and fossil fueled vehicles	• Policies for the vehicle market so that price variations between fossil fueled and alternate vehicles are minimized • Require subsidies on choice technologies/fuels/services to make informed decision in mobility • Require alternative vehicle infrastructure at a level pegging with fossil fuel based infrastructure
Vehicle Users	• Have access to a number of solutions for fast, easy transport • Infrastructure for fossil fueled vehicles well developed; others not so • Sustainable mobility options not attractive enough for permanent uptake	• Require subsidies on choice technologies/fuels/services to make informed decision in mobility • Require alternative vehicle infrastructure at a level pegging with fossil fuel based infrastructure • Ease of access and safety essential for any transport system
Gov. – Transport Authority	• Alternate fueled cars not breaking into the market despite many measures • Infrastructure for alternate fueled vehicles not so developed • All externalities not adequately internalized with current policies	• Urgent need of policies which facilitate rapid transition without compromising on fiscal revenue and which negatively affects manufacturers and buyers • Tax policies in the future need to ensure that all externalities are internalized • Large investments required to make the required changes in infrastructure
Gov. – Energy Authority	• Current energy tax consists of a fuel tax based on quantity and an arbitrary CO_2 tax based on gCO_2/km • Alternate fuels acceptance in the market not at the required phase • Infrastructure for fossil fueled vehicles well developed; others not so	• Must go for a volume based energy tax and a content based carbon tax as soon as possible, to promote fuels with higher energy and lesser carbon • Fueling infrastructure for alternative fuels to be rapidly expanded. • Subsidies for biofuels, batteries, solar panels etc. to boost alternative fuel adoption.
Fuel(Energy) suppliers & Infrastructure	• Well developed supplier and fueling network for fossil fueled vehicles	• Need favorable policies to adapt and grow during transition as the demand in fossil fuel shifts • Electricity generation and utility companies need to be incentivized to provide clean power to cater to the extra demand in the future
Vehicle Repair & Infrastructure	• Well developed vehicle repair and infrastructure network for fossil fueled vehicles	• Vehicle repair and service companies to be incentivized to build their knowledge and expand their network, to provide quality service to clean vehicles.
Vehicle Dealers	• Well developed vehicle dealer network for fossil fueled vehicles; Dependent on market	• Vehicle dealers to be incentivized to build their knowledge and expand their network, to provide quality customer service to buyers and help choose most sustainable options for their needs
Insurance companies	• Well developed insurance policies for the current vehicle market.	• Insurance policies to be incentivized towards cleaner vehicles and future transport systems
Banks	• Well developed insurance policies for the current vehicle market.	• Banks to be incentivized to provide zero or low interest loans for cleaner vehicles, needed for transition

Table 2: Description of gaps between present situation and envisioned situations at 2030 and 2050

At present	Dimensions impacted	At 2030	At 2050	Gap
People have limited options to choose fossil free personal mobility	Social/Ecological/Economical	People have easy, competitive options to choose fossil free personal mobility	People have no other choice other than clean mobility	Development of cleaner mobility systems; Phase out of fossil fuel based mobility systems
Urban areas congested with traffic at peak times	Social	Congestion to be reduced by taxation and replacement of mobility need, i.e. faster and efficient	Highly efficient mobility system; least congestion possible	New/Improved services replacing need for mobility; developing ITS systems of the future to reduce congestion
High air pollution and noise in urban areas at peak times;	Social/Ecological	Strict regulation and transition reduces overall emissions; polluting vehicles allowed in urban areas only at night	Bans and regulations keep polluting vehicles away from urban areas at all times, i.e. zero emission	Policies and regulations which reduce overall emissions and help in transition to cleaner fleet
Use of alternate cleaner fuels very low compared to fossil fuels	Social/Ecological	Alternate fueling infrastructure and economics competitive to fossil fuels; energy volume based fuel tax system would be a start	Alternate fuel used only outside urban areas; Demand regulated so as to prevent excess resource use;	Policies to promote alternate fuels to be competitive to fossil fuels; Policies to ensure fair fuel taxation; Regulations to ensure fair use of resources for production.
Future of clean electricity uncertain with nuclear phase out still a possibility	Social/Ecological/Economic	Increased demand in electricity to be supplied/bought from clean power	Both electricity generation and transport systems are mostly fossil fuel free	Policies to ensure that the expected increased demand in electricity is supplied by clean sources; including policies to support clean energy investment.
Use of fossil fuels and its infrastructure provide the treasury with large tax money;	Social/Economic	Fiscal deficit due to transition from fossil fuels to be recovered by a infrastructure use based tax system	Efficient and a well regulated system with a total use based tax system for all mobility services	Policies to ensure fossil fuel tax revenue is adequately replaced over time through new tax measures compatible with new mobility systems
Stigma towards use of cleaner mobility systems, as fossil fuel technology has been ever present and highly developed; technology lock-in	Social/Ecological/Economic	People have the choice to go for clean mobility systems or continue with current fossil fuel mobility systems, i.e. both transport systems competitive to each other.	People have no other choice other than clean mobility	Policies which gradually introduce and cause transition so that welfare and well being of people is not affected.

8 Deriving an ideal policy & legislation ecosystem

8.1 Introduction

With all the data available from the previous backcasting steps, the thesis moves on to designing an effective policy eco-system for a sustainable transition of a fossil fuel dominated personal transport sector in Sweden, to a fossil fuel free one, within the span of 34 years. This chapter aims to result in such an ecosystem, through the following sections:

- A deeper look into the current Swedish market for personal vehicles and helpful statistical inferences;
- A study into criteria for a sustainable transition in the personal transport sector;
- Market reaction and new targets in a sector undergoing a sustainable transition;
- Development of a policy eco-system which would fulfil the transition criteria and market targets;

8.2 Personal vehicle market statistics and inferences

To understand the real challenge for the transition, it is very useful to deep dive into the current statistics of the personal vehicle fleet in Sweden. Annex II at the end of the thesis provides all the statistical information derived from sources such as BIL Sweden, Sveriges officiella statistik and European vehicle market statistics. From the tables 8 to 10 in the Annex II section of the thesis, the following deductions can be taken:

- Volvo V70 was the most popular car in Sweden for 2015.
- Top 5 selling cars take up almost 30% of the market sales.
- Top 50 selling cars take up almost 75% of the market sales.
- Volkswagen group sold the most cars in Sweden, followed by Volvo.
- Medium, Large, CUV/SUV & Executive are the most popular car segments, respectively.
- Except the medium segment, Volvo is the market leader in all segments.
- Medium and CUV/SUV segments are the most competitive, with more than 12 cars each in the top 50 cars.

It was evident from the analysis so far that the consumer base in Sweden preferred certain brands such as Volvo and Volkswagen and had a strong preference for big cars in luxury segments. Table 12 from the Annex II looks at the CO_2 emission potential of top 4 selling cars from each size category, and some of the main inferences are given below:

- If there are no emission limits and regulations, and people would tend to buy the highest CO_2 emitting variant of the current 50 top selling cars in Sweden, the normalized average CO_2 emission of the new fleet would be 185.73 g CO_2/km.
- If only the least CO_2 emitting variant of the current 50 top selling cars are allowed to be sold in Sweden, the normalized average CO_2 emission of the new fleet would go down to 84.93 gCO_2/km.

The target put forward by the report in 2013, mentioned in step 2 of backcasting, is an average fleet emission of new cars to be 95 gCO_2/km by 2020. From the above calculation it can be argued that this target is achievable without a major change in consumer behaviour. But most certainly, policies need to be designed so that lesser emitting variants of the top selling cars become more attractive. As 2020 is just four years away, these policies need to be implemented fairly quickly as well.

Table 14 from the Annex II provides a picture of the age of the current fleet of cars in Sweden, and an estimate of how much emission they cause. Euro emission standards provides an accurate picture of local emission parameters, and the following deductions can be taken:

- 11% of all cars in Sweden are aged 19 years and above (Thus mostly Euro 1 emission standard)
- More than a quarter of cars running today are 15 years and above.
- 12% of all cars on the road come under the Euro 2 standard and 17% come under the Euro 3 standard.
- Both Euro 4 and Euro 5 standard registrations, each amount up to 26% of all running vehicles.

From this analysis, it is also evident that if there is no scrap policy in place which would encourage the phasing out of old, more polluting cars, 20 to 25% of pre Euro 6 cars would remain in traffic at 2030. This would obviously make the goal of a fossil independent fleet for 2030 extremely difficult. Thus an effective scrap policy is paramount in reduce the average CO_2 emission of the fleet and attain the goal for 2030.

The Euro emission standards provide an important metric in terms of local air pollution, but not for CO_2 emission. But they do adhere to certain ranges of CO_2 emissions, as was found out by studying the top selling 5 cars per year from 1998 and their CO_2 emissions. The average within this range was taken to represent the class and the resulting analysis can be seen in table 16 in the Annex II. It is to be mentioned that quality of data was seen to increase chronologically, so the calculations and assumptions are more precise as the Euro standards progresses. The main inferences from this dataset are:

- The average CO_2 emission of the entire current fleet of cars in Sweden is calculated to be 190 gCO_2/km.
- An overwhelming majority of Euro 1, 2 and 3 vehicles are gasoline powered, and this skews the CO_2 emission profile to high levels. (an average emission of more than 200 gCO_2/km)
- The increased popularity of diesel cars from 2006 onwards have increased the efficiency of the fleet and the average CO_2 emission of new cars have reduced dramatically.

From this analysis it is clear that average CO_2 emission of the Swedish personal car fleet would go down irrespective of any new policy measures, due to the fact that old, inefficient gasoline cars are being replaced slowly by new efficient diesel cars. The question to be asked is, whether this natural transition would achieve the 2030 and 2050 targets. The commission had proposed to bring down the new car fleet emissions to 95 gCO_2/km by 2020; would it be possible to set a numeric target to achieve 2030 and 2050 targets as well? The table below attempts to answer this:

Table 3: Average CO_2 emissions from personal vehicle fleet according to year

Year	Total registration (from 2000)	Gasoline car share	Diesel car share	Other car share	Avg. CO_2 emissions (gCO_2/km)
<2007	2632699	84.9%	11.4%	3.7%	216
2016	4412700	66.0%	29.3%	4.7%	190
2030	?	?	?	?	45*
2050	?	?	?	?	0*

* - Targeted values

The table 3 summarizes the engine type and emissions of cars registered in Sweden from 2000 onwards. The first row presents the number of cars currently working in the fleet which were registered before 2007. This number is used to represent the personal vehicle fleet in 2007, and it can be seen that they are dominated by gasoline cars, which take up almost 85% of the market share. The average emission of the entire fleet is calculated to be 216 gCO_2/km. The 2nd row depicts the state of the personal vehicle fleet as of now, in 2016. Diesel car share have increased and newer, more efficient cars have helped reduce the average emissions to 190 gCO_2/km.

The third row presents the status of personal vehicles for the year 2030. The number of cars registered or their engine type is unknown, however, the average emission of the fleet can be calculated. As mentioned in the previous chapter, the 2030 target can be represented mathematically as an 80% reduction of fossil fuel usage from 2007 levels; 80% reduction in the average fleet emission of 216 gCO_2/km would be roughly 43 gCO_2/km. Rounding off to 45, the thesis proposes a numeric target for the 2030 goal - decreasing the average emission of the Swedish personal car fleet to 45 gCO_2/km.

Such an exercise for the 2050 goal is relatively simple. Fossil fuel freedom for 2050 would mean fossil fuels are no longer used in transport, and clean or zero net carbon emitting fuels are the only ones permitted. Thus, the thesis proposes a numeric target for the 2050 goal – decreasing the average emission of the personal car fleet to net 0 gCO_2/km.

8.3 Policy needs for a sustainable transition

Can such a rapid reduction in emissions be achieved in the relatively short time period available, while all the stakeholders involved are given a fair shot at sustainable growth? The following factors might be key to answer this question:

8.3.1 Internalization of externalities

Identifying the external effects or externalities caused by personal transport and effectively internalizing them, effectively sets the route and set the wheels in motion for the required transition. Externalities of personal transport can be categorized into the following:

- Congestion
- Accidents
- Air pollution
- Noise
- Climate change
- Wear and tear of infrastructure
- Impact on nature and landscape

Congestion is currently internalized as a ‘static’ (blanket) tax measure in Stockholm and Gothenburg; its effect has been largely positive, with reduction on congestion during peak hours. Public opinion also favours the measure [Elliasson, 2014]. The tax is now currently applicable to all kind of cars, irrespective of technology and emissions. In terms of accidents, Sweden has the safest roads in the world, only 3 in 100,000 die in road accidents per year [Road safety statistics, 2015]. The government has committed to total safety through the ‘Vision Zero’ project, initiated in 1997.

Air pollution by personal vehicles has been steadily decreasing in Sweden. SOx and NOx taxes introduced along with CO_2 taxes in 1991 has helped internalize them and reduce their emissions, although the number of vehicles have increased. Sweden performs well in terms of European air quality standards [Air quality in Europe report, 2016], except in some urban areas. The local pollution and PM levels in these areas could still increase with more usage of fossil fuels, and there is a case for regulating the use of polluting vehicles in urban areas at least.

Coming to noise, traffic is said to be the number one contributor to large noises in urban areas and causes annoyance, sleep deprivation and cognitive dysfunction. Moving towards a fossil free vehicle fleet might reduce the noise levels substantially; As such more research would be needed to understand whether noise would need to be internalized during and after the transition. Climate change and the vehicle sector’s contribution to the same has been covered in the previous chapters, with internalization (partially) through the implementation of a carbon tax. Increasing carbon tax could be crucial in helping decarbonizing the transport sector, but would need high political will to do so.

Recent study results suggests that the marginal costs to society due to wear and tear of infrastructure have been increasing. The impact on nature and landscape are also similar. The cost of wear and tear is currently internalized as a component in the annual vehicle tax, which is in turn based on emission rate and weight. In a usage based tax system, the cost of wear and tear, and impact on nature should be transferred to the user according to their use.

Thus the policy eco-system should ideally cater to these following points:

- Policies where congestion can be eased by dynamic charging and according to how polluting/noisy the vehicle is.
- Policies to ensure road accidents are reduced to zero.
- Policies which effectively internalize local pollution and PM emission in urban areas where the risk/impact is high.
- Effects of noise to be monitored and internalized if impact is found to be substantial.
- Policies which reflect the true value of carbon in fuel taxes.
- Policies that ensure wear and tear, and impact on nature are appropriately internalized through registration/annual vehicle tax.

8.3.2 Vehicle age and lifetime

In 2014, the average age of the Swedish car fleet was 6.71[EEA, 2016]. While the average age of the diesel vehicle fleet was 3.55, the same for the gasoline fleet was 8.09[EEA, 2015]. This data proves what is already deduced from the previous section; that older gasoline cars are skewing the average emission scale towards 200 gCO_2/km. Diesel cars are newer, more efficient and market forecasts suggest their popularity to continue. Alternative fuel and zero emission vehicles however are still a niche area with a very small customer base.

Car longevity is another essential factor to consider. Typically, Swedish made cars are known to have a high lifetime, between 15 to 25 years of use. The older the vehicle gets, the lesser it's mileage. The mileage of a ten year old car is said to be half of that of a new car [Kågeson, 2012]. If we consider 20 years as the average lifetime of a car, then at 2030, gasoline and diesel cars from 2010 could be expected to be in use in the vehicle fleet. This would make it very challenging to achieve the 2030 target, even if policies are in place for supporting the clean vehicle market, in the next decade. The 2050 target, on the one hand seems all the more difficult, but on the other hand, the 34 year gap (2016 – 2050) suggests that the vehicle fleet can be refreshed at least two times fully, providing enough opportunity to influence the market sufficiently. Thus the following would be key for both targets:

- Policies to ensure that inefficient and old cars are phased out from the vehicle fleet.
- Policies which ensure clear mandate for the stakeholders to plan ahead for achieving the targets.
- Policies to ensure that their replacement are either highly efficient diesel/gasoline vehicles or alternative fuel/zero emission vehicles.

8.3.3 Resource efficiency

According to the sustainability framework discussed previously, resource use must be made as efficient as possible. This would mean a 'cradle to cradle' flow of resources, where an industrial economy produces minimum waste and pollution by design. The phase out of old, inefficient vehicles in order to meet the targets would then need an effective scrappage system, designed to ensure that vehicle owners are incentivized enough to scrap their cars and if needed, are supported to buy a better choice of personal vehicle.

Another factor for efficiency is the effective use of existing infrastructure. As transition progresses, certain infrastructure may be in low demand and eventually become obsolete, as they do not contribute to the envisioned future. Steps must be made to ensure that these manmade structures are effectively utilized during and after the transition. This would also ensure the continuity of economic and social progress in local communities which depend on these structures. Thus we have the following points to consider:

- Policies which ensure that resource use is as efficient as possible, by closing the resource flow loop.
- Policies which ensure that existing infrastructure for current mobility systems are functional and transformed for better service during and after the transition.

8.4 Development of the policy ecosystem

With the essential policy needs charted in the previous section, this section looks at the possible policy options to consider to fulfil the needs. The current set of policies and proposed set of policies in the Swedish personal transport context, can be categorized as below:

- Incentives
  - Bonus systems
  - Green car rebates
  - Tax exemption
- Taxation
  - Malus systems
  - Registration tax
  - Vehicle tax
  - Fuel tax
- Regulation
  - Bans

With respect to the previous chapters and sections, the thesis deduces the following with respect to the design of the new policy eco-system:

- The Swedish government has been mulling the implementation of a Bonus-Malus system, similar to the successful French implementation, to lower the average emission of the personal vehicle fleet. From a sustainable transition point of view, it seems to a great approach for a market based policy system, provided the 'transition point' is appropriately set [D'Haultfœuille et al., 2014]. Consumers who buy a low emission vehicle are rewarded, while consumers who buy a high emission vehicle are duly punished by the system, i.e. the polluter pays principle. The fiscal deficit in principle is zero, which fits into the economic sustainability criteria for transition. The effectiveness of the system would be determined by how attractive the bonus is, and how repelling the malus is, and the transition point. The system should also be initially attractive for all buyers, and as the industry and market get more time to adjust, the malus can be increased and the bonus reduced. With time the system would need to be more stringent, so that interim targets are achieved.

- The super green car rebate scheme for vehicles which emit lesser than 50 gCO_2/km would need to be continued, in order to further boost the clean vehicle market and drag the average CO_2 emission of new cars to interim target levels. With time, this rebate can be phased out. This would undoubtedly create a fiscal deficit for the government, which would need to be compensated by taxation.
- Registration tax is a proposed tax measure where one has to pay for the right to buy and use a vehicle, and is independent of the amount of emission the vehicle would produce while driving. The thesis reiterates that this tax would be a necessary component in the policy eco-system. By buying a car, one is choosing a comparatively unsustainable option for travelling while other sustainable means are accessible. The tax need to be set at an appropriate level to reflect this.
- Vehicle tax is the annual tax component for vehicles where some of the externalities like CO_2 emission, wear and tear of infrastructure etc. are internalized. Within, the new policy eco-system, this tax would be set to continue and its value should correctly reflect the actual cost of the externalities.
- Currently, environmental friendly cars, including EV have their first 5 years of annual vehicle tax exempted. EV company cars are also provided a tax discount, the maximum amount being 16000 SEK per year. With the thesis final proposal, the environmental car definition would change (over time as well) and these tax exemptions would not be an important policy component, in terms of the transition required.
- Fuel tax on petrol and diesel consists of arbitrary components for carbon and energy tax currently. In the future policy eco-system, the energy tax would be based on energy per volume and the carbon tax would be based on the carbon content of the fuel, which makes it fair and equal. Biofuel would have an energy tax component, but not a carbon tax component, if its production and use is certified as net zero carbon.
- Bans would be a crucial component in the new policy eco-system. Legislation for bans show ambition and political will, a show of walking the talk by the politicians. If the ban is in the distant future, it gives the market and stakeholders to adjust and plan ahead for life after the particular ban.

8.5 Introducing the proposed final policy ecosystem

The previous sections of the chapter discussed on the policy objectives needed to achieve the targets, and the different policy measures which can be used to meet the objectives. The thesis's final proposal for the policy eco-system, categorized as major and minor, is presented below:

8.5.1 Major policies

8.5.1.1 Factor based Bonus Malus system including a transition point

A kr/gCO_2/km factor based system where high emission vehicles are taxed and low emission vehicles are awarded a bonus, with respect to a transition point. For example:

- Consider a Transition point = 95 gCO_2/km; Bonus-Malus factor = 400 kr/gCO_2/km
    - Customer 'A' buys a car 'T' which emits 55 gCO_2/km
        - 'A' receives a bonus = (95-55) * 400 = 16000kr
    - Customer 'B' buys a car 'V' which emits 175 gCO_2/km
        - 'B' pays a malus = (175-95) *400 = 32000 kr

The transition point determines the definition of an environmental friendly car; in the case above any car which emits below 95 gCO_2/km is an environmental car. Both the factor and transition point change with time, so that the interim targets can be achieved. 95 gCO_2/km is chosen as the first transition point as it the recommended new car emission average by the commission report, by the year 2020. The factor is chosen so that initial bonus/malus is substantial enough to influence decision making by the consumers. The manner in which they change is presented in the next chapter, the policy implementation roadmap.

8.5.1.2 Super green car bonus

A super green car bonus is given to vehicles which emit below 50gCO_2/km, bypassing the factor based Bonus Malus system. Thus the Bonus Malus system is in function until vehicle emission is till 50 gCO_2/km, below which the super green car bonus takes over. The super green car bonus would have a structure similar to the following example:

- 60000kr for zero emission vehicles
- 45000kr for vehicles emitting less than 35 gCO_2/km
- 35000kr for vehicles emitting less than 50 gCO_2/km, but more than 35 gCO_2/km

The values of the bonus is the same as recommended by the commission report on the topic. The bonus would gradually reduce with time, providing an initial boost to the clean vehicle market and time for stakeholders to adjust to the new market.

8.5.1.3 Scrappage system with bonus

A scrap/replacement initiative can be designed in similar ways, using the Euro standards. For example:

- Consider a scrappage bonus = 3000kr and green choice bonus = 10000kr
    - Customer 'A' scraps their Euro 2 standard car
        - 'A' receives a bonus = 3000kr
    - 'A' then buys a car 'V' which emits 45 gCO_2/km
        - 'A' receives a rebate of 35000kr (super green car rebate) + 10000kr = 45000kr.

The green choice bonus is only applicable when the customer buys a super green car.

8.5.1.4 Fuel flexibility incentive

A fuel flexibility incentive can also added to the bonus malus ecosystem, and provide which would motivate the manufacturers to reduce the average emission of their most selling car variants. For example:

- Consider a car 'T' has maximum emission of 145 gCO_2/km (With diesel fuel only)
- Car 'T' has a minimum emission of 22 gCO_2km (With 85% ethanol)
- Then the 'emission' of 'T' would be the average of both = (145+22)/2 = 84 gCO_2/km
    - Customer 'A' buys diesel car 'V' which emits 145 gCO2/km
        - Customer pays malus = (145-95) *400 = 20000kr
    - Customer 'B' buys car 'T', with max emission at 145 gCO_2/km and min emission at 22 gCO_2/km
        - Customer receives a bonus = (95-84) * 400 = 4400kr

8.5.1.5 Bans

The thesis proposes that the certain bans are deemed necessary for the fulfilment of the targets; the timelines for when these bans need to be implemented would be explained more in the next chapter.

- Ban on the use or registration of non-zero emission personal vehicles in Sweden.
- Ban on the use of fossil fuels for personal vehicles in Sweden.
- Ban on the sale of new non-zero emission personal vehicles in Sweden.
- Ban on the use of Euro 6, 5, 4, 3, 2, 1 personal vehicles in Sweden.
- Ban on use of non-zero emission personal vehicles during day time in urban areas in Sweden.

8.5.2 Minor policies

8.5.2.1 Fuel tax revision

The thesis proposes that fuel tax be revised so that each fuel is represented better by its energy content per volume and carbon content, which would make up the basis for the energy tax and the carbon tax respectively. The earlier this is done, the better, as it would be beneficial for the customer to understand and choose the better fuel in terms of emission quotient.

8.5.2.2 Vehicle tax revision

Vehicle tax is to be made dynamic in the future, as in the main component determining the tax level would be the amount of distance (kilometres) covered by the said vehicle. Then other parameters such as age, size, emission standard etc. come into the calculation to give the final tax amount. High amount of infrastructure and IT systems would be needed to monitor such a system, but would be essential to cover the fuel tax losses, due to fossil fuels being gradually phased out.

8.5.2.3 Tax exemption revision

With the advent of the Bonus-Malus system and super green car bonuses available for all consumers, including company car registrations, the thesis proposes that continuing the current tax exemptions for environmental friendly cars would be an overkill of subsidies. However, if the government can afford such a scheme, then the exemption can remain.

9 Deriving an implementation strategy for the policy & legislation ecosystem

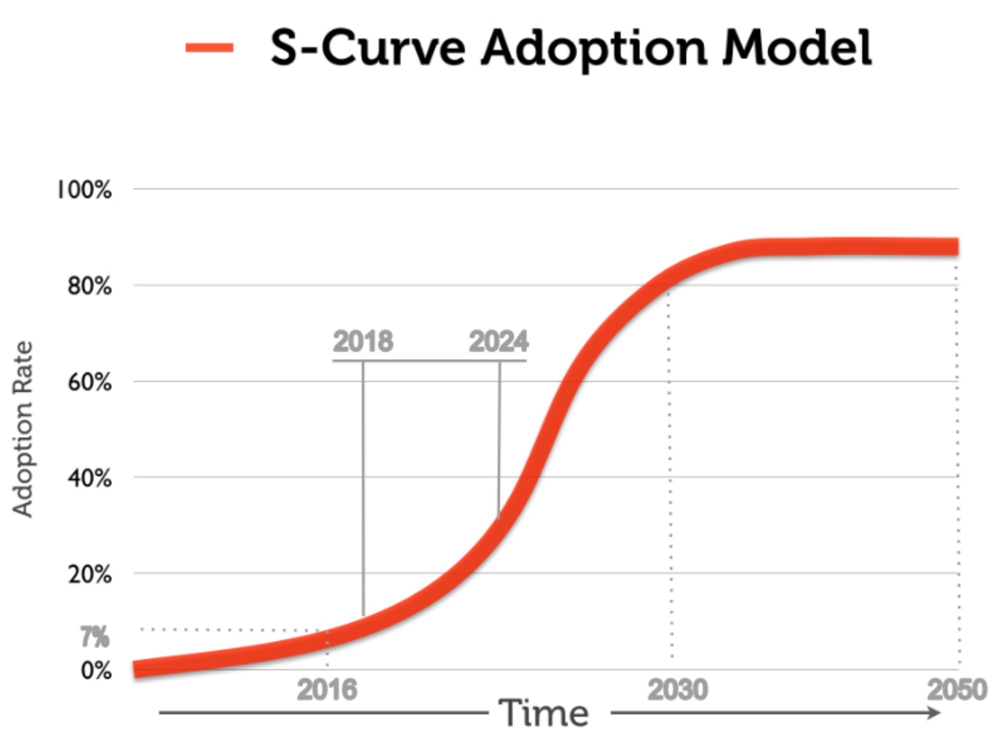
9.1 Introduction

With the policy eco-system now in place, the final chapter of this thesis studies and derives a possible implementation strategy for the same. From the previous chapters, the following information is available:

- A vision for personal transport in Sweden and numeric targets for the decarbonizing the vehicle fleet, for the years 2030 and 2050.
- Present scenario in terms of market demand, policies and future challenges.
- A policy eco-system for the future dedicated to initiate and cause a sustainable transition to a fossil free personal transport sector.

The total period of transition can be established as the time from the present year, 2016 till 2050; which is a total time of 33.5 years. To understand the pace and progress of a required transition, the S-curve adoption model for new technologies can be used for reference and guidance. The following diagram, from the book 'Diffusion of innovations' depicts the S-curve and the problem at hand [Rogers, 1962]:

Figure 12: S – curve adoption model for new technologies



The S-curve adoption model suggests that adoption of any technology from niche to mainstream would follow the S-curve according to time – an initial slow growth, a tipping point followed by exponential growth, and finally flatlining of the same. Since the thesis looks at adoption of low to zero emission technologies over current polluting technologies for personal transport, this model can be used to study the problem and provide crucial inferences which would be useful for the creation of the required strategy.

The X-axis of the graph is time and the Y-axis is the adoption rate of the particular technology. The 7% in the figure indicates the present condition of the required adoption; As of 2016 in Sweden, approximately 7% of all personal vehicles are fossil fuel independent (Hybrids, BEVs, Biogas and FFVs) [European vehicle market statistics, 2015]. From this, the location of this year, the start of the transition period is located in the graph. The numerical targets for 2030 and 2050, which are 80% and 100% adoption rates respectively, are also represented in the graph. The following can be inferred from the graph:

- To achieve the target at 2030, the policy eco-system needs to be implemented as soon as possible. The graph suggests that the period from 2018 – 2024 is the most crucial period for policy injection, and it includes the required tipping point for mass adoption of cleaner vehicles. This suggests that the policies introduced during this period should make it an easy choice for the consumer to use/buy a low emission vehicle.
- The bulk of the transition should occur by 2030, which means that bulk of the policies needed to ensure transition, should be implemented before this year. This also means that between 2018 and 2030, in a matter of 12 years, the market should look topsy-turvy to what it looks now, with demand for low or zero emission vehicles very high compared to high emission vehicles.
- From 2030 – 2050, the transition would slow down, as services/personal transport which need replacing with cleaner technology becomes more and more expensive. For example, travelling to remote areas in the cold of winter with less reliability on infrastructure such as electric supply. These journeys can be replaced with cleaner technology, only if required infrastructure is present in these areas, and thus would need more time and investment for change.

9.2 Injection of policies/legislations and their effects

To decide which different policies would be needed from the start, and which can start later, it would be good to know the effects of different policies on the average emission of the total personal vehicle fleet at 2030. This calculation would of course need many assumptions, but it would still give a reasonable impression of the effect of different policy measures on emissions. The following scenarios are tested:

- Base case – no specific transition policy implemented till 2030
- 4 phase Bonus-Malus system only, from 2018 to 2035.
- Phasing out/Scrapping Euro 5 and below personal vehicles from the fleet by 2030.
- 4 phase Bonus-Malus system + Phase out

9.2.1 Scenario 1 – Base case

- No new special policies dictate the path to fossil independence (till 2030).
- Only EU regulations and emission reduction criteria is followed.
- The following assumptions have been made for the calculations till 2030:
    - 100% of all vehicles 25 years and above (pre 2006) have been scrapped.
    - 25% of all vehicles between 15 and 25 years of age have also been scrapped.
    - Annual car sales of 250,000 cars from 2016 till 2030. (based on average of the sales data from the last 10 years)
    - EU regulations suggest average emission of new cars to be 90 gCO_2/km at 2020, 75 gCO_2/km at 2025 and 60 gCO_2/km at 2030.

The calculations made with these criteria and assumptions, together with data from Annex II are presented in the table below. The assumptions made for the calculation of normalized average CO_2 emission of fleet is given in Annex III.

Table 4: Car share % and normalized average emission of fleet – Scenario 1

Year	Total fleet	Car share (e= 0 gCO_2/km)	Car share (0 < e < 50 gCO_2/km)	Car share (50 < e < 100 gCO_2/km)	Car share (100 < e < 150 gCO_2/km)	Car share (e > 150 gCO_2/km)	Normalized average emission of fleet (gCO_2/km)
2016	4412700	0%	1%	2%	10%	87%	190
2030	5233417	1%	4%	20%	50%	25%	128

Where e = emissions;

9.2.2 Scenario 2 – Bonus Malus system + Super green car bonus only

- Implementation of a 4 phase Bonus – Malus system from 2018 till 2035.
- Also comply with EU regulations for reducing emissions.
- The following assumptions have been made for the calculations till 2030:
    - 100% of all vehicles 25 years and above (pre 2006) have been scrapped.
    - 25% of all vehicles between 15 and 25 years of age have also been scrapped.
    - Annual car sales of 250,000 cars from 2016 till 2030.

The calculations made with these criteria and assumptions, together with data from Annex II are presented in the table below. The assumptions made for the calculation of normalized average CO_2 emission of fleet is given in Annex III.

Table 5: Car share % and normalized average emission of fleet – Scenario 2

Year	Total fleet	Car share (e= 0 gCO_2/km)	Car share (0 < e < 50 gCO_2/km)	Car share (50 < e < 100 gCO_2/km)	Car share (100 < e < 150 gCO_2/km)	Car share (e > 150 gCO_2/km)	Normalized average emission of fleet (gCO_2/km)
2016	4412700	0%	1%	2%	10%	87%	190
2030	5233417	5%	22%	20%	33%	20%	101

Where e = emissions;

9.2.3 Scenario 3 - Scrappage system/phase out only

- Phase out/Scrappage program for old, polluting vehicles from the personal vehicle fleet
- Systematic phasing out of Euro 1 to Euro 5 vehicles from the period of 2018 - 2030
- The following assumptions have been made for the calculations till 2030:
    - Annual car sales of 250,000 cars from 2016 till 2030.
    - EU regulations suggest average emission of new cars to be 90 gCO_2/km at 2020, 75 gCO_2/km at 2025 and 60 gCO_2/km at 2030.

The calculations made with these criteria and assumptions, together with data from Annex II are presented in the table below. The assumptions made for the calculation of normalized average CO_2 emission of fleet is given in Annex III.

Table 6: Car share % and normalized average emission of fleet – Scenario 3

Year	Total fleet	Car share (e= 0 gCO_2/km)	Car share (0 < e < 50 gCO_2/km)	Car share (50 < e < 100 gCO_2/km)	Car share (100 < e < 150 gCO_2/km)	Car share (e > 150 gCO_2/km)	Normalized average emission of fleet (gCO_2/km)
2016	4412700	0%	1%	2%	10%	87%	190
2030	5233417	1%	4%	25%	63%	7%	113

Where e = emissions;

9.2.4 Scenario 4 - Bonus Malus system + Super green car bonus + Phase out/Scrappage program

- Implementation of a 4 phase Bonus – Malus system from 2018 till 2035.
- Also comply with EU regulations for reducing emissions.
- Systematic phasing out of Euro 1 to Euro 5 vehicles from the period of 2018 - 2030
- The following assumptions have been made for the calculations till 2030:
  - Annual car sales of 250,000 cars from 2016 till 2030.
  - EU regulations suggest average emission of new cars to be 90 gCO_2/km at 2020, 75 gCO_2/km at 2025 and 60 gCO_2/km at 2030.
  - 2% of all Euro 5 and below cars abandoned (not scrapped)

The calculations made with these criteria and assumptions, together with data from Annex II are presented in the table below. The assumptions made for the calculation of normalized average CO_2 emission of fleet is given in Annex III.

Table 7: Car share % and normalized average emission of fleet – Scenario 4

Year	Total fleet	Car share (e= 0 gCO_2/km)	Car share (0 < e < 50 gCO_2/km)	Car share (50 < e < 100 gCO_2/km)	Car share (100 < e < 150 gCO_2/km)	Car share (e > 150 gCO_2/km)	Normalized average emission of fleet (gCO_2/km)
2016	4412700	0%	1%	2%	10%	87%	190
2030	5233417	10%	34%	28%	21%	7%	70

Where e = emissions;

From the above results the following deductions can be made:

- The proposed Bonus-Malus system and phasing out of older vehicles need to be combined from the very start of the implementation.
- Even with these policies, the physical transition of vehicles can only achieve an average emission of fleet of 70 gCO_2/km at 2030, which is very much above the required target of 45 gCO_2/km.
- Bringing emissions down from 70 gCO_2/km to 45 gCO_2/km would need the market share of alternative fuels to be increased rapidly. This would mean favourable policies from the government side which would make uptake of alternative fuels more attractive. This could be by taxing fossil fuels higher or creating subsidies for drop-in fuels such as biodiesel, bioethanol etc.

10 Results

10.1 Roadmap till 2050: Policy ecosystem implementation strategy

The following passage describes the final result of this thesis; a timeline for the implementation of the policy eco-system so that the targets for 2030 and 2050 are achieved in the personal vehicle sector in Sweden – a policy roadmap till 2050.

The first set of policy measures starts with the year 2018.

- 2018
    - Launch of Factor based Bonus Malus policy system - Phase 1 (2018 - 2022)
        - 60000 kr bonus for zero emission vehicles,
        - 45000 kr bonus for < 35 gCO_2/km emitting vehicles
        - 35000 kr bonus for < 50 gCO_2/km emitting vehicles
        - Flexi fuel vehicles have their average emissions (Max + Min /2) to be considered for this system.
        - Above 50 gCO_2/km, factor based bonus - malus system springs into action.
        - Transition point : 95 gCO_2/km
        - Bonus - Malus factor : 400 kr/gCO_2/km
    - Launch of scrap & replacement incentive policy system - Phase 1 (2018 - 2022)
        - Scrap bonus for Euro 1 and Euro 2 cars, incentive only if they scrap and buy a low emission car
        - Incentive to reduce year by year.
    - Ban on usage of Euro 1 & Euro 2 cars by 2023.
        - Complete phase out of these cars by Dec 31st 2022.
- 2020
    - Review of the Bonus - Malus system - Phase 1
        - Change the factor if needed
    - Review of the scrap system - Phase 1
        - Change the incentive if needed

- 2023
  - Launch of factor based Bonus Malus policy system - Phase 2 (2023 - 2026)
    - 30000 kr bonus for zero emission vehicles
    - 20000 kr bonus for < 35 gCO_2/km emitting vehicles
    - 15000 kr bonus for < 50 gCO_2/km emitting vehicles
    - Above 50 gCO_2/km, factor based bonus - malus system springs into action.
    - Transition point : 75 gCO_2/km
    - Bonus - Malus factor : 600 kr/gCO_2/km
  - Launch of scrap & replacement incentive policy system - Phase 2 (2023 - 2026)
    - Scrap bonus for Euro 3 and Euro 4 cars, incentive only if they scrap and buy a low emission car.
    - Incentive to reduce year by year.
  - Ban on usage of Euro 3 & Euro 4 cars by 2027
    - Complete phase out of these cars by Dec 31st 2026.
  - All new fossil fuel based cars to have at least 50% flex fuel capability with biofuels
- 2025
  - Review of the Bonus - Malus system - Phase 2
    - Change the factor if needed
  - Review of the scrap system - Phase 2
    - Change the incentive if needed
- 2027
  - Launch of factor based Bonus Malus policy system - Phase 3 (2027 - 2030)
    - 15000 kr bonus for zero emission vehicles
    - 10000 kr bonus for < 45 gCO_2/km emitting vehicles
    - Transition point : 45 gCO_2/km
    - Bonus - Malus factor : 800 kr/gCO_2/km
  - Launch of scrap & replacement incentive policy system - Phase 3 (2027 - 2030)
    - Scrap bonus for Euro 5 cars, incentive only if they scrap and buy a low emission car.
    - Incentive to reduce year by year.
  - Ban on usage of Euro 5 cars by 2031.
    - Complete phase out of these cars by Dec 31st 2030.

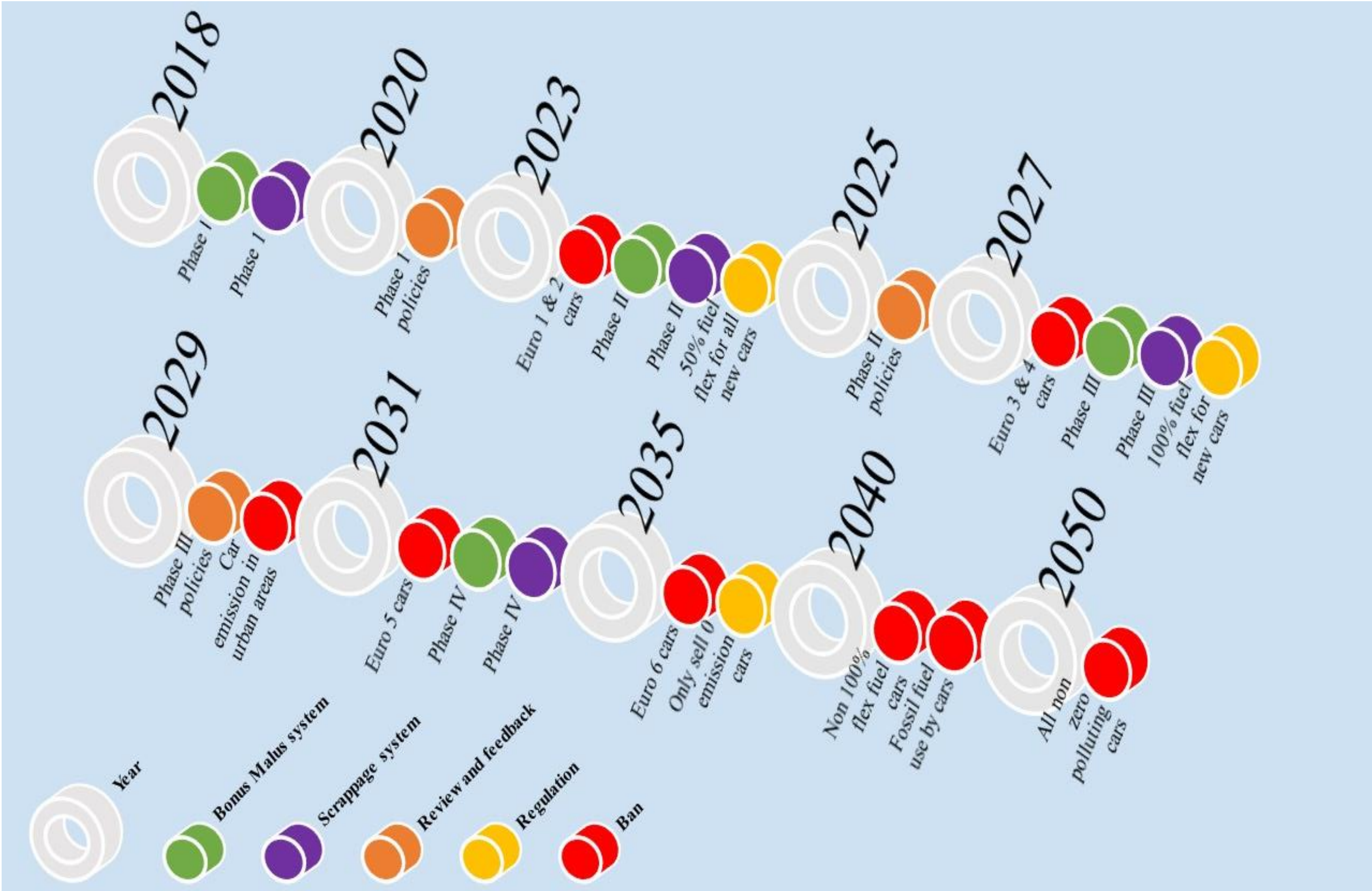
    - All new fossil fuel based cars to have 100% flex fuel capability with biofuels.
- 2029
    - Review of the Bonus - Malus system - Phase 3
        - Change the factor if needed
    - Review of the scrap system - Phase 3
        - Change the incentive if needed
    - Restriction on emissions in urban areas
        - All cars are allowed to be run on ‘0 emission mode’ only in city limits.
- 2031
    - Launch of factor based Bonus Malus policy system - Phase 4 (2031 - 2034)
        - No more bonus;
        - Transition point : 0 gCO_2/km
        - Bonus - Malus factor : 1000 kr/gCO_2/km
    - Launch of scrap & replacement incentive policy system - Phase 4 (2031 - 2034)
        - Scrap bonus for Euro 6 cars and non-flex fuel cars; incentive only if they scrap and buy a low emission car
        - Incentive to reduce year by year.
    - Ban on usage of Euro 6 cars by 2035.
        - Complete phase out of these cars by Dec 31st 2034.
- 2035
    - Bonus - Malus system is completed.
    - Only zero emissions vehicles are now sold/registered in the country.
- 2040
    - All non 100% flex fuel vehicles are phased out.
    - Fossil fuels are no longer allowed to use for personal transport in the country.
- 2050
    - Complete phase out of non-zero emission vehicles.

The effects of such an implementation, over the time period of 34 years, can be summarized as the following:

- Advantages
    - High incentive to buy a low emission vehicle
    - Moderate incentive to not to buy a high emission vehicle
    - High incentive for manufacturers to reduce emissions
    - High incentive for manufacturers to promote and make flexi fuel options
    - High incentive for existing car owners to replace their polluting vehicle
    - High application as a long term strategy
- Disadvantages
    - Retail price for popular car variants in Sweden to be higher in the short term
    - Need government certified and verified emission testing to eliminate fraud
    - Huge fiscal deficit caused by transition may need to be acquired via tax increase in other sectors
    - Unpopular measure of a fossil fuel tax increase would still be needed to reach the intended targets.

The strategic roadmap can be summarized in the figure below:

Figure 13: Roadmap of the policy implementation required for the transition towards a fossil free personal vehicle sector by 2050



11 Discussion

11.1 Backcasting for sustainable development

As a resulting of the backcasting process, the following were studied and identified:

- A sustainability framework for the future development of personal transport in Sweden
- The current situation in terms of vehicle market, policies and proposed measures with regard to decarbonizing the personal vehicle sector in Sweden
- An overarching vision for sustainable personal mobility, to be used as a guide for planning sustainable transition measures.
- Identifying externalities caused by personal transport in the Swedish context and studying their internalization
- Using market based policy and regulation methods to be used for physical transition of the vehicle fleet.
- Designing an implementation timeline for the policies and regulations in order to meet the governmental targets, while provide time for the market to adjust to the changes.

Initially, the thesis was intended to cover all aspects of transport in Sweden, but due to time constraints, the scope was defined only for personal transport. During the process, it became even more clear that the focus need to be made on the physical transition of the vehicle fleet to a fossil free one, as the behavioural transition is a vast research area by its own. And even more focus were put on during solution design phase, with emphasis on market based policy and regulation measures to promote the transition. The main assumption for a market based approach is that people would make decisions rationally and with logic, i.e. when offered a choice, consumers should pick the option which provides them with more value.

Thus it can be testified that the backcasting process, while providing valuable insight to understanding the processes at work with its system level view and thinking, it is easy to go astray and miss out on points while focusing on the design of solutions; even overwhelming at times if a person is working alone on the topic. Maybe it could be recommended to involve more experts and divide the work during the solution design process at least, so that a comprehensive plan can be developed.

11.2 Technological roadmap for 2050

What would be the technological development associated with this proposed strategy and policy implementation? As mentioned before, currently the personal vehicle market is optimized for ICE based fossil fuel/alternative fuel powered ones, with hybrid, BEV, biogas and hydrogen cars catering to a niche audience only. This thesis has strived to provide an unbiased neutral approach in terms of technology, with the impact on the environment the overriding deciding factor; i.e. market policies are implemented in such a way that cleaner technologies are supported and unclean technologies are made more expensive.

If the proposed policy strategy is implemented, the following can be expected in terms of technological transition till the period of 2050:

- The policy eco-system concentrates on making cleaner vehicles progressively cheaper while making polluting vehicles progressively expensive. This would mean that big powerful vehicles would be very expensive, while compact, lighter vehicles would be cheaper than today. The natural selection would see the fleet gradually transition towards smaller, compact cars in the future.
- The implementation strategy suggest that low emission variants of popular cars would be relatively cheaper, while their high emission variants would be relatively expensive. Table 8 in the annex provides the same information for such a popular car. This could mean that popular cars could remain popular, but the market would slant towards the cleaner variants such as hybrids and battery powered vehicles. Thus this thesis expects electric hybrid technology to be the prominent technology to cause the tipping point in terms of emission reduction.
- The expected hybridization would make sense in local and system level energy issues, as hybrid vehicles are helped by technologies such as regenerative brake system, providing higher energy efficiency than conventional vehicles. In terms of global issues, Swedish energy system is relatively carbon free, with almost 95% of its energy supply coming from hydro and nuclear technologies. This could also mean that coal technology is on the margin, so that when there is an energy demand spike due to increased plug-in hybrids or BEVs on the road, more coal would be burnt to produce them, resulting in more emissions. With the ETS and cap on carbon emission at a European level, this would mean that other sectors would be forced to reduce their emissions to keep the limit. This can be prevented by proper planning and increasing the capacity of renewable technology like wind and solar in Sweden, provided their economic viability remains intact.
- If the required target is met in 2030, this would mean that almost all of the vehicles in the current fleet would be replaced by smaller, cleaner, mostly hybrid or flex-fuel vehicles. Hybrid technology could be developed enough so that under city limits, all the cars can travel under the influence of its batteries only. This can be made into a regulation (proposed in the policy), where during day time in urban areas the traffic and congestion is expected to be high, no car is allowed to emit pollutants in these areas.
- The second generation of cars from 2035 onwards would be zero emitting ones, as per the policy strategy, and this would mean, in current terms, a very good market for BEVs and Hydrogen vehicles. By that time, these vehicles would be more developed and mature and affordable cars for all would be available.
- Biofuels and alternative fuels have a crucial role to play in the transition if the intended targets are to be met. Not everyone would be wanting to buy a car which is cleaner and would intend to use their own fossil fuel based vehicle as long as they can. Some needs of personal transport could be even technologically locked into fossil fuel based vehicles. For these customers, biofuels remain only the viable alternative which can replace fossil fuels and the thesis expects the demand to increase during the main transition and then get normalized.

- For 2050, only net zero emission fuels are present and technologies which cause local pollution would not be allowed into urban areas. This could mean that the personal vehicle fleet would have a majority of BEV, Hybrid with biofuel and Hydrogen powered vehicles at 2050, with certain technology locked in requirements being catered to by biofuel as well.
- The vehicle market in Sweden is very small compared to the European and world market for vehicles, and as such the vehicle fleet transition proposed inside Sweden would not influence other markets for the same. This can be seen simultaneously both as a threat and an opportunity; stakeholders in Sweden would have to adjust to a changing internal market while catering more or less the same for the world market, threatening their business model. On the other hand, Sweden provides a hotbed for testing innovations in technology and services, which can be introduced later in world markets for their inevitable transition as well.

11.3 Infrastructure roadmap for 2050

Infrastructure development would be an essential cog in the intended transition, as well as to meet the targets in intended time. Some of the features expected if the policy strategy is implemented are:

- Fuel infrastructure would see a major shift and would need to become fuel 'hubs', catering to all kind of fuel needs for the changing market. Current fuel infrastructure would need to be redesigned and rebuilt to include alternative fuels and electricity. This is essential when a sustainable transition is in question; otherwise fossil fuel refuelling infrastructure would go obsolete once the transition is completed.
- Road infrastructure would need to change with the times as technologies such as autonomous vehicles come into the picture more. Currently urban areas around the world are redesigned for the people to live in, rather than an area to drive around and this would be seen in Sweden as well. Electric highways for large trucks have been tested with positive results in the past few months in Sweden. Such developments in infrastructure would be essential to reduce the overall emissions from transport.
- Battery charging infrastructure network would need to be built all around Sweden, as the transition would not progress without adequate refuelling is not provided. Regulations might be needed to monitor this network, with charging modes and standards to be kept on check as well.

11.4 Sustainable development roadmap for 2050

How would society transform during the time period of transition and how would the transition affect people? The thesis has already established in the previous chapters, that this transition to a fossil free transport and economy is urgent and essential for society to continue as it can be seen today, and for generations to come. Sustainable development can only occur by increasing the wellbeing of a society within the sustainability constraints, and the following effects could be expected from the implementation of the strategy:

- In the short term, wellbeing would be affected by the strategy, as the policies try and test the market and find the tipping point, after which mass transition can happen. This would mean deliberately trying to change behavioural patterns and thinking, so that alternative life choices could be made.
- Making popular cars more expensive, the big and powerful ones which pollute more, would prove unpopular in the beginning as the Swedish consumer base is accustomed to life with such vehicles.
- Tax increases may be necessary to reduce the fiscal deficit due to losses in fuel tax income, tax exemptions and bonuses such as super green car bonus and scrappage bonus.
- The effect of the proposed policies would be different for people from different wakes of life; e.g. people living in urban areas would be more affected by the policies as monitoring during the transition can be done only within the urban boundaries. Also enforced bans/phase out of older cars mean poorer people who can only afford to buy or use older vehicles would be more affected, and are forced to buy more expensive vehicles instead. On the other end of the spectrum, richer folks could buy cleaner vehicles as their second or third vehicle and use them only when they are forced to do so.

However, the Swedish government taking unpopular decisions for the benefit of the transport sector and to society in general would not be new. The implementation of congestion tax system in Stockholm in 2006 was initially unpopular among people who were affected. Now the congestion tax system is widely seen as successful in reducing traffic at peak times, and has hence gained societal favour for it [Eliasson, 2014]. Such an impact could also be expected with the current question in hand.

12 Conclusions

This thesis takes up the question of how to achieve the following challenging targets for the Swedish personal transport sector:

- To be fossil free by 2050;
- To be fossil independent by 2030; which is interpreted as:
    - 80% reduction of carbon emissions from 2007 levels;
    - Replacement of fossil fuels through the use of alternative fuels;

The thesis then proceeded to study and analyse the past, current and proposed initiatives, intended to achieve these targets; and the following conclusions are made:

- Considering the present vehicle market, the current and proposed initiatives from the government will miss both the targets for 2030 and 2050.
- This can be attributed to the following causes:
    - Lack of a concrete strategy to achieve the same;
    - Lack of incentive for customers to choose cleaner transport;
    - Lack of incentive for buyers to choose cleaner vehicles;
    - Lack of incentive for manufacturers to make cleaner vehicles;

The thesis then proceeds to study the challenge as a sustainability transition question and proposes a market based policy strategy to achieve the dual targets for 2030 and 2050. The following conclusions can be made from the result:

- To achieve the fossil independence target for 2030, for both the interpretations, the following policies must be in place, starting from 2018;
    - A dynamic, factor based Bonus-Malus system for new vehicle sales;
    - Flexi-fuel regulations for new vehicles;
    - Nationwide scrappage system for very old, inefficient vehicles;
    - Phase out program of older, polluting vehicles;
    - Fuel tax reforms to make alternative fuels competitive to fossil fuels;
    - Large scale, rapid investments in infrastructure and technology for a cleaner transport system;
- To achieve the fossil fuel freedom target for 2050, along with the above mentioned policy framework, the following strict regulations must be in place;
    - Only net zero emission vehicles are sold from 2035.
    - Fossil fuels are phased out by 2040 (For personal vehicles only).
    - All non-net zero emission vehicles are phased out by 2050.

The thesis also concludes that present and future transport systems must be designed with the following principle in mind:

> Personal mobility as a need, is minimized, and as a choice, is clean efficient and easily accessible;

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Annex I – Workshop with experts

A workshop was conducted on June 2nd, 2016 at SWECO Headquarters in Stockholm, between the times 14 to 17 on this topic. The panel included the following experts:

- Magnus Nilsson; Environment, transport & climate consultant, Magnus Nilsson Produktion
- Anne Bastian; PhD student; Centre for Transport Studies, KTH
- Thomas Sjöström; ITS & traffic system group manager, SWECO
- Dr. Cecilia Wallmark; Section manager; Energy strategies, SWECO
- Jonas Sundberg; Adj. professor, BTH; ITS consultant, SWECO

The details of the thesis, the methods followed and the results were presented to the panel in an hour long presentation and individual assessments were noted and discussed in the next one hour. Some of the salient points from the discussion were:

- The general opinion from the experts regarding the policy strategy was that is a well thought and very much possible policy eco-system strategy, with an oversight and depth not seen in any other study/strategy yet.
- However, there can be many multiple combinations of these policies together, with different timelines, such that this strategy would be one of many different strategies to consider. A study would then be needed to see which strategy option would be the best one to go for.
- The current political situation in Sweden and in Europe suggests that such an elaborate plan where the government would need to spend billions of crowns for transition, would not be a realistic option. The strategy proposed starts at 2018, which is an election year and thus there is a high risk of such a plan never taking off itself.
- Fossil fuel taxation is still the best way to induce the transition required, together with bans on use of polluted vehicles from a certain timeline. These are necessary policies, but could be unpopular and tough on the middle class society; it is a matter of political will which is lacking in the current political climate.
- Behavioural change is crucial in terms of achieving the targets and it was noted that the thesis doesn't focus on this aspect. It is still a huge topic for research and analysis and should be used to question and challenge personal mobility in the future.

Annex II – Data for calculations and inferences

Table 8: Best selling cars in Sweden for 2015[BIL Sweden, 2016]

Rank	Vehicle Name	No of units	Market Share
1	Volvo V70	28.613	8.5%
2	Volkswagen Golf	22.779	6.8%
3	Volvo XC60	14.834	4.4%
4	Volvo S/V60	14.698	4.4%
5	Volkswagen Passat	14.392	4.3%
			Total - 28.4%

Table 9: Bestselling car brands in Sweden for 2015 [BIL Sweden, 2016]

Rank	Manufacturer	Market Share
1	Volvo	21.1%
2	Volkswagen	14.9%
3	Toyota	5.8%
4	Audi	5.7%
5	BMW	5.5%
		Total - 53.0%

Table 10: Bestselling car conglomerates in Sweden for 2015 [BIL Sweden, 2016]

Rank	Vehicle Name	Brands included	Market Share
1	Volkswagen Group	Volkswagen, Audi, Skoda, SEAT	26.2%
2	Volkswagen	Volvo	21.1%
3	Hyundai Group	Hyundai, Kia	7.3%
4	Renault Group	Renault, Nissan, Dacia	6.7%
5	BMW Group	BMW, Mini	6.4%
			Total – 67.7%

Table 11: Top selling 50 cars by category in Sweden for 2015 [Derived with data from BIL Sweden, 2016]

Rank	Euro Market Segment	Prominent cars	Number	Market share
1	C - Medium	Golf, V40, Auris, Cee'd, 308, Focus, A3, Leon, 1 series, Astra, i30, CLA, Megane	13	6.8 + 3.1 + 2.0 + 2.0 + 1.2 + 1.1 + 1.1 + 0.8 + 0.7 + 0.7 + 0.6 + 0.6 + 0.5 = 21.2%
2	D - Large	V60, Passat, Octavia, 3 series, A4, C class, Avensis, Mondeo, Outback, Superb	10	4.4 + 4.3 + 1.6 + 1.6 + 1.4 + 0.9 + 0.9 + 0.7 + 0.6 + 0.6 = 17.0%
3	J - SUV/CUV	XC60, Qashqai, Outlander, Tiguan, Captur, Sportage, RAV4, Duster, XC90, ASX, Q5, CR-V,	12	4.4 + 1.4 + 1.2 + 1.0 + 1.0 + 1.0 + 0.8 + 0.7 + 0.7 + 0.6 + 0.5 + 0.5 = 13.8%
4	E - Executive	V70, A6, 5 series, E class	4	8.5 + 1.6 + 1.3 + 0.8 = 12.2%
5	B - Small	Fabia, Yaris, Polo, Clio, Rio, 208, Fiesta, Cooper, i20, Corsa	10	1.5 + 1.4 + 1.4 + 1.2 + 0.8 + 0.7 + 0.6 + 0.6 + 0.5 + 0.5 = 9.2%
6	A - Mini	Picanto	1	0.6 = 0.6%
			Total - 50*	**Total - 74%***

Table 12: Average CO_2 emissions of top selling four cars from each category in Sweden for 2015[Derived with data from BIL Sweden]

Euro Market Segment	**Prominent cars**	**Total market share**	**gCO_2 / km (Highest polluting variant)**	**gCO_2 / km (Lowest polluting variant)**
C - Medium	Golf, V40, Auris, Cee'd	13.9%	190,194,143,171 = 174.5	85,88,79,97 = 87.25
E - Executive	V70, A6, 5 series, E class	12.2%	164,229,247,237 = 219.25	107,109,109,102 = 106.75
D - Large	V60, Passat, Octavia, 3 series	11.9%	237,155,149,204 = 186.25	48,39,85,44 = 54
J - SUV/CUV	XC60, Qashqai, Outlander, Tiguan	8%	249,138,154,199 = 185	117,99,42,125 = 95.75
B - Small	Fabia, Yaris, Polo, Clio	5.5%	148,127,139,144 = 139.5	88,75,82,82 = 81.75
		Total - 51.5%	**Normalized Average - 185.73****	**Normalized Average - 84.93****

Table 13: Volkswagen Golf variants retail price differences according to the proposed Bonus Malus system

Vehicle Brand	**Emission**	**Current Price (2016)**	**Price in 2018**	**Price in 2023**	**Price in 2028**
VW Golf R 2.0 TSI BlueMotion, Petrol	165 gCO_2/km	392 600	420 600 (+28000)	446 600 (+54000)	488 600 (+96000)
VW Golf 1.2 TSI BlueMotion, Petrol	112 gCO_2/km	218 100	224 900 (+6800)	240 300 (+22200)	271 700 (+53600)
VW Golf 1.6 TDI BlueMotion, Diesel	99 gCO_2/km	225 600	227 200 (+1600)	240 000 (+14400)	268 800 (+43200)
VW Golf GTE 1.4 TSI Plug-In-Hybrid	37 gCO_2/km	376 000	341 000 (-35000)	361 000 (-15000)	366 000 (-10000)
VW E-Golf	0 gCO_2/km	389 900	329 000 (-60000)	359 000 (-30000)	374 000 (-15000)

Table 14: Age of current Swedish fleet and their fleet share % [Derived from Fordon 2015 and European Vehicle Market Statistics 2015]

Year	Age	Registrations	Fleet share %	Emission Standard	Diesel car share %
<1998	>18	501135	10.73	Euro 1	-
1998	18	136469	2.92	Euro 2	4
1999	17	219933	4.71	Euro 2	5
2000	16	198784	4.25	Euro 2	5
2001	15	169258	3.62	Euro 3	6
2002	14	194954	4.17	Euro 3	7
2003	13	212834	4.56	Euro 3	8
2004	12	223987	4.80	Euro 3	12
2005	11	244125	5.23	Euro 3	14
2006	10	252817	5.41	Euro 4	20
2007	9	278403	5.96	Euro 4	35
2008	8	228827	4.90	Euro 4	36
2009	7	183724	3.93	Euro 4	41
2010	6	277821	5.95	Euro 4(70%)/Euro 5(30%)	51
2011	5	289970	6.21	Euro 4(25%)/Euro 5(75%)	61
2012	4	248257	5.32	Euro 5	67
2013	3	254142	5.44	Euro 5	61
2014	2	291155	6.24	Euro 5	59
2015	1	261989	5.61	Euro 5(70%)/Euro 6(30%)	60
2016	0	473	0.01	Euro 6	-

Table 15: Changes in retail price of bestselling cars in different segments according to the proposed Bonus Malus system

Vehicle Brand	Segment	Emission	Current Price	Price in 2018	Price in 2023	Price in 2028
VW Golf GTE 1.4 TSI PHEV	C - Medium	37 gCO_2/km	376 000	341 000 (-35000)	361 000 (-15000)	366 000 (-10000)
Volvo V60 Twin Engine PHEV	D - Large	48 gCO_2/km	483 900	448 900 (-35000)	468 900 (-15000)	486 300 (+2400)
Volvo XC90 Twin Engine PHEV	J - SUV	49 gCO_2/km	816 800	781 800 (-35000)	801 800 (-15000)	820 000 (+3200)
Mitsubishi Outlander PHEV	J - CUV	42 gCO_2/km	400 900	365 900 (-35000)	385 900 (-15000)	390 900 (-10000)

Table 16: CO_2 distribution of Swedish car fleet by Euro standards and engine type [Derived from data from BIL Sweden, Fordon 2015 and European Vehicle Market Statistics 2015]

Emission Standard	Total Registration	Gasoline car share	Avg. CO_2 emission	Diesel car share	Avg. CO_2 emission	Other car share	Avg. CO_2 emission (combined)
Euro 1	501135	96%	230(¤)	3.5%	180(¤)	0.5%	227
Euro 2	555186	93.5%	230(¤)	6%	175(¤)	0.5%	225
Euro 3	1045158	88.1%	226	9.7%	175	2.2%	216
Euro 4	1138246	53.3%	221	37.1%	182	9.6%	185
Euro 5	1094378	33.5%	175	60.9%	137	5.6%	142
Euro 6	78597	33.5%	139	60.0%	118	6.5%	117
All	4412700	66.0%	220(**)	29.3%	155(**)	4.7%	190

Annex III – Calculation of fleet emission

The following table (Table 3) in chapter 9 provides the information on normalized average CO_2 emission of fleet (gCO_2/km) in the case where no specific policies have been introduced for transition:

Year	Total fleet	Car share (e= 0 gCO_2/km)	Car share (0 < e < 50 gCO_2/km)	Car share (50 < e < 100 gCO_2/km)	Car share (100 < e < 150 gCO_2/km)	Car share (e > 150 gCO_2/km)	Normalized average emission of fleet (gCO_2/km)
2016	4412700	0%	1%	2%	10%	87%	190
2030	5233417	1%	4%	20%	50%	25%	128

The assumptions used in calculating the value of 190 and 128 are given below:

- E0 = average emission of vehicles, where e = 0 gCO_2/km = 0
- E1 = average emission of vehicles, where 0 < e < 50 gCO_2/km = 25 gCO_2/km
- E2 = average emission of vehicles, where 50 < e < 100gCO_2/km = 75 gCO_2/km
- E3 = average emission of vehicles, where 100 < e < 150gCO_2/km = 125 gCO_2/km
- E4 = average emission of vehicles, where e > 150 gCO_2/km = 200 gCO_2/km

Normalized average emission of fleet (gCO_2/km) for the year 2016 =

E = (4412700*(0%*E0+1%* E1+2%*E2+10%*E3+87%*E4))/4412700

E = 190 gCO_2/km

Normalized average emission of fleet (gCO_2/km) for the year 2030 =

E = (5233417*(1%*E0+4%*E1+20%*E2+50%*E3+25%*E4))/5233417

E = 128 gCO_2/km