Air pollution and Greenhouse gas emissions in Sweden: The transport sector

(A draft)

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1 GAINS and GAINS-Sweden

1.1 Introduction

In this report the focus is on the transport sector. One reason for this focus is that contrary to other emission sources, the emissions from transport are increasing over time. Except for some air pollutants such as NOx and SO2 emissions from the transport sector have increased since the 80ies. This applies to the emissions of particulate matter, which is expected to have a negative influence on human health, and also to GHG, especially CO2. The main problem is the increase in road transport. Although new registered vehicles to some extent are emitting less substances, the increase in the number of vehicles and thereby the increase fuel demand have led to higher emissions of different substances in the transport sector compared to other sectors.

What also makes the transport sector special is that the emissions come from diffuse emissions sources and many users. Hence, controlling emissions and the increase in emissions is not as easy as in other sectors. To some extent the increase in emissions is related to the economic activity in society, since transport is a derived demand, but there is also the influence of changes in tastes among the general population. Moreover, road transport is of interest since the emissions often occur in close proximity to where people live. Hence, for emissions that have a negative impact on human health road transport makes an important contribution. The RAINS/GAINS model was originally developed to support regional (transboundary) air pollution policies which means that adaptations have to be made to account for the impact on a more local scale. Since the approaches used within GAINS needs to be validated, it is of interest to compare the results with those from other studies. Since similar studies have been done on Swedish data within the transport area, this is an additional reason to undertake these case studies. Thereby the results from the GAINS model can be compared to the outcome from other projects and models.

The objective of this part is a presentation and review of RAINS and GAINS and how GAINS could be developed to answer the objectives of SCARP including a GAINS Sweden.

The outline of this report is as follows. Chapter 1 is a review of the GAINS model and a presentation of GAINS Sweden. In chapter 2 the online GAINS is used to estimate Swedish transport emissions and their costs. In chapter 3 Markal is used to calculate Swedish emission reductions of CO2. Chapter 4 is about behavioural change related to modal choice and its impact on emission reduction. This chapter also compares and discuss the results of the different used models.

1.2 Integrated assessment models

An integrated assessment model is defined broadly as any model which combines scientific and socio-economic aspect. This is done primarily for the purpose of assessing policy options. Integrated assessment is even defined more broadly as any model which draws on
knowledge from research in multiple disciplines.\textsuperscript{1} Integrated assessment models have for instance provided negotiators with an integrated regional view of the air pollution problems and their potential solutions. The usefulness of such models is that a great deal of information is required to understand policy relevant questions concerning air pollution and the models allow the information to be combined to investigate different strategies for the reduction of transboundary air pollution.\textsuperscript{2} Furthermore, Integrated Assessment Modelling is defined as inherently trans-disciplinary, encompassing science which captures pollutant emissions (from energy, transport, agriculture etc.), complex atmospheric chemistry, meteorology and other dispersion processes, responses of the natural environment to acidic and eutrophic deposition, influences on human health, abatement potential, economics and policy (Oxley (2007)).

### 1.3 The RAINS model

The RAINS (Regional Air Pollution Information and Simulation) model is a partial equilibrium model that basically integrates an atmospheric transportation model and data on abatement costs on a country level. The RAINS model combines information on economic and energy development, emission control potentials and costs, atmospheric dispersion characteristics and environmental sensitivities towards air pollution (Schöpp \textit{et al.}, 1999). The RAINS describes the pathways of pollution from anthropogenic driving forces to various environmental impacts. The model addresses threats to human health posed by fine particulates and ground-level ozone as well as risk of ecosystems damage from acidification, excess nitrogen deposition (eutrophication) and exposure to elevated ambient levels of ozone. These air pollution-related problems are considered in a multi-pollutant context (Amann (2004)).

### 1.4 Control Costs

Within the tradition of partial equilibrium models of environmental economics there are two basic approaches to connect environmental variables with the activities of firms (see, e.g. Baumol and Oates, 1975).\textsuperscript{3} Both approaches link activities of economic agents (most commonly firms) to the generation of residuals that may be polluting. The difference is how the environment is linked to emissions. In the \textit{damage function approach} the adverse environmental effects of polluting residuals are evaluated and monetized through a function termed the damage function. Optimal pollution policies are then based on minimizing the sum of control costs of residuals generation and environmental damages. The \textit{environmental standards approach} links generation of polluting residuals to standards of exposure to pollution at various receptor sites. Optimal pollution policies are then based on either maximizing the benefits from being able to pollute, or minimizing control costs of pollution, subject to the environmental standards as constraints. Hence, instead of environmental damage functions environmental standards are introduced linked to the deposition of pollutants.

\textsuperscript{1} http://www.econ.ucsb.edu/papers/wp31-98.pdf
\textsuperscript{2} (http://www.york.ac.uk/inst/sei/rapidc2/iam.html
\textsuperscript{3} Försund (2000)
-Optimization

In general the term optimization refers to the study of problems in which one seeks to minimize or maximize a function by systematically choosing the values of variables from within an allowed set. The function may be a cost function as in RAINS:

Total cost = \sum \text{cost}

Specifically the general form of a total cost function may be:

\[ TC = \sum (I^{an} + OM + CS) \]

TC: total cost, \( I^{an} \): annualized investment, OM: operating and maintenance cost, CS: cost saving.

The optimization procedure in RAINS consists of the following steps:

- set target values for the environmental impacts
- minimize costs for achieving these targets
- read off on cost curves the optimal emission levels, costs and control strategies for all pollutants and countries.

Since the objective function and all constraints are linear functions in the decision variables, the problem can be solved using linear programming methods:

\[
\begin{align*}
\text{Min} & \quad \sum c_i (e_i^0 - e_i^i, e_i^0) \\
\text{Subject to} & : \\
& e_i^{\text{min}} (e_i^0) \leq e_i^i \leq e_i^0, \quad i = 1,...,N \\
& \sum_{i=1}^{N} a_{ij} e_i^i + b_j \leq d_j, \quad j = 1,...,R
\end{align*}
\]

Where
\( C_i \): cost function of country \( i \)
\( e_i^0 \): initial emission of country \( i \)
\( e_i^i \): optimal emission
\( a_{ij} \): atmospheric transportation coefficient from country \( i \) (\( i=1,...,N \)) to receptor \( j \) (\( j=1,...,R \)) i.e., the EMEP grids.
\( b_j \): background deposition.


\( d_j^* \) relates to environmental objectives specified as emission targets

\section*{1.5 The GAINS model}

In order to include investigation of strategies for the reduction of green house gases the RAINS model has been expanded. The result is the GAINS (Greenhouse gas – Air pollution Interactions and Synergies). The GAINS model includes, in addition to the air pollutants covered in RAINS, carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and the F-gases (Klaassen et al., (2004)). Thereby, the traditional RAINS model constitutes the air pollution-related part of the GAINS model, while the GAINS extensions address the interactions between air pollutants and greenhouse gases. Hence, the GAINS model is used to simultaneously manage both air pollution and greenhouse gases imposed by the fact that these pollutants have common sources i.e. their emissions interact in the atmosphere and separately or jointly they cause a variety of environmental effects at the local, regional or global scale.\(^4\)

In RAINS/GAINS the cost function is a quantification of values to society of the resources diverted to reduce emissions (Klimont et al., 2002). In practice, these values are approximated by estimating costs at the production level rather than at the level of consumer prices.

Formally the cost function in GAINS takes the following form:

\[
C = \sum_{i,k} \left( \sum_{m} c_{i,k,m}^x x_{i,k,m} + \sum_{k'} c_{i,k,k'}^y y_{i,k,k'} \right)
\]

Where the first term relates to costs for end of pipe technologies (i.e. each control technology that reduces an emission factor without changing the underlying activity) and the second term represents total substitution/energy efficiency cost. In the GAINS model the cost function includes the following decision variables:

1. The activity variables \( x_{i,k,m} \) for all countries \( i \), activities \( k \), and control technologies \( m \);
2. The substitution variables \( y_{i,k,k'} \) representing fuel substitutions and efficiency improvements (replacing activity \( k \) by \( k' \)). These variables relates to structural measures that supply the same level of (energy) services but with less polluting activities.

The methodology in GAINS uses the application of individual emission control options as decision variables. All economic and emission-relevant features are directly connected to these variables. This allows to fully capturing all interactions between pollutants for each individual emission control measure. In such a way, the traditional ‘cost curve’ approach of the RAINS model is replaced by a ‘technology-driven’ problem formulation (Klaasssen et al (2004).

\(^4\) http://www.iiasa.ac.at/rains/gains/index.html
3. Except the decision variable \( x_{hk,m} \) as well as the substitution variable \( f_{hk,m} \), the GAINS model considers a further variable related to greenhouse gases. The net cost to emit greenhouse gases equals the (permit) price per unit of pollutant \( T_p \) (e.g., price of emission permits) times the (net) quantity bought \( Q_{ip} \).

the complete total cost function takes the form:

\[
C = \sum_{i,k} \left( \sum_m c_{i,k,m} x_{i,k,m} + \sum_{k'} c_{i,k,k'} y_{i,k,k'} \right) + \sum_i T_P Q_{ip}
\]

Formally, the objective function of the optimization procedure in GAINS is specified as follows:

**Total cost = EoP cost + FSW cost + (Ceq revenues)**

EoP cost = End-of-pipe control costs
FSW = Fuel substitution costs. GAINS offers the option to replace certain given baseline activities by others (e.g., coal by gas) in response to a set of environmental targets (or simply as a more cost-effective energy scenario).

Ceq-revenues = Climate”Penalty” Term which forces the model to react to a non-zero exogenous carbon price i.e. a CO2-equivalent carbon price.

-The constraints

As discussed above, optimization procedure includes an objective function, constraints and restrictions which serve to define or limit the value of the variables included in the constraints. The constraints are about objectives to be considered during the optimization. The constraints used for the GAINS optimization may be dealt into two categories i.e. there are constraints that are used to ensure consistency across the model, and constraints whose numerical values represent data that are collected in the GAINS/RAINS databases, such as maximum application rates and resource constraints. The constraints used in GAINS are summarized below (Wagner et al (2007)):

1. Balance Equations
Balance equations ensure the consistency between activity data variables and fuel substitution variables: if an activity changes relative to the baseline then a transition variable describing this change takes a corresponding non-zero value. In this way it is ensured that the change is accounted both for the activity that is being replaced, but also for the activity with which it is replaced. The consistency is ensured by imposing the following constraints:

- Energy Balance - Electricity
- Energy Balance - Heat

2. Technological Constraints
• Applicability of technologies. Certain technologies, in particular the best available technology for a given sector-activity combination, may not be applicable beyond a certain limit. This may be due to the fact that, e.g., there is not enough space close to a power plant for housing the additional equipment, etc. This is reflected by imposing an upper limit on the application rate.
• Minimum application rates for NH3 technologies.
• Emission standards. It is required in the model that for each sector-activity combination the emissions of any pollutant can only decrease, but not increase.
• Technology standards. Certain control technologies, e.g. those resulting from earlier emission control legislation, must not increase their share in optimized scenarios.
• Technology potentials. The absolute amount of activity that can be controlled may be the absolute amount of activity that can be bounded either from above or below:

3. Activity constraints.
• Resource/scraping constraints: If an activity level can change in GAINS then it is associated with a corresponding upper and/or lower bound.
• Bounds on fuel substitutions: In addition to the resource/scraping constraints there may also be limitations to individual fuel substitutions.

4. Aggregations/Consistency
• Aggregating power plant types. GAINS distinguishes between different power plant types:
• Boiler type shares are constant
• Aggregation of solid fuels
• Aggregations of fuel substitutions. This aggregation is imposed in order to ensure consistency in the power sector not only with regard to the activity levels but also with regard to the fuel substitutions.

Furthermore, environmental constraints are used for environmental target setting in policy applications.

These constraints are:
• Years of life lost (YOLL) indicator i.e. the loss of life expectancy.
• Acidification indicator: The impact indicator used is the average accumulated exceedance of acidification.
• Eutrophication indicator: The impact indicator used is the average accumulated exceedance of eutrophication.
• Ozone indicator: The impact indicator used is \( SOMO35 \). SOMO35 is calculated as the sum of the daily eight-hour maximum ozone concentrations in excess of a 35 ppb threshold, integrated over the full year.
The valuation of premature deaths from chronic exposure to PM concentrations is a controversial issue, since there are basically two ways to value health impacts, either through a ‘Value of a Statistical Life’ (VSL) or a ‘Value Of a Life Year lost’ (VOLY) method. In the first, one values a premature death against the VSL, while in the second one estimates the number of ‘Years Of Life Lost’ (YOLL) and multiplies these with the VOLY. The European Commission decided for the CAFE program to adopt the precautionary principle, and thus employed the higher damage estimates from the VSL approach, also because they argue it to be more statistically reliable than the VOLY method (Bollen et al (2007)).

1.6 Gains and the transport sector

-Cost efficiency analysis

There are two main methods used to evaluate the outcome of policy instruments in economics terms. In Cost-Benefit Analysis, which was the method used in the CAFE programme for example, the evaluation is based on a comparison of all benefits and costs in monetary terms. For this type of analysis external cost calculations, such as those described previously, are needed. However, especially for the impact of emissions on the natural environment, such estimates are difficult to quantify. Hence, in evaluation of environmental policies it has been more common to rely on cost-efficiency analysis. As discussed in the introduction to this report, this method rests on a quantification of the costs and effects of implementing various policies. It is also for this purpose that the RAINS/GAINS model has been developed.

The RAINS/GAINS model however has originally been developed to evaluate policy measures aimed at stationary sources. Hence, the focus in the approach has been on the implementation of technical measures for emissions that will have an impact over larger areas. Nevertheless, this is not a correct description of the emissions of the transport sector, nor of the policy instruments that can be used to reduce transport emissions. This is also an issue that was discussed regarding the use of the RAINS/GAINS model in the CAFE programme.6

There are basically two problems with the RAINS/GAINS model that needs to be addressed before the RAINS/GAINS model is applied to the transport sector; the exposure

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5 In CAFE, stakeholders requested that mortality be valued using two approaches: one based on the loss of life expectancy and valued using the value of a life year (VOLY), and the other valuation made against the number of deaths linked to pollution exposure valued using the value of a statistical life (VSL). For the former, an estimate of 52,000 Euros was adopted for the VOLY, which drew on EU research then available. However, further research on the value of a lost life year (VOLY) has been carried out in a larger number of European countries since the original CAFE methodology was agreed. This has led to a downward revision of the recommended VOLY to 40,000 Euros.

modelling of emissions with a local impact and the inclusion of other than technical abatement measures. We give a short description on each of them in turn:

- The RAINS/GAINS model uses a 50 km grid scale for its exposure and deposition modelling. This however excludes the possibility to take into account the finer scales in emissions and effects. The resolution is not enough to fully assess urban air pollution problems and local ecosystem impacts. This problem is also fully acknowledged and efforts have been made, mainly through the research project City-Delta, to find ways to modify the RAINS/GAINS model. However, as stated in a report that presents the results from this project, serious uncertainties exist with the results which in part is due to the input data used. The conclusion therefore is that “More accurate information on city-specific meteorological data and information on the characteristics of local emission sources, as well as monitoring data, are important prerequisites for a further refinement of the methodology.”

- In the RAINS review it was concluded that since the model only deals with technical measures the results are biased since it over-emphasizes costly (end-of pipe) solutions and overlooks less expensive options implied or inherent in structural changes and economy reactions to market stimuli. Therefore it was suggested that further work, in cooperation with experts from Member states, was needed to ensure that all the potential abatement measures have been identified and that the most representative cost information is being used in the modelling. Furthermore IIASA should analyse which aspects of the calculation are the most significant sources of bias (by sector and pollutant) leading to the greatest deviation between the ex-ante and ex-post cost assessments. Since adaptation in behaviour could be one important measure to achieve lower emissions from transportation, the exclusion of non-technical measures may be particularly troublesome for analysis done for this sector.

If the City Delta approach is used as described in [http://www.iiasa.ac.at/Admin/PUB/Documents/IR-07-001.pdf](http://www.iiasa.ac.at/Admin/PUB/Documents/IR-07-001.pdf), then this exposure modelling rests on modelling the concentration increase in the urban air-shed from local emissions sources. This increase is then added to the concentrations modelled using the EMEP regional scale results that are the basis for the RAINS/GAINS model. The formula used for modelling the contribution from local sources is the following:

\[
CD = \alpha \cdot \Delta Q \cdot \frac{1}{\sqrt{U}} \left(1 + \beta \frac{d}{365} \right) \cdot \sqrt{\frac{D}{A_c}} - \frac{4}{\sqrt{A_E}}
\]

where

Q = emission rates
U = wind speed rate
D = diameter of the city
\(d\) = low wind speed days in winter

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9 [http://www.iiasa.ac.at/Admin/PUB/Documents/IR-07-001.pdf](http://www.iiasa.ac.at/Admin/PUB/Documents/IR-07-001.pdf)
A=area (C-city related data and E=EMEP data)
\( \alpha, \beta = \) estimated parameters.

These concentrations will then have to be combined with population data to arrive at an estimate of the population weighted exposure.

This approach is similar to the assessment of exposure in earlier epidemiological studies which usually rested on measured concentrations at a few monitoring stations. However, it is not as detailed as the concentration data used in more recent epidemiological research where the contribution from single streets or other emission sources are modelled. This kind of detailed bottom-up research is commonly used in the Impact pathway approach that has been developed in the ExternE-projects. These projects reveal the importance of accounting for population density close to the emissions sources for the health impact calculation (i.e. the population weighted exposure estimate). Hence, since the approach used in RAINS/GAINS estimate the population weighted exposure without accounting for how emission densities varies with population densities, there is a risk that the exposure, and hence the health impact, is underestimated.\(^{10}\)

Regarding the quantification of the health impacts it seems that the only health endpoint considered is reductions in premature mortality.\(^{11}\) What is important in these calculations is the exposure-response function used in the estimation as well as the assumptions used to quantify the loss in expected life years. In GAINS the loss of life expectancy (for the population above 30 years of age) is a represented as a sum of two terms:\(^{12}\)

\[
YOLL^K_t(K) = \sum_{k \in K} YOLL^A_k + \sum_{k \in K} YOLL^D_k
\]

The first term reflecting the population-weighted PM 2.5 concentration at the national scale, the second representing the 'City-Delta' contribution.\(^{13}\) It appears that the current YOLL calculations rest on the exposure-response function proposed by Pope et al. (2006).

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\(^{10}\) In 2007 a review of some parts of the GAINS model was undertaken. The reviewers however suggested that further inquiries were needed, for example regarding the City Delta approach.


\(^{12}\) For more details on health effects see the appendix

\(^{13}\) The City-Delta is an open model inter-comparison exercise to explore the changes in urban air quality predicted by different atmospheric chemistry-transport dispersion models in response to changes in urban emissions. Comparisons are conducted for a number of European cities with distinct differences in climatic conditions (e.g., Northern and Southern Europe), the vicinity of the sea, differences in meteorological situations, and emission densities. Practical considerations included the availability of suitable models, of emission inventories for gaseous and particulate pollutants, of sufficient meteorological information, and monitoring data. Eight cities have been selected: Berlin, Copenhagen, Katowice, London, Marseille, Milan, Paris and Prague. [http://aqm.jrc.ec.europa.eu/citydelta/](http://aqm.jrc.ec.europa.eu/citydelta/)
However, as discussed in a peer review of the methodology used for the Cost-Benefit Analysis for the CAFE programme (http://ec.europa.eu/environment/archives/air/cafe/activities/pdf/krupnick.pdf), more recent research supports higher estimates—some 3 or 4 times larger than the Pope et al. (2002) estimates. The latter is more likely to be applicable to primary particulate matter which has a local impact, such as those from transport. If these results are correct, then the approach used in RAINS/GAINS underestimate the health impact from transport (and other local emission sources). Regarding the calculations for YOLL, we have not been able to assess to what extent these results are similar or different compared to the results of other projects.

1.7 GAINS Sweden

Based on the discussion above the integrated assessment model GAINS includes 2 decision variables being an activity variable, a substitution variable as well as a variable related to greenhouse gases. However, the GAINS does not explicitly capture the costs of behavioural changes that may reduce the anthropogenic driving forces generating pollution. The reference of cost behaviour is not based on whether the behaviour is bad or good. Cost behaviour refers to the sensitivity of consumers and/or producers to costs. These considerations may also be related to benefits (negative costs) or energy saving as well as environmental concerns. The inclusion of these considerations in the GAINS would most probably lead to further decreasing the cost of emission reduction both at the micro (firm, household) and macro level. Furthermore, abatement procedures are loaded with transaction costs that may be significant and would increase the costs of emission reduction. Therefore, in order to add cost behaviour as well as transaction costs into the GAINS we suggest the following objective function:

\[
\text{Total cost} = E_{op} \text{cost} + FSW \text{cost} + (Ce_{q - revenues}) + Bh_{v} \text{cost} + Trsct \text{cost}
\]

Where Bhv cost relates to costs behaviour and Trsct cost pertains to transaction costs. Except the constraints (presented above) related to the first three variables on the right hand side of the cost function, the inclusion of the decision variables Bhv cost as well as Trsct cost would require a set of other constraints. However, since the total cost function is a quantification of values to society of the resources diverted to reduce emissions the general form of the total cost function would be such as:

\[
C = \sum_{i,k} \left( \sum_{m} c_{i,k,m} \cdot x_{i,k,m} + \sum_{k'} c_{i,k,k'} \cdot y_{i,k,k'} \right) + \sum_{i,k} T_{p} Q_{ip} + \sum_{i,k} c_{i,k,m} \cdot b_{i,k,m} + \sum_{i,k} c_{i,k,m} \cdot r_{i,k,m}
\]

Hence cost behaviour and transaction costs are the aggregated values of these at the country level. However, since optimization includes constraints, the constraints of cost behaviour as well as transaction costs are several:

- Cost behaviour: At the micro level a distinction is to be made between consumer and producer where according to mainstream economics the consumer is concerned with utility maximization such as:
Maximize $u(x)$
such that $px \leq m$
$x$ is in $X$

$U$ utility
$x$ good
$p$ price
$m$ budget
$X$ consumption set

This formulation is also about the behaviour of a consumer to optimize utility constrained by a limited budget $m$. If for instance energy prices increase the consumer may behave in such a way that her utility is maximized whilst the amount of consumed energy is kept constant. That is the consumer adapts to energy price changes but reduces the consumption of other goods. Based on environmental considerations the consumer may also reduce his energy consumption and thereby emission reduction. In other words, the consumer may behave in a cost effective way. Based on environmental considerations the consumer may also behave in such a way that his reduced energy consumption leads to reduced comfort.

In the GAINS it seems that the assumptions done are that consumers adapt to new prices. Adaptation takes the form of energy efficiency and/or energy substitution if prices of alternative energy are lower.

On the other hand the producer is in general concerned with profit maximization. In the short run the profit maximization is (given prices of input and output):

$$\pi(p) = \max \; py$$
such that $y$ is in $Y$

$\pi$ profit
$p$ price
$y$ production
$Y$ production set

This optimization is also about a producer’s behaviour to minimize costs and thereby increase benefits. Such as in the case of consumers the producer may be cost effective or shift to substitutes if the price of these is lower. In GAINS it is assumed that producers output is fixed. This is in line with Baumol et al (1975) where it is stated that the firms need not be simple profit-maximizers; they may choose to maximize growth, sales (total revenues), their share of the market, or any combination of these goals (or a variety of other objectives). Since the effective pursuit of these goals typically entails minimizing the cost of whatever outputs are produced.

Since the cost function is aggregated the behavioural costs would be the total value of aggregated costs over consumer at producers at the nation level. Further, transactions to reach feasible abatements are assumed to be constant such as in the case of output.
1.8 Discussion

The GAINS model and the estimated results has been sometimes criticised because of uncertainties related to several factors. The following points are suggestions on how to increase credibility of GAINS:

- Replace the City Delta estimates with meaningful information about PM concentrations over short time periods, for specific locations (e.g., hot spots, street canyons), and for other PM size fractions than PM2.5.
- Include health effect on the whole population and not only population aged less than 30 years.
- Consider cost behaviour using different elasticities. These costs may lead to lower abatement costs,
- Considering transaction costs would change the estimated costs,
- The dynamic impact of the measures of one period on another is not considered since the model is static,
- Reduce uncertainties in the GAINS estimations are since these are several. An analysis of uncertainties including a sensitivity analysis is crucial for the credibility of the estimated results: These uncertainties include the following:

- Data uncertainty,
- Model uncertainty including causal links between the different variables included in the model,
- Uncertainty about the future characterized by the chosen discount rate as well as assumptions related to economic growth, future prices etc,
- Uncertainties about dose-response functions,
- Uncertainties about the City Delta estimates,
2 Cost effective measures for air pollution and GHG abatement: GAINS Sweden and the case of the transport sector

2.1 Introduction

The objective of this chapter is an assessment of Swedish transport emissions and their costs using the GAINS model.

2.2 The Swedish transport sector

- Vehicle demand

Historically, there has been a strong correlation between economic growth and transport demand including both private and freight transport. In Sweden, economic growth symbolised here by GDP/capita is, in average, higher than the average growth in transport demand. Population growth has also contributed to the increased transport demand. The transport sector, being both one of the drivers and consequence of economic growth, has seen a constant growth in Sweden. Since 1980, the growth of vehicle in use has been dominated by lorries followed by private cars as shown in Table 1.

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<td>motorcycles</td>
</tr>
<tr>
<td>15312</td>
</tr>
<tr>
<td>41066</td>
</tr>
<tr>
<td>144255</td>
</tr>
<tr>
<td>.</td>
</tr>
<tr>
<td>terrain scooter</td>
</tr>
<tr>
<td>73839</td>
</tr>
<tr>
<td>137093</td>
</tr>
<tr>
<td>142723</td>
</tr>
<tr>
<td>190886</td>
</tr>
<tr>
<td>2.585165</td>
</tr>
<tr>
<td>population</td>
</tr>
<tr>
<td>8317937</td>
</tr>
<tr>
<td>8590630</td>
</tr>
<tr>
<td>8882792</td>
</tr>
<tr>
<td>9256347</td>
</tr>
<tr>
<td>1.112818</td>
</tr>
<tr>
<td>gdp /capita (PPP)</td>
</tr>
<tr>
<td>9953.52</td>
</tr>
<tr>
<td>18080.29</td>
</tr>
<tr>
<td>26336.34</td>
</tr>
<tr>
<td>37761.98</td>
</tr>
<tr>
<td>3.793831</td>
</tr>
</tbody>
</table>

For lorries their increased growth is related to the fact that freight is increasingly transported by road. When it comes to passenger vehicles, there growth has been dominated by cars with heavier engine size as shown in Figure 1 for the period 1990-2003. However, although new cars energy efficiency has increased, this has not contributed a lot to emissions reductions in Sweden where the increase in CO2 emissions for instance depends mainly on the continuous growth in transport demand, growing vehicle stock and thereby increasing fuel demand.

16
For the period after 2003 Figure 2 (although it is related to emissions) it shows that the gap in emissions between new registered vehicles in Sweden and in EU 15 persists confirming that Swedish consumers’ preferences for larger engine sizes did not change considerably.
Figure 2: Fuel use for new passenger vehicles

Fuel use for new passenger cars based on car-producers information (/100 km)

-Fuel demand

In Sweden gasoline demand is almost at the same level as in 2000. As for diesel its demand has increased by 63 percent. Further, the share of diesel vehicles and especially passenger cars is lower to the general share of this kind of vehicle in Europe. However, depending on energy content as well as lower taxes compared to gasoline diesel fuel is gaining shares of the total fuel demand in Sweden. The Swedish market share of newly registered diesel passenger cars increased from 10% in 2005 to 40.8% in January 2009, thereby approaching the diesel share in EU being in average 53% of newly registered vehicles according to BilSweden (2009).  

For bio fuels in general including ethanol, biogas and FAME, their share has increased by more than 4 percent since 2000. The increase of bio fuel has been motivated in general by the lower prices, being a result of tax-exemptions of these fuels compared to fossil fuels i.e. gasoline and diesel.

**Transport emissions**

Although the *pros* of the transport sector are well recognised e.g. engine of economic growth, the *cons* of this sector are several including different externalities such as emissions of different substances and noise as well as accidents and congestion.

Greenhouse gas emissions in the transport sector continue to increase steadily depending on the fact that this sector is the fastest growing consumer of energy and producer of greenhouse gases in the EU. Although improvements have been made in the energy efficiency of various transport modes and non-fossil fuels have been introduced, increased transport demand is outweighing these benefits.\(^{15}\)

The emissions of different substances from the transport sector are giving rise to different environmental and health effects. The primary emissions of greatest concern are particulate matter (PM), nitrogen oxides (NO\(_X\)), sulphur dioxide (SO\(_2\)), carbon monoxide (CO) and volatile organic compounds (VOC). PM is believed to be the main cause of health risks associated with traffic and the European Commission has estimated that NO\(_X\) has health effects and contributes to acidification and over-fertilization. SO\(_2\) is a major contributor to

the acidification of land and water but also contribute to damage on buildings and construction and to particle formation. VOC comprises a number of toxic substances and will, in combination with NO\textsubscript{X}, lead to the formation of the secondary pollutant ozone (O\textsubscript{3}) which in turn has effects both on health and on plants.

Figure 3 shows how CO\textsubscript{2} emissions from the transport sector have evolved in Sweden since the 90ies. Whilst, CO\textsubscript{2} emissions are decreasing in all other sectors, those in the transport sector continue to augment.

![Figure 3: CO\textsubscript{2} emissions in different sectors in Sweden](image)

When it comes SO\textsubscript{2}, for instance, its share from the transport sector has decreased (because of different measures) from 10 000 tones in 1990 to 2 500 in 2006.\textsuperscript{16} In the case of NO\textsubscript{X} the emissions of this substance from the transport sector has decreased from 190 000 tones in 1990 to 90 000 in 2006.\textsuperscript{17}

When related to particles one distinguishes between primary and secondary particles. The primary particles are directly released into the atmosphere by wind, combustion processes, or human activities. The secondary particles are those that form in the atmosphere from other gaseous pollutants, particularly sulphur dioxide, nitrogen oxides, ammonia, and volatile organic compounds.

Table 2 illustrates emissions of primary particles i.e. PM 10 and PM 2.5 in the transport sector.

\textsuperscript{16} [http://www.ekonomifakta.se/sv/Fakta/Miljo/Luft_och_klimat/Partikelemissioner/]

\textsuperscript{17} Ibid
Table 2: Emissions of particles in the transport sector

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PM 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger cars</td>
<td>2.31</td>
<td>1.53</td>
<td>0.84</td>
<td>0.47</td>
</tr>
<tr>
<td>Light duty vehicles</td>
<td>0.24</td>
<td>0.34</td>
<td>0.41</td>
<td>0.41</td>
</tr>
<tr>
<td>Heavy duty vehicles</td>
<td>2.65</td>
<td>2.37</td>
<td>1.47</td>
<td>1.00</td>
</tr>
<tr>
<td>Mopeds &amp; Motorcycles</td>
<td>0.07</td>
<td>0.07</td>
<td>0.06</td>
<td>0.13</td>
</tr>
<tr>
<td>Tyre and brake wear</td>
<td></td>
<td></td>
<td>1.33</td>
<td>1.43</td>
</tr>
<tr>
<td>Road abrasion</td>
<td></td>
<td></td>
<td>6.00</td>
<td>6.49</td>
</tr>
<tr>
<td>PM 2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger cars</td>
<td>2.20</td>
<td>1.45</td>
<td>0.80</td>
<td>0.45</td>
</tr>
<tr>
<td>Light duty vehicles</td>
<td>0.22</td>
<td>0.32</td>
<td>0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>Heavy duty vehicles</td>
<td>2.52</td>
<td>2.25</td>
<td>1.39</td>
<td>0.95</td>
</tr>
<tr>
<td>Mopeds &amp; Motorcycles</td>
<td>0.07</td>
<td>0.06</td>
<td>0.06</td>
<td>0.13</td>
</tr>
<tr>
<td>Tyre and brake wear</td>
<td></td>
<td>0.72</td>
<td>0.78</td>
<td>0.87</td>
</tr>
<tr>
<td>Road abrasion</td>
<td></td>
<td>3.24</td>
<td>3.50</td>
<td>3.88</td>
</tr>
</tbody>
</table>

Source: Swedish EPA

As shown the emissions of PM10 and PM2.5 has increased since 1980 when it comes to light duty vehicles as well as mopeds and motorcycles. These emissions have also increased since 1990 when the source is tyre and brake wear and road abrasion.

2.3 External effects of emissions

Air pollution has been one of Europe's main political concerns since the late 1970s. The reason is that the emissions from different combustion sources have a negative impact on the environment and human health. By economists this is referred to as the external effects of emissions, i.e. impacts that are not controlled through the forces of the market system. However, although several measures have contributed to mitigate the impacts of air pollution this problem is still an issue of major concern in the EU in general and in Sweden in particular. In many cities high concentrations of fine particles and ground level ozone still cause health problems.\(^{18}\) In addition, large contributions from road wear causes exceedances of air quality limit values in larger Swedish cities.

In recent years the problems of climate change caused by greenhouse gases (mainly CO2) have also received increasing attention both in policy and in research. These emissions are expected to have an impact on the earth's climate, resulting in increased desertification, raised sea levels, serious harm to agriculture and other destructive environmental and health-

related side-effects. The Stern Report published in 2006 gives a list of potential impacts from floods to drought and loss of species.\textsuperscript{19}

Table 3 is an illustration of important pollutants related to transport, their physical interactions as well as the different impacts.

Table 3: Impacts and physical interactions of pollutants

\begin{tabular}{cccccccccccc}
  PM & SO\textsubscript{2} & NO\textsubscript{x} & VOC & NH\textsubscript{3} & CO\textsubscript{2} & CH\textsubscript{4} & N\textsubscript{2}O & CFCs & HFCs & SF\textsubscript{6} \\
  \hline
  Health impacts: & & & & & & & & & & \\
  -PM & √ & √ & √ & √ & & & & & & \\
  -O\textsubscript{3} & & & & & & & & & & \\
  Vegetation damage: & & & & & & & & & & \\
  -O\textsubscript{3} & & & & & & & & & & \\
  Acidification & √ & √ & √ & & & & & & & \\
  Eutrophication & & & & & & & & & & \\
  Radiative forcing: & & & & & & & & & & \\
  -direct & √ & √ & √ & √ & & & & & & \\
  -via aerosols & √ & √ & √ & & & & & & & \\
  -via OH & & & & & & & & & & \\
  Source: Amann et al.
\end{tabular}

In general traditional air pollutants and greenhouse gases have:\textsuperscript{20}
- common sources (e.g. the transport sector including road, air and water)
- their emissions interact in the atmosphere, and
- Separately or jointly they cause a variety of environmental effects (at local, regional and global scales).

Measures to reduce GHG emissions will therefore not only have an impact at global level but they can also bring benefits locally by reducing other air quality pollutants linked to energy consumption in all sectors in general and in the transport sector in particular. Recognizing that there are potential synergies between abatement of GHG and air quality pollutants, several studies such as Proost et al (2003) have shown that a combination of abatement measures are more cost effective compared to separate measures to abate the pollutants.

One way to quantify the size and importance of the external effects is to calculate their external costs. A method commonly used today to assess transport externalities as well as their external costs is the impact pathway approach that has been developed within the EU-funded ExternE projects.\textsuperscript{21} It is the approach that was used in the Cost-Benefit Analysis in the CAFE programme.

\textsuperscript{20} http://www.iiasa.ac.at/rains/gains/model\%20description.html
\textsuperscript{21} http://www.externe.info/
This method is based on the following steps:
- emissions and inventories
- dispersion modelling of the emissions
- exposure calculation to the emission concentrations
- impact calculation on humans and ecosystem of the emissions
- external costs calculation, i.e. valuation of impact

According to these calculations the external costs are dependent on several variables such as:
- The damage or the degree of harm implied by the externality including the size of this harm e.g. number of deaths and/or cases of illness as well as exceedance of certain ecosystem levels below which the harm may be assumed to be nil
- the cost of the harm e.g. medical costs in the case of illness or the cost of remediation in the case of ecosystem e.g. the cost of liming related to acidification.

The latter are measured through the use of different valuation methods:
- The willingness to pay to reduce or to avoid the externality
- The damage cost which can be based on dose response functions
- The avoidance cost to prevent the negative harms.

External costs from the transport sector are estimated in similar ways. Still the estimated cost will depend on the mode of transportation in question and where it takes place since the emissions released will differ as well as the estimated impact due to the location of the emissions. In 2006, the European Parliament asked the Commission to present "a generally applicable, transparent and comprehensible model for the assessment of all external costs to serve as the basis for future calculations of infrastructure charges". In response to this the Commission recently presented a handbook jointly prepared by several transport research institutes, which summarizes the state of the art as regards the valuation of external costs.  

Table 4 shows marginal costs that are based on different methods i.e. EPS 2000 (Environmental Priority Strategies (Steen (2007))), the impact pathway method (Holland et al (no date) and results from the HEATCO project presented in the Handbook on External Costs. The Stern (2007) value is based on consequence analysis of climate change (Belhaj et al (2008)).

---

Table 4: Marginal external costs of emissions (€/kg)

<table>
<thead>
<tr>
<th>Impact pathway &amp;</th>
<th>EPS 2000</th>
<th>HEATCO**</th>
<th>Stern</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>0.108</td>
<td>0.0024</td>
<td>0.12</td>
</tr>
<tr>
<td>NOₓ</td>
<td>2.13</td>
<td>2.6</td>
<td>1.2</td>
</tr>
<tr>
<td>SO₂</td>
<td>3.27</td>
<td>1.7</td>
<td>6*</td>
</tr>
<tr>
<td>CO</td>
<td>0.331</td>
<td>0.7</td>
<td>0.35</td>
</tr>
<tr>
<td>VOC</td>
<td></td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>NMVOC</td>
<td>2.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM₂₅</td>
<td>1.7</td>
<td>33*</td>
<td>113.4</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>36</td>
<td></td>
<td>45.4</td>
</tr>
<tr>
<td>Fossil oil reserves</td>
<td>0.507</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* city of 100,000 people, ½ mio x 5, 1 mio x 7.5.
** Appendix D in Handbook. Factor costs in €2,000 values. PM costs are for urban areas (not metropolitan).

In addition to the methods discussed above to estimate damage costs, these costs may also be based on integrated assessment models such as the GAINS and the PAGE model where this one has been used to estimate the Stern results. These models are often used to estimate the social costs of carbon using different discounting rates (Brännlund 2009). Below is a metaanalysis of different results from different studies published in Tol (2008). As shown in Table 5 the mean damage costs have decreased since 1996. The decrease in the damage costs is, however, not the result of decreasing CO₂ effects; they are a consequence of different estimations-models.

Table 5: Descriptive statistics to estimate damage costs (€/kg CO₂)* based on results from different studies in Tol (2008)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.027</td>
<td>0.020</td>
</tr>
<tr>
<td>Median</td>
<td>0.004</td>
<td>0.009</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.070</td>
<td>0.028</td>
</tr>
<tr>
<td>Min-max</td>
<td>0.00 – 0.32</td>
<td>0.0 – 0.15</td>
</tr>
<tr>
<td>Number of observations</td>
<td>21</td>
<td>73</td>
</tr>
</tbody>
</table>

* 1€ = 10 SEK

As shown in the Table the median results range between 0.004€ and 0.009€/kg. These results are almost in the same range as in the Impact pathway approach.

The recommended marginal costs for CO₂ by ExternE are depicted in Table below

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Low</th>
<th>Central estimate</th>
<th>High</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>0.0001</td>
<td>0.0014</td>
<td>0.0024</td>
<td>0.0041</td>
</tr>
</tbody>
</table>

The estimates in this Table are lower than the values that are used in a range of other recent studies (Mayeres et al 2001). The results presented here should therefore not be taken as final estimates. The impacts covered by the models used are only a fraction (of unknown size) of all climate change impacts. Particularly, large-scale disruptions, such as a breakdown of North Atlantic Deep-Water formation or a collapse of the West-Antarctic Ice Sheet or impacts in the 22nd century, are excluded from the analysis. The methodologies to estimate climate change impacts in a different future remain weak.
2.4 Policy instruments to reduce external effects

In general, environmental instruments, sometimes also called environmental policy instruments or just policy instruments, have the objective to promote environmental protection, i.e., to reduce the external effects. These instruments used by government can be categorised as regulatory, incentive based or market based instruments such as taxes. Other policy instruments include information, voluntary as well as co-operative efforts (policy instruments are discussed in detail in chapter 4).

There are a number of instruments that have been used to influence the external effects of transport. Mostly these belong to so called command and control systems. By this is meant policy measures that put a restriction on the emissions or the use of vehicles. Examples include the EU directives that place limit values for emissions from heavy and light duty vehicles, the mandatory installation of catalytic converters in new vehicles, standards related to fuel quality, low emissions zones etc. Fiscal or economic incentives have been less common, partly due to the problem of charging and monitoring. However, since the White paper (“European transport policy for 2010: time to decide”) was adopted by the European Commission in 2001 infrastructure charging has received increasing attention, partly due to the possibilities offered with recent developments in information technology. The recent introduction of road user charging in London and Stockholm are examples of this new development.

Regarding GHG, since the transport sector does not belong to the sectors included in the EU emission trading system, the most discussed instruments in this sector are taxes. In the case of Sweden the level of these in 2007 is depicted in Table 6.

Table 6: Taxes in the transport sector 2007

<table>
<thead>
<tr>
<th></th>
<th>Energy tax</th>
<th>CO2 tax</th>
<th>Total</th>
<th>öre/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline class I, SEK/l</td>
<td>2.95</td>
<td>2.34</td>
<td>5.3</td>
<td>58.5</td>
</tr>
<tr>
<td>Diesel class I, SEK/l</td>
<td>1.23</td>
<td>2.88</td>
<td>4.1</td>
<td>41.3</td>
</tr>
<tr>
<td>Naturalgas_metan, SEK/m3</td>
<td>-</td>
<td>1.28</td>
<td>1.28</td>
<td>11.6</td>
</tr>
<tr>
<td>Gasol, SEK/l</td>
<td>-</td>
<td>1.58</td>
<td>1.58</td>
<td>12.4</td>
</tr>
</tbody>
</table>

Source: Energimyndighet

As shown in the Table taxes on gasoline are higher than taxes on diesel. As discussed above and except the fact that diesel is more energy intensive than gasoline, the low taxes on diesel have led to the increased share of new registred passenger cars in Sweden. On the other hand, biofuels such as biogas are not taxed at all. These fuels, where the content of CO2 is very limited, are exempted from taxes in order to speed there use and to substitute certain proportion of fossil fuels.

2.5 GAINS and the Swedish transport sector

- The GAINS-online version

In general emissions abatement costs are defined as costs related to abatement measures to reduce emissions. In the GAINS model these costs are based on the so-called end of pipe measures, substitution as well as abatement costs to reduce GHG.

Regarding the health impact assessment, two assumptions are crucial for the outcome. One relates to the exposure modelling as discussed previously and the other to the quantification of the health impacts.

In order to estimate costs to reduce emissions of air pollutants and GHG (especially CO2) the following is assumed.

- Costs of reducing CO2 emissions are included in energy system costs. For measures that influence more than one pollutant at the same time, the presented results report their total costs under the main pollutant. In particular, if a measure reduces (inter alia) NOx emissions, all costs of that measure are reported under NOx. Second priority is given to PM, i.e., if a measure reduces PM and other pollutants (but not NOx), all costs are reported under PM. However, these rules are only applied for the reporting of costs in the GAINS-online version. For the GAINS optimization, costs of multi-pollutant measures are not allocated to a single pollutant, but are associated with the particular measure, for which the simultaneous impacts on several pollutants are accounted (the "technology-based" approach of GAINS).

- All scenarios use a 4% discount rate. The costs are in million Euros (M€) per year.

To estimate cost effectiveness five scenarios are used:

- To start with all the used scenarios are related to: NEC nat cle 4 review (National Activity Projection) final version of the national baseline scenario with emission controls reflecting current legislation (national activity paths, CLE control strategies). This scenario is henceforth called the NEC scenario.

The related scenarios are:

1. 10% renewable fuels: The measure is yet another scenario in which 10 % bio fuels are introduced into the TRA_RD (road transport) sector. The difference from earlier scenarios is that this scenario is fully based on the NEC_NAT_CLE4REV scenario

2. Small cars (120 g CO2 / km) Long Vehicle Trucks. This scenario includes a change in the TRA_RD_LD4C sector, in which 120 g CO2 / km are ensured by 2020. Apart from this, the scenario is based on the NEC_NAT_CLE4REV scenario.

3. Long Vehicles Trucks. This scenario includes long vehicle in the TRA_RD_HDT sector. Apart from this, the scenario is based on the NEC_NAT_CLE4REV.
4. All measures: 1, 2, 3: This scenario i.e. IVL_TRA_comb is combining the earlier partial analysis as provided by the BIO, 120 g CO2 / km and Long vehicles scenarios. This scenario is based on the NEC_NAT_CLE4REV scenario.

2.6 Emissions using GAINS online version

To start with, emissions using all scenarios except congestion scenario are shown in Figure 5. As shown, the reduction in CO2 emissions in 2020 would not be very high for the different scenarios separately compared to the NEC scenario. The emissions reduction would be more than 5 million tones (Mt) if all measures are considered together.

Figure 4: CO2 emissions for different scenarios (million tones)

In the case of NOx, Figure 6 depicts the emission reductions in 2020 using different scenarios. In the IVL Bio scenario emissions would be equivalent to the emissions in the NEC scenario assuming that IVL Bio would not contribute to emission reductions of NOx. In IVL Long the emissions reduction of NOx are more that 5 Mt in 2020. In the scenario IVL 120 g CO2 the emission reductions are quite marginal.
When it comes to particles and especially PM10 the emission reductions of this substance in 2020 are shown in Figure 7 where there levels are quite marginal when compared to the emissions in the NEC scenario.
2.8 Cost to reduce emissions of NOx

To start with, the costs to reduce emission of PM are included in the NOx emission reduction costs. Based on GAINS the estimation of abatement costs to reduce emissions of NOx has been made for the selected scenarios discussed above. These costs include end of pipe as well as substitution costs. Table 7 shows these costs for road transport for different years. In 2020 these costs would be in the range of 704.5 M€ in the case of the NEC scenario. As shown, the abatement costs are highest for heavy vehicles-trucks followed by light duty vehicles including cars and small buses with 4 stroke engines.

Table 7: Cost efficiency in road transport (M€): NEC scenario

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy duty vehicles - buses</td>
<td>0.3</td>
<td>0.6</td>
<td>3.8</td>
<td>10.6</td>
<td>20</td>
<td>26.5</td>
<td>28.8</td>
</tr>
<tr>
<td>Heavy duty vehicles - trucks</td>
<td>...</td>
<td>1.3</td>
<td>26.7</td>
<td>98.5</td>
<td>195.6</td>
<td>290.2</td>
<td>351.3</td>
</tr>
<tr>
<td>Motorcycles, mopeds and cars with 2-stroke engines</td>
<td>...</td>
<td>...</td>
<td>0.1</td>
<td>1.1</td>
<td>3.3</td>
<td>5.6</td>
<td>6.8</td>
</tr>
<tr>
<td>Light duty vehicles: cars and small buses with 4-stroke engines</td>
<td>29.7</td>
<td>62.7</td>
<td>136.2</td>
<td>177.4</td>
<td>204</td>
<td>235.3</td>
<td>271.2</td>
</tr>
<tr>
<td>Light duty vehicles: light commercial trucks with 4-stroke engines</td>
<td>1.4</td>
<td>3</td>
<td>7.6</td>
<td>11.6</td>
<td>16.2</td>
<td>24</td>
<td>33.3</td>
</tr>
<tr>
<td>Motorcycles with 4-stroke engines</td>
<td>...</td>
<td>...</td>
<td>0.1</td>
<td>1.7</td>
<td>6.8</td>
<td>10</td>
<td>12.9</td>
</tr>
<tr>
<td>Total</td>
<td>174.5</td>
<td>300.9</td>
<td>445.9</td>
<td>591.6</td>
<td>704.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When it comes to the scenario IVL bio control costs in this scenario are not different from the ones related to the NEC scenario.

However, when it comes to cost efficiency to reduce emissions of NOx based on IVL long scenario these costs are lower than those for the NEC scenario. These costs are lower for heavy duty vehicles- trucks being 333.6 M€ in the IVL long and 351.3 M€ in the NEC scenario. The lower costs in the IVL long are based on the fact that the number of the duty vehicles in this scenario is lower than in the case of the NEC scenario. The consequence of fewer vehicles is lower fuel consumption as well leading to lower emissions and thereby lower costs.

Table 8: Cost efficiency in road transport (M€): IVL long scenario

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Heavy duty vehicles - buses</td>
<td>0.3</td>
<td>0.6</td>
<td>3.8</td>
<td>10.6</td>
<td>20</td>
<td>26.5</td>
<td>28.8</td>
</tr>
<tr>
<td>Heavy duty vehicles - trucks</td>
<td>...</td>
<td>1.3</td>
<td>26.7</td>
<td>98.5</td>
<td>195.6</td>
<td>290.2</td>
<td>351.3</td>
</tr>
<tr>
<td>Motorcycles, mopeds and cars with 2-stroke engines</td>
<td>...</td>
<td>...</td>
<td>0.1</td>
<td>1.1</td>
<td>3.3</td>
<td>5.6</td>
<td>6.8</td>
</tr>
<tr>
<td>Light duty vehicles: cars and small buses with 4-stroke engines</td>
<td>29.7</td>
<td>62.7</td>
<td>136.2</td>
<td>177.4</td>
<td>204</td>
<td>235.3</td>
<td>271.2</td>
</tr>
<tr>
<td>Light duty vehicles: light commercial trucks with 4-stroke engines</td>
<td>1.4</td>
<td>3.0</td>
<td>7.6</td>
<td>11.6</td>
<td>16.2</td>
<td>24.0</td>
<td>33.3</td>
</tr>
<tr>
<td>Motorcycles with 4-stroke engines</td>
<td>...</td>
<td>...</td>
<td>0.1</td>
<td>1.7</td>
<td>6.8</td>
<td>10.0</td>
<td>12.9</td>
</tr>
</tbody>
</table>

In the case of the scenario IVL 120 g the abatement costs are shown in Table 9. This scenario is also based on the introduction of small passenger cars where the consumption of fuel would be lower. Hence, compared to the NEC scenario the abatement costs are in the range of 263.2 M€ in 2020. The difference in costs based on these 2 scenarios is marginal being around 25 M€ in 2020.
Table 9: Cost efficiency in road transport (M€): IVL 120g scenario

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</thead>
<tbody>
<tr>
<td>Fuel production other than in power plants: Combustion</td>
<td>...</td>
<td>0.1</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Heavy duty vehicles - buses</td>
<td>0.3</td>
<td>0.6</td>
<td>3.8</td>
<td>10.6</td>
<td>20.0</td>
<td>26.5</td>
<td>28.8</td>
</tr>
<tr>
<td>Heavy duty vehicles - trucks</td>
<td>...</td>
<td>1.3</td>
<td>26.7</td>
<td>98.5</td>
<td>195.6</td>
<td>290.2</td>
<td>351.3</td>
</tr>
<tr>
<td>Motorcycles, mopeds and cars with 2-stroke engines</td>
<td>...</td>
<td>...</td>
<td>0.1</td>
<td>1.1</td>
<td>3.3</td>
<td>5.6</td>
<td>6.8</td>
</tr>
<tr>
<td>Light duty vehicles: cars and small buses with 4-stroke engines</td>
<td>29.7</td>
<td>62.7</td>
<td>136.2</td>
<td>177.4</td>
<td>200.9</td>
<td>230.0</td>
<td>263.2</td>
</tr>
<tr>
<td>Light duty vehicles: light commercial trucks with 4-stroke engines</td>
<td>1.4</td>
<td>3.0</td>
<td>7.6</td>
<td>11.6</td>
<td>16.2</td>
<td>24.0</td>
<td>33.3</td>
</tr>
<tr>
<td>Motorcycles with 4-stroke engines</td>
<td>...</td>
<td>...</td>
<td>0.1</td>
<td>1.7</td>
<td>6.8</td>
<td>10.0</td>
<td>12.9</td>
</tr>
</tbody>
</table>

When the consequences of all scenarios are aggregated in the IVL INTRA_comb scenario the cost efficiency of emission reductions are shown in Table 10. When combining the IVL long scenario together with the IVL 120g scenario the total emission reduction costs would be around 679.3 M€. This cost is lower than emissions costs which would prevail using the NEC scenario being a baseline scenario with emission controls reflecting current legislation (national activity paths, CLE control strategies).

Table 10: Cost efficiency in road transport (M€): IVL TRA_comb scenario

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<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel production other than in power plants: Combustion</td>
<td>...</td>
<td>0.1</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Heavy duty vehicles - buses</td>
<td>0.3</td>
<td>0.6</td>
<td>3.8</td>
<td>10.6</td>
<td>20.0</td>
<td>26.5</td>
<td>28.8</td>
</tr>
<tr>
<td>Heavy duty vehicles - trucks</td>
<td>...</td>
<td>1.3</td>
<td>26.7</td>
<td>92.4</td>
<td>184.1</td>
<td>275.0</td>
<td>333.6</td>
</tr>
<tr>
<td>Motorcycles, mopeds and cars with 2-stroke engines</td>
<td>...</td>
<td>...</td>
<td>0.1</td>
<td>1.1</td>
<td>3.3</td>
<td>5.6</td>
<td>6.8</td>
</tr>
<tr>
<td>Light duty vehicles: cars and small buses with 4-stroke engines</td>
<td>29.7</td>
<td>62.7</td>
<td>136.2</td>
<td>177.4</td>
<td>200.9</td>
<td>230.1</td>
<td>263.3</td>
</tr>
<tr>
<td>Light duty vehicles: light commercial trucks with 4-stroke engines</td>
<td>1.4</td>
<td>3.0</td>
<td>7.6</td>
<td>11.6</td>
<td>16.2</td>
<td>24.0</td>
<td>33.3</td>
</tr>
<tr>
<td>Motorcycles with 4-stroke engines</td>
<td>...</td>
<td>...</td>
<td>0.1</td>
<td>1.7</td>
<td>6.8</td>
<td>10.0</td>
<td>12.9</td>
</tr>
<tr>
<td>Sum</td>
<td>175.2</td>
<td>295.5</td>
<td>432</td>
<td>571.9</td>
<td>679.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.9 Congestion charging versus road pricing

This case study was undertaken since these policy instruments are of interest because they will reduce several harmful pollutants simultaneously. It is however questionable how well the RAINS/GAINS model can correctly compare the outcome of these policy measures. The problem is related to the initial discussion about the representation of the transport sector in the RAINS/GAINS model, i.e. that it only in a crude way accounts for the exposure differences between different areas and that the cost of adaptations in behaviour are not included in the model. Hence, the main purpose with this case study was to explore how the RAINS/GAINS model would perform in this context. For this purpose we compare two cases:

- Case 1: A raise of the fuel taxes in Sweden
- Case 2: Congestion charges in larger cities in Sweden, low and high cases (elasticities)
The idea is to compare the outcome of a 1% reduction in total mileage in Sweden (0.6 billion vehicle-km) in both cases. The main interest is to evaluate the difference in the health impact of these two policies. Since congestion charging in larger cities will reduce traffic in areas where emissions occur in close proximity to where people live, it is expected that the reductions in health impact will be larger for this policy measure. However, since this policy measure would target less people, one can expect that the price increase needed to achieve the change would need to be larger. How much larger is however unclear because people in larger cities have more substitutes for using car since the public transport systems are more elaborate. This difference is also interesting since it may well imply different long term impacts of these two policy measures. With more substitutes available a congestion charge may be a trigger to induce people to use public transport increasingly over time, hence contributing to a change in tastes. Another difference between the two policy measures is the cost of implementation where congestions charging rely on the implementation of new technology while road pricing simply requires a government decision. A summary of the differences between the two scenarios are given in Table 11.

Table 11: Incentives and effects for the two cases (short term)

<table>
<thead>
<tr>
<th></th>
<th>Fuel tax</th>
<th>Congestion charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price increase (% of current price)</td>
<td>+ 7.8% per vkm</td>
<td>Max + 37.5% per vkm</td>
</tr>
<tr>
<td>Emissions per vkm</td>
<td>-1%</td>
<td>Min - 1.5%</td>
</tr>
<tr>
<td>Local pop. exposure</td>
<td>&lt;- 1%</td>
<td>&gt; -1%</td>
</tr>
<tr>
<td>Regional pop. exposure</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Other effects</td>
<td>?</td>
<td>Reduced congestion</td>
</tr>
</tbody>
</table>

The way this was modelled in GAINS online was a reduction of reduced mileage of LD4C vehicle transport. The reduction is a consequence of Gvehkm is set to 1% of the traffic intensity at 2005 (0.6 Gvehkm). What could also be accommodated within the model is the difference in fuel efficiency between the two policy measures. A national fuel tax will affect fuel consumption in a 1:1 relation to the reduced mileage. A congestion charge will however increase the energy efficiency since the fuel per vkm are higher in cities due to the slower pace and more stop and go. Hence the affected fuel consumption will have a 1:1.5-3 relations to the reduced mileage. To achieve these changes in the model the GAINS model year 2005 illustrate the emissions in the baseline, the GAINS model year 2010 illustrate the fuel tax case. Regarding the congestions charge the GAINS model year 2015 illustrate the low estimate (1.5% reduced fuel use) and the GAINS model year 2020 illustrate the congestion charge - high estimate (3% reduced fuel use) The value for 2005 are taken from national reported estimates in 2007.

In the GAINS online version other differences between the two scenarios was not possible to illustrate. Hence, the differences in human exposure to particulate matter are not accounted for in the results. Nor could we get estimates of the calculated YOLL using different exposure-response estimates. Therefore, the results that are presented in Figure 8
to 9 only reveal minor differences between the different scenarios. The results presented are the result for CO2 emissions, the difference in PM2.5 emissions and the impact on the concentrations of PM2.5.

Figure 7: Emissions of CO2(Mt) for BAU, road pricing and congestions charging.
What can be concluded from the figures is that the impact is truly minor. However, although these results do not reveal the expected differences between the scenarios, there are still some interesting findings. The first is that the 7.5% increase in fuel tax is of the size that was
suggested by the Swedish Environmental Objectives Council in 2008 in the report: “Sweden’s Environmental Objectives: No time to Lose”. They suggested an increase in the fuel tax of 0.75 SEK. As shown in the figures above, the effect of this policy measures on emissions is minor. The reason is that the demand elasticity of car travel is very inelastic. Hence changes in price will in general have a small impact on total distance travelled. This in turn is explained by car travel being an integral part of modern society, especially in a sparsely populated country like Sweden. People are likely to reduce expenses on other goods rather than to change their travelling behaviour. Moreover, since travel to and from work are tax deductible, where the deductible amount increases when the price of fuel increases, this reduces the impact of a fuel tax increase on the household economy. Hence, the individual’s response behaviour is important to account for when evaluating different policy measures that aim at the transport sector.

Another result is the modelled changes in PM2.5 concentrations with the GAINS model. According to these results, car traffic in Sweden makes a contribution to the average concentrations of PM2.5 of 0.5 µg/m³. This can be compared to the measured concentrations of PM2.5 in Sweden that ranges from 14 µg/m³ to 1 µg/m³ PM10 from the south to the north. Around 80% of the PM10 concentration is constituted of PM2.5, mainly secondary PM (Forsberg et al, 2005), hence around 10 µg/m³ in the south of Sweden. Car traffic thus makes a minor contribution to the total according to the GAINS modelling, and contrary to the results of the GAINS-modelling the contribution is likely to vary over the country. It will be larger in the south where emissions densities are higher than in the north. The averaged used in the GAINS modelling will therefore result in an underestimate of the population weighted exposure since population densities are higher in the south where the emission densities are higher.

Another aspect that would be interesting to evaluate is if the GAINS modelling results in reasonable concentration estimates. We have not however found this type of data to compare with so we can only do a preliminary evaluation based on secondary data. According to the National Inventory Report 2009 that was submitted in accordance with the Kyoto Protocol by the Swedish EPA the total emissions of CO2 in Sweden are around 65 million tonnes. According to the GAINS estimates in this report car traffic contributes with 12 million tonnes. Assuming a linear relationship between CO2 emissions and emissions of PM2.5, then car traffic would contribute to 20% of the total emissions of PM2.5 per year (12/65). 20% of an average concentration level of PM2.5 of 5 µg/m³ is 1 µg/m³. Hence, these results suggest that the concentration contribution from car traffic is underestimated. However, this conclusion is based on a number of assumptions and should be verified by similar modelling using other models, e.g., the MATCH model that is used by SMHI.

Another aspect that we have not been able to investigate using GAINS online is the cost-efficiency of these two policy instruments. These policy instruments do not really involve any technical measures so the question is how the cost of these measures should be accounted for. Both policy measures result to some extent in changes in behaviour that is not accounted for in GAINS. Congestion charging in particular is difficult since it involves a number of different consequences:

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25 Some indication of the size of these consequences can be obtained from the Stockholm trial. The cost of implementation was approximated to 270 million SEK p.a. The congestion charge gave a revenue of 763
- Technical measures – cost of implementation
- Incentives – price increase (cost driver, gain society)
- Changes in behaviour (benefit and cost for driver/society)
- Effects on emissions and other dimensions (time, health, travel time reductions).

How such aspects can be accounted for in a cost-efficiency analysis has not been discussed in the literature. In most applications such behavioural changes are not accounted for (see Nerhagen and Li, 2009, for a discussion). Including them all would move cost-efficiency analysis towards cost-benefit analysis. Hence, this case study highlights that there is also a need to discuss the usefulness of cost-efficiency analysis in different contexts. It is not only the issue of quantifying the costs in several dimensions but also that the effects are in several dimensions. Currently GAINS for example only estimates the health impact as changes in YOLL but there are pollutants that are likely to have more important consequences on morbidity which is not accounted for.

### 2.10 Discussion

The causes of non adequate results being based on GAINS are the consequences of the following:
- Health effects on the population aged less than 30 years is not considered in the GAINS analysis.
- Cost behaviour using different elasticities would imply lower abatement costs
- Considering transaction costs would change the estimated costs
- The dynamic impact of the measures of one period on another is not considered since the model is static.

In the case of congestion charges the following applies:
- Effect calculation
  - Effect on emissions larger for congestions charging
  - Effect on emission not equal to effect on exposure
  - Effect on concentration of secondary PM?
- Cost calculation
  - Difficult to assess costs for measures that implies behavioural changes
  - Behavioural changes possible reason for policy measures not undertaken although negative abatement cost estimate
  - Is there a need for cost-benefit analysis (do right things and not things right) or can CE include adaptation?

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million SEK p.a. which is equal to the cost of a change in behaviour. The net benefit for other effects (time, health, safety) was estimated to be 800 million SEK p.a
3 Biofuels and the transport sector in Sweden: Markal optimisation

3.1 Introduction

The objective of this chapter is to estimate emissions reductions and the related costs in the Swedish transport sector using Markal model.

3.2 Markal model in brief

MARKAL is a model to analyse energy systems in which the studied system is optimized by minimizing its costs. As in the case of GAINS, optimization takes place through linear programming. In its simple version Markal consists of the following entities for optimisation (Loulou et al (2004):

- Objective function: expressing the criterion to minimise or maximise,
- Decision variables: i.e. the unknowns to be determined by the optimisation,
- Constraints: equations or inequations involving the decision variables that must be satisfied by the optimal solution.

As discussed in the GAINS preview, environmental impacts including human health are explicitly considered in the model optimisation's constraints. However, in Markal the environmental impacts are implicitly considered while setting such limits as emissions caps where exceedance of these levels would jeopardise environmental conditions.

In the case of energy efficiency the optimization process chooses a combination of energy technologies and fuels that cost less to meet the demand for energy services. More specifically, the minimisation is about the discounted present value of costs incurred during the entire studied period. Commonly, the model studies a number of different scenarios with different conditions such as current fuel prices and demand for emission reduction or emission control. The system studied is defined by the system boundaries of different characters being e.g. geographical (the area being studied), temporal (the time horizon considered) and sectoral (sectors included in model description).

3.3 Optimisation using Markal: the case of transport sector in Sweden

In this chapter the application of MARKAL illustrates the stationary energy system (electricity and heat production, energy use in industry, households, etc.) in the Nordic countries i.e. Sweden, Norway, Denmark and Finland as well as the Swedish transport sector. Whilst Sweden and the Swedish transport sector are in focus in this optimisation process the interaction between the constituent countries is to some extent limited and consists basically of the Nordic electricity market being a potential concurrent when it comes to bioenergy.
Furthermore, a common emission cap for CO2 is applied. The studied period is from 1995 to 2051 being the maximum period for the optimisation process.

In the model description of the Swedish transport sector a variety of fuels are included i.e. gasoline, diesel, ethanol, biomethan (biogas and SNG), biodiesel (RME), methanol, DME, FT-diesel and hydrogen. In addition, electricity is loaded from the network to plug-in hybrids and pure electric vehicles. Techniques for the production of motor fuels are described in the model by costs and conversion efficiency. The transport module is powered by an exogenous given transport demand in vehicle-km. Transport demand is exogenously given in the model and is divided into groups related to the following vehicles: passenger cars, light trucks, heavy trucks, buses and MC. Demand in the heavy vehicle groups (buses and trucks) are further divided into urban and non urban traffic. Vehicle technology as well as fuel production are described with energy efficiency (fuel consumption per vehicle-km) and vehicle costs. These parameters depend on the vehicle group, fuels and propulsion technologies. In addition to conventional propulsion technologies based on the internal combustion engine (spark ignition or diesel) hybrids, plug-in hybrids, electric vehicles and fuel cell vehicles are included. Besides the chosen parameters existing fuel production and vehicle technologies are also other assumptions concerning e.g. distribution and raw material acquisition that are important for the final results.

3.4 Biofuels in the Swedish transport sector

- The assumptions

This scenario is a study of cost-effective technologies and fuels as well as the effects on CO2 and the system costs when biofuels are introduced in the Swedish transport sector according to the shares shown in Figure 11. The rates for 2010 and 2030 are in accordance with the established EU goals while subsequent levels are a linear extrapolation that is related to a constant increase in transport demand. In year 2037, the share of biofuels reaches 30% of the total fuel use. Besides, biofuels requirement in the scenario, no other forms of instruments in the transport sector, i.e. no fuel taxes, vehicle taxes nor restrictions etc are imposed.
Figure 10: The shares of biofuels the Swedish transport sector

Figure 12 illustrates a cap on CO2 emissions in the Nordic stationary energy system, i.e. all CO2 emissions in the system except emissions from the transport sector. This emissions cap forces the CO2 emissions from the Nordic stationary energy system to be reduce by 20% in 2020 (EU targets) and by approximately 45% in 2037. All these emissions reductions are relative to the reference year 1995. The idea of an exogenous emission cap indirectly creates a cost to CO2 emissions in the form of costly technologies and fuels. The cap is similar to the current system of emissions trading at EU level, albeit with a different geographical system boundary (An alternative approach would be to impose an exogenous cost of CO2 emission levels such as taxes and to allow the model to endogenously determine the levels of CO2 emissions). In addition to the CO2 emissions ceiling added in this scenario, no other forms of policy instruments such as energy taxes and emission charges are imposed on the stationary energy system.

Figure 11: A cap limiting CO2 emissions in the Nordic stationary energy system

26 In the area of fuels, the 2001 Biofuels Directive requires that 5.75% of all transport fossil fuels (petrol and diesel) should be replaced by biofuels by 31 December 2010, with an intermediate target of 2% by the end of 2005. However, MEPS have since voted to lower this target in the wake of new scientific evidence about the sustainability of biofuels and the impact on food prices. In a vote in Strasbourg, the European parliament’s environment committee supported a plan to curb the EU target for renewable sources in transport to 4% by 2015. They also said that a thorough review would be required in 2015 before the EU could progress to an 8-10% mark by 2020. [http://en.wikipedia.org/wiki/European_emission_standards](http://en.wikipedia.org/wiki/European_emission_standards)
When it comes to the supply side Table 12 brings together the assumed prices and costs for different fuels and raw materials as well as potential supply of biofuels. For energy crops a maximum cultivable area of 800 000 ha is assumed to be fully accessible by 2030. For rapeseed and based on crop rotation reasons a limited cultivated land of 150 000 ha is assumed. Nevertheless, import of biofuels is excluded.

Table 12: Biofuels prices and potential supply

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<tr>
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<tbody>
<tr>
<td><strong>Fossil fuels</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy fuel oil</td>
<td>24 / 27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light fuel oil</td>
<td>28 / 32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas</td>
<td>16 / 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>6 / 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline/diesel (before distr.)</td>
<td>29 / 32</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Biofuels</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forestry products</td>
<td>11 – 17</td>
<td></td>
<td>80 / 85</td>
</tr>
<tr>
<td>Industry by-products</td>
<td>1 – 7</td>
<td></td>
<td>55 / 66</td>
</tr>
<tr>
<td>Bio-waste (for biogas)</td>
<td>-22</td>
<td></td>
<td>9 / 10</td>
</tr>
<tr>
<td>Energy forest</td>
<td>17</td>
<td></td>
<td>6 / 48</td>
</tr>
<tr>
<td>Wheat</td>
<td>25</td>
<td></td>
<td>3 / 25</td>
</tr>
<tr>
<td>Crops for biogas</td>
<td>14</td>
<td></td>
<td>4 / 36</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>38</td>
<td></td>
<td>2 / 3</td>
</tr>
</tbody>
</table>

3.5 The results

- Transport biofuel demand
Figure 13 shows biofuels demand based on the assumptions discussed above. Until 2009 the options are very limited and the choice of biofuels is strongly dependent on what is available on the market. From year 2016 all biofuels and technologies are available options in the model. However, methanol produced by biofuel gasification is the optimal choice based on model assumptions.

Figure 12: Biofuels use

![Biofuels use graph](image)

**-Fuel in use in the transport sector**

Figure 14 shows the total fuel use divided into groups of vehicles and vehicle technologies. Since no fuel tax or other incentives for energy efficiency are assumed to be adopted in the model scenario it is shown that the use of alternative fuel-efficient vehicle technologies like hybrids is low, although the bus hybrids are introduced in urban traffic in the second part of the studied period. Further, the share of diesel vehicles in the car group is low for similar reasons.

Figure 13: Fuel use for different vehicles and years. (Biodiesel and ethanol used in low blend in diesel and petrol are not distinct on this figure)
- The Costs

Marginal cost of CO2 emissions arise since CO2 emissions from the stationary energy system in the Nordic model is limited by emissions caps. Figure 15 shows marginal cost partly for a case with quotas for biofuels (as shown in Figure 11) and partly for a case without quotas (in this case, however, a certain percentage of biofuels is included in the system until 2009).

As shown in the figure a high percentage of biofuels in the transport sector impacts on costs of CO2 reduction in the stationary energy system. This is primarily due to the increasing competition for biofuel resources arising from the requirement for an increasing share of these fuels. Note that CO2 emissions from stationary energy are the same in both cases i.e. it is exogenously determined as an emission ceiling as shown in Figure 12. Furthermore, CO2 emissions from transport sector will therefore be lower in proportion to a higher percentage of biofuels. Figure 16 shows this CO2 emission reductions resulting from the introduction of biofuels.
Figure 14: Marginal cost of CO2 reduction in the Nordic stationary energy system with and without quotas of biofuels in the Swedish transport sector from 2016 onwards.

Figure 15: CO2 reduction per year in the Swedish transport sector in comparison to cases without biofuels.
The introduction of biofuels gives rise to additional costs in the system. The additional costs are shown in Figure 17. The costs are shown for both discounted and undiscounted values where a discount rate of 5% has been used. Note that the additional costs for the introduction of biofuels are sensitive to the fuel to be used. The costs are in particular sensitive to the relationship between oil and biofuel prices. A higher oil price would imply a lower cost of biofuels.

Figure 16: The system's costs per year of biofuel case compared to cases without biofuels
4 Impacts of behavioural change in the transport sector

4.1 Introduction

Travel is a complex behavioural process and a trip is only one constituent part of a highly complex system which involves, at one and the same time, the location of activities and housing, a whole range of social practices and relations and, of course, transports networks and supply (Bonafous (2008)). The objective of this chapter is to assess the implication of behavioural change on emission reduction related to passenger transport.

4.2 Modal choice

-The model
Modal choice is concerned with the study of the decision that the consumer makes when confronted with alternative choices.

The utility function for the individual decision-maker is specified as:

\[ U_i = V(\beta; X_i, S) + \varepsilon (X_i, S) \]

with \( i = 1, \ldots, J \) and where \( U_i \) is the utility associated with transportation using mode \( i \).

The utility function is comprised of an observed and an unobserved, or random, component. The observable part of the utility function is \( V(\beta; X_i, S) \), where the vector function \( V \) consists of a vector of unknown parameters, \( \beta \), a set of modal attributes, \( X_i \), and the socioeconomic characteristics of the decision-maker, \( S \). \( V \) is systematic utility, that is, the same functional form applies to all individuals. The random portion of the utility function is \( \varepsilon (X_i, S) \). This component of the utility reflects the unobserved tastes, preferences and characteristics of the individual decision-maker. Consequently, this term varies across decision makers.

According to the utility maximization assumption, the individual chooses a particular mode \( i \) only if the utility realized from choosing mode \( i \) is greater than the utility realized from any other mode. Thus, the individual will choose mode \( i \) if \( U_i > U_j \) for all \( i,j \). In this model choices are predicted as probabilities, where the probability that the individual chooses mode \( i \) is:

\[ P_i = \text{Prob} [U_i > U_j \text{ for all } i,j] \]

Thus, the mode-choice probabilities depend, in part, on the random utility differences \( (\varepsilon_i - \varepsilon_j) \), and their distribution.

Except the binary choice where the individual decision-maker has two alternatives e.g. driving a car or taking public transportation, the alternatives may be several including

\[ \text{http://www.nets.iwr.usace.army.mil/docs/other/05-NETS-R-01.pdf} \]
bicycles, walking etc. This last case where the utility function considers several modes of transport is referred to as a multinomial choice model

**The Swedish Modal choice**

The National Travel Survey, RES 2005–2006, contains data on the everyday movements and longer journeys made by Swedish residents between the ages of 6 and 84. In total, 27 000 interviews were conducted. Some of the results that were obtained from the survey are:

- On an average day, 83% of Swedish residents left their home on some sort of trip. 30% of all trips were to work, business-related or to school where the distribution of the types of trips is an even between women and men. Furthermore, service and shopping constitutes 31% of trips and 33% of the trips is associated to leisure.

Figure 17: Allocation of trips by purpose

- On an average day, the combined total distance travelled was 363 million km. The car was the most common mode of transport that was used, representing 64 percent of the total kilometres travelled. Travel by car was used much more often than public transportation. Approximately 90% of the population travelled by car at least once per week, while just 30% used public transportation sometime during the week. On an average day, 53% travelled by car, 14% by public transportation and 5% by both car and public transportation. Figure 18 shows the distribution of travel demand in Sweden.

Gasoline, the most common fuel used in cars, was used eight times as much as diesel. However, as shown in figure 3 above, while the share of gasoline has been almost constant since 2000, the shares of diesel as well as biofuels are increasingly demanded in the transport sector.

In general several factors have significant impact on the choice of travel mode. The significance of each of these factors varies depending on the circumstances of the commuter. In general, cost of travel is likely to be a more significant factor for low-income commuters than wealthy ones. Another factor is the provision of good public transport. A dispersed population as is the case in several regions of Sweden has much higher car
ownership than in the city centre and that the vast majority of motorised travel is by private car. Below is a list of several factors with effects on modal choice in general.

- Commute distance
- Cost of travel
- Work schedule
- Reliability and convenience of the commute option
- Need for vehicle during, before or after work
- Desire for privacy or company
- Environmental concern
- Desire for comfort/relaxation

In a survey conducted by Eriksson et al (2008) to assess commuters' behaviour and the factors having effects on modal choice the following question was asked:

*What would make you use the car less often?*

Except the travelled distance being a variable that is often difficult to have an effect on, at least in the short run, since for instance the locations of working place and housing are fix the reasons that would make commuters using car less often are shown in table 13:

<table>
<thead>
<tr>
<th>Motives</th>
<th>Answers</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Work from home some days</td>
<td></td>
<td>22.0</td>
</tr>
<tr>
<td>2 More flexible working hours</td>
<td></td>
<td>3.6</td>
</tr>
<tr>
<td>3 Company-supplied car/bike/carpool</td>
<td></td>
<td>6.0</td>
</tr>
<tr>
<td>4 Car-pooling</td>
<td></td>
<td>7.6</td>
</tr>
<tr>
<td>5 Higher parking fees</td>
<td></td>
<td>3.4</td>
</tr>
<tr>
<td>6 Improved public transport</td>
<td></td>
<td>22.0</td>
</tr>
<tr>
<td>7 Pre-paid travel card</td>
<td></td>
<td>4.9</td>
</tr>
<tr>
<td>8 Self-generated</td>
<td></td>
<td>6.5</td>
</tr>
<tr>
<td>9 Nothing/don't know</td>
<td></td>
<td>23.6</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

As shown several motives i.e. motive number 3, 4, 5, 6 and 7 are dealing explicitly with travel costs. This cost may be direct taking the form of lower travel costs or indirect relating to the time the trip takes. For instance, improved public transport would lead to lower use of own car. Higher parking fees makes public transport an efficient substitute.

### 4.4 Policy instruments

In order to apply the polluter pays principle the costs of environmental impacts of an activity should be internalized. This could be done by applying policy instruments also called environmental instruments. The most common policy instruments that are used by governments can be categorised into: regulatory, informational and incentive based.
The regulatory instruments often refer to the Command and Control Approach (CAC). The CAC policy uses regulations as instruments, fixing environmental standards to polluters. Polluters’ compliance is based on monitoring and enforcement. Four types of standards can be considered: ambient quality standards, emission or discharge standards, process standards and product standards. Traditionally, CAC policies are regarded as being effective, easy to manage, relatively simple to impose and broadly accepted. The CAC measure is a lever with an impact on car speed: a one-third reduction in car speed is achieved through regulation and restrictions. It is the measure that has the most pronounced impact on transport by car, achieving a 22 per cent decline in vehicle-kilometres travelled. However, from welfare economic point of view they are often non efficient (Duarte, 1999).

For informational instruments a distinction is usually made between information strategies for production and information strategies for consumption. The strategies for production may include promoting the adoption of targeted, high-profile demonstration projects, to demonstrate the techniques and cost-saving opportunities associated with cleaner production. The strategies for consumption would include encouraging educational institutions to incorporate preventative environmental management within their curricula.

The incentive-based instruments are based on the market approach. This policy is related to economic incentives which “provide market signals” in the form of a modification of relative prices having impacts on demand. The demand side control measures reduce emissions by reducing the demand for product or service causing emissions instead of applying end-of-the-pipe control technologies (ref). Demand side control measures often include behavioural changes and are in general cost effective e.g: changes in vehicle stocks, changes in vehicle usage and changes between modes for transportation.

In order to study the effect of higher prices on fuel demand elasticities are estimated. In general, elasticities measure the responsiveness of the quantity demanded of a good to a change in the price of that good.

After a detailed review of international studies, Goodwin (1992) summarises various studies of long run price effects and produced the average elasticity values shown in table 14.29 Goodwin noted that the price impacts tend to increase over time as consumers have more options (related to increases in real incomes, automobile ownership, and now telecommunications that can substitute for physical travel.

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29 These results are in line with several results published in international journals.
Table 14: Transportation elasticities

<table>
<thead>
<tr>
<th></th>
<th>Short run</th>
<th>Long run</th>
<th>Not defined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel demand WRT fuel price</td>
<td>-0.27</td>
<td>-0.71</td>
<td>-0.53</td>
</tr>
<tr>
<td>Traffic levels WRT fuel price</td>
<td>-0.16</td>
<td>-0.33</td>
<td></td>
</tr>
<tr>
<td>Bus demand WRT fare cost</td>
<td>-0.28</td>
<td>-0.55</td>
<td></td>
</tr>
<tr>
<td>Railway demand WRT fare cost</td>
<td>-0.65</td>
<td>-1.08</td>
<td></td>
</tr>
<tr>
<td>Public transit WRT fuel price</td>
<td></td>
<td></td>
<td>0.34</td>
</tr>
<tr>
<td>Car ownership WRT general public transport costs</td>
<td></td>
<td></td>
<td>0.1 to 0.3</td>
</tr>
</tbody>
</table>

("WRT" = with regard to)

As shown fuel taxes leading to higher fuel prices would serve a very important role for the environment i.e. lower fuel demand and thereby lower emissions. However, the relatively low elasticity of driving with respect to fuel prices (e.g. -0.27) hides a much higher overall elasticity of driving. Fuel is only about a quarter of the total cost of driving (Litman, 2005). An elasticity of -0.3 for vehicle travel with respect to fuel price indicates that the overall price elasticity of driving is about –1.2, making driving an elastic good with respect to total vehicle costs.

The costs of owning a car includes both fixed and variable costs. The fixed costs are the sum of insurance costs, taxes as well as parking and value depreciation of the vehicle. The variable costs are the sum of fuel costs, maintenance costs and mileage based depreciation. The variable costs are often referred to as marginal costs of driving. In the case of owning a car the proportion of variable costs is in the range of 50 percent and the difference between new and used cars is not very significant.

Table 15: The costs of owning a car: SEK/Swedish mile (1 mile= 10 km)

| Costs of owning a new car | New car price | 40.30 | 47.50 | 26.50 |
| When: New car price       | 175 000       | 220 000 | 280 000 |
| Costs of owning a used car | 19 | 25 | 32 |
| When: Price of used car (model 1998) | 23 500 | 42 400 | 59 500 |

When it comes to public transport a higher fare cost would lead to lower public transport and vice versa. A price increase of fare cost by 1%, *ceteris paribus*, would lead to 0.55 reductions in public transport in the long run.

**4.5 Behavioural change and emissions reductions**

In order to estimate the impact of behaviour change on emission reduction of CO2 as well as NOx and PM for year 2020 the Vägverket database is presented and used. The Vägveket database and prognoses for passenger cars in year 2005 are a result of a bottom up process that is built on NVDBs (Nationell vägdatabas) roadlinks and the SIMAIR for traffic data as...
well as the travel demand model SEMPER and the route-choice model Emme. The results for year 2005 are shown in table 16.

Table 16: Swedish CO2 and air pollution in 2005

<table>
<thead>
<tr>
<th>Milliard driven kilometres</th>
<th>Emission factors (km)</th>
<th>Total emissions (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg /Co2</td>
<td>g /NOx</td>
</tr>
<tr>
<td>Gasoline</td>
<td>52.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Diesel</td>
<td>9.8</td>
<td>0.17</td>
</tr>
<tr>
<td>E85</td>
<td>1.2</td>
<td>0.05</td>
</tr>
<tr>
<td>CNG</td>
<td>0.2</td>
<td>0.08</td>
</tr>
<tr>
<td>Sum</td>
<td>64.0</td>
<td></td>
</tr>
</tbody>
</table>

Based on a bottom up model the results for the year 2020 are shown in table 17: As shown although the sum of driven kilometres by passenger cars would increase from 64 billion kilometres to around 72 kilometres the total emissions of CO2, NOx and PM would decrease based partly on the assumption that emission factors would be lower in 2020 compared to 2005. The lower emissions factors are a consequence of policy instruments.

Table 17: Swedish CO2 and air pollution in 2020

<table>
<thead>
<tr>
<th>Milliard driven kilometres</th>
<th>Emission factors km</th>
<th>Total emissions (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg /Co2</td>
<td>g /NOx</td>
</tr>
<tr>
<td>Gasoline</td>
<td>42.7</td>
<td>0.17</td>
</tr>
<tr>
<td>Diesel</td>
<td>24.3</td>
<td>0.15</td>
</tr>
<tr>
<td>E85</td>
<td>4.7</td>
<td>0.04</td>
</tr>
<tr>
<td>CNG</td>
<td>0.3</td>
<td>0.07</td>
</tr>
<tr>
<td>Sum</td>
<td>71.9</td>
<td></td>
</tr>
</tbody>
</table>

Based on the Vägverket data including driven kilometres and emission factors the use of demand elasticities and especially the long term one in the case of gasoline demand i.e -0.6 gives the following results when it comes to emissions in year 2020 (these results are equivalent to the ones estimated by SIKA for year 2020):

- CO2 = 8539766 tons
- NOx = 6028 tons
- PM = 90 tons

When comparing the prognoses of 2020 based on Vägverket’ results to those based on Vägverket ground data for year 2005 but using elasticities leads to quite higher total emissions when using elasticities. The differences are in the range of 15 percent in the cases of CO2 and NOx and PM emissions. While prognoses based on elasticities assume that all

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30 http://www.vv.se/Trafiken/Miljo---dokument--lankar/Vagverkets-ovriga-miljodokument/Handbok-for-vagtrafikens-luftfororingar/
other variables such as income, vehicle stock are constant the vägverket prognoses being a product of a bottom up model consider almost all variables leading to changes in travel demand and the derived emissions. These results and especially the differences between estimations using elasticities or other models support the findings of Litman (2005) where fuel is only a fraction of the total cost of driving.

4.6 Concluding remarks

This report includes a presentation of 2 optimisation models i.e. GAINS and Markal as well as results based on both these models and others. Since the results are built on different assumptions, the related results are different. Table 18 is a recapitulation of the results.

Table 18: Emission reductions of CO2 in 2020 (million tons)

<table>
<thead>
<tr>
<th></th>
<th>GAINS</th>
<th>Markal</th>
<th>Vägverket</th>
<th>Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission reduction</td>
<td>5.5</td>
<td>3</td>
<td>-3.3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-1.2</td>
<td></td>
</tr>
</tbody>
</table>

- In GAINS, the CO2 reductions in 2020 being around 5.5 million are the sum of different measures including:
  1. 10% renewable fuels: The measure is yet another scenario in which 10% bio fuels are introduced into the TRA_RD (road transport) sector. The difference from earlier scenarios is that this scenario is fully based on the NEC_NAT_CLE4REV scenario.
  2. Small cars (120 g CO2 / km) Long Vehicle Trucks. This scenario includes a change in the TRA_RD_LD4C sector, in which 120 g CO2 / km are ensured by 2020. Apart from this, the scenario is based on the NEC_NAT_CLE4REV scenario.
  3. Long Vehicles Trucks. This scenario includes long vehicle in the TRA_RD_HDT sector.

The reductions using GAINS are relative to NEC nat cle 4 review (National Activity Projection) final version of the national baseline scenario with emission controls reflecting current legislation (national activity paths, CLE control strategies) as shown in figure 4.31

- In Markal the reductions of CO2 in 2020 are about 3 million tons. As discussed above, this scenario is a study of cost-effective technologies and fuels as well as the effects on CO2 and the system costs when biofuels are introduced in the Swedish transport sector according to the shares shown in Figure 11. The shares are in accordance with the established EU goals while subsequent levels are a linear extrapolation that is related to a constant increase in transport demand. Besides biofuels requirement in the scenario, no other forms of instruments in the transport sector, i.e. no fuel taxes, vehicle taxes nor restrictions etc are imposed.

31 This scenario relates to “National activity projections, "current legislation" control strategies. Euro 5 and 6 on light-duty vehicles, Euro V on heavy-duty trucks and buses".
The Vägverket prognoses of CO2 emissions in 2020 are estimated to be 3.3 million tons if only gasoline demand is concerned. Total emission reductions would be only 1.2 million tons if all fuels are considered. The lower total emissions of CO2 are based on the fact that while gasoline vehicles are replaced with diesel, ethanol and CNG vehicles as well as the number of these last vehicles is assumed to increase in the future, the net effect of replacing gasoline cars with others is low.

When using long run elasticities the emission reduction of CO2 in 2020 would be about 2 million tons. Here emission reductions of CO2 are a result of increased gasoline price (all other things being constant).

Except the Vägverket results that are based on prognoses based on national data related to travel demand, GAINS and Markal model results are based on optimisation procedures and elasticity results are a consequence of higher gasoline price in the long run. It is however, not easy to classify the results of neither GAINS, Markal nor elasticities as solely the results of behavioural change. Using GAINS and Markal is also a substitution to other fuels and/or vehicles being the effect of behavioural change. However, results based on elasticities are behavioural. This is because the increased price of gasoline would lead to higher demand of public transport, using a bicycle or walking. Hence, the emission reduction of about 2 million tons may be commented as supplementary emission reductions and can be added to the results of GAINS or Markal. Using the results of GAINS for instance and adding the elasticity estimations the emission reductions of CO2 would be about 7.5 million tons in 2020.
References

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Appendix

In GAINS the loss of life expectancy (for the population above 30 years of age) is a represented as a sum of two terms:

$$YOLL^{bk}(K) = \sum_{k \in K} YOLL^b_k + \sum_{k \in K} YOLL^CD_k$$

The first term reflecting the population-weighted PM 2.5 concentration at the national scale, the second representing the 'City-Delta' contribution.

In GAINS various receptor regions K are considered, for instance K = EU25, K = EU27, K = (EU27 + Norway + Switzerland), etc. More explicitly,

$$YOLL^b_k = C_k \cdot POP30_k \cdot PM2.5_{k, pop-w}$$

where Ck a (receptor-) country-specific parameter that can be derived from the Cox Proportional Hazards Model, taking into account the changes in life expectancy for each cohort.

The parameter POP30k is the population above 30 years of age in (receptor-) country k.

The population-weighted PM 2.5 concentration is given by:

$$PM2.5_{k, pop-w} = pPM_{k, pop-w} + sPM_{k, pop-w} + aPM_{k, pop-w} + nPM_{k, pop-w} + h_{k, pop-w}$$

Here the individual terms are

- $pPM_{k, pop-w} = \sum_{i \in I} \pi_{i,k} \cdot emissions_{i, PM}$
- $sPM_{k, pop-w} = \sum_{i \in I} \sigma_{i,k} \cdot emissions_{i, SO_2}$
- $aPM_{k, pop-w} = \sum_{i \in I} \alpha_{i,k} \cdot emissions_{i, NH_3}$
- $nPM_{k, pop-w} = \sum_{i \in I} \nu_{i,k} \cdot emissions_{i, NO_x}$

The constant $h_{k, pop-w}$ is used to calibrate the linear approximation and includes also the mineral component of PM 2.5. The City-Delta contribution to the YOLL function is given by
\[ \text{YOLL}^{\text{CD}}_k = C_k \cdot \text{POP30}^U_k \cdot \text{PM2.5}^{\text{CD}}_k \]

where

\[ \text{POP30}^U_k \]

is the urban population above 30 years of age in country k, and The City-Delta contribution to the population weighted PM 2.5 concentration is

\[ \text{PM2.5}^{\text{CD}}_k = \sum_{i \in I} \sum_{\text{SNAP1}} \delta_{i,k} \cdot T^{\text{SNAP1}}_{i,k} \cdot \text{emissions}^{\text{PM,SNAP1}}_{i,k} \]

Here the sum runs over all SNAP1 sectors, and ‘emissions^{\text{PM,SNAP1}}_{i,k}’ are the primary PM2.5 emissions by SNAP1 sector in country i and

\[ T^{\text{SNAP1}}_{i,k} \]

is the transfer of primary PM 2.5 from i to k. In fact, for the City Delta only the local contribution is relevant, and this is ensured in this formulation by using the Kronecker \[ \delta_{i,k} \]

which is equal to 1 for \( i = k \) (emitter = receptor region), and zero otherwise.