report

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Climatic Impact of Future Swedish Transports

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Abstract

In this study, the concept of radiative forcing is used to predict and quantify the enhancement of the greenhouse effect caused by future Swedish transports. The results are compared to existing estimates of how large an enhancement of the greenhouse effect the Earth can sustain without unacceptable effects on the climate and the ecosystems of the planet.

Three different scenarios are compared and evaluated regarding their emissions of the greenhouse gases CO_2, N_2O and CH_4. The first scenario is based on the assumption that no changes in traffic policy will take place until 2020. The second scenario, developed by Kommunikationskommittén, implies a 15 % decrease in CO_2-emissions by 2020 compared to the levels of 1990. The third scenario, developed by Forskningsgruppen för miljöstrategiska studier, presents a radically different transport system by 2040, with large reductions in greenhouse gas emissions.

At present the radiative forcing emanating from Swedish transports is rising rapidly. Large reductions in greenhouse gas emissions are required to reach a sustainable radiative forcing. Even the long term goal of Kommunikationskommittén, implying a 60 % reduction in greenhouse gas emissions from the transport sector by 2050, is insufficient to reach a sustainable radiative forcing.

The results show that CO_2 is the most important greenhouse gas emitted by transports. CH_4 from Swedish transports will not have a significant impact on the future radiative forcing. It also seems unlikely that N_2O-emissions from transports will affect the enhancement of the greenhouse effect greatly in the future. However, data on emission factors for N_2O are unsatisfactory and thus the significance of N_2O can be considerably larger than what our results imply.

The calculated radiative forcing is markedly affected by the definition of atmospheric background greenhouse gas concentrations. This definition is partly a political choice.

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1. Introduction

1.1 Background

Throughout the history of the Earth the climate has undergone many changes and will no doubt continue to change in the future. The climate is always evolving and must not be regarded as having a constant nature. However, in recent years scientists and politicians have raised the issue of anthropogenically induced changes of the climate.

The infrared radiation sent out by the warm Earth is to a certain extent absorbed by gases in the atmosphere, preventing some of the heat from escaping. This is what is commonly called the greenhouse effect. It is one of the most important factors governing the climate of the Earth. Without the greenhouse effect, the Earth would be covered with ice (Ramanathan, 1988). Thus there is no doubt that the natural greenhouse effect is necessary for human life as we know it. The most important greenhouse gases are water vapour, carbon dioxide and ozone (Wallace & Hobbs, 1977).

Many of the processes governing the climate of the Earth are still poorly understood and the issue of global warming is not without controversy. Nevertheless, there seem to be a consensus throughout the scientific world that the climate of the Earth is now changing due to human activities in a way unprecedented in history (IPCC, 1995). In particular, one is worried that the increasing emissions of heat-absorbing gases, e. g. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), are enhancing the greenhouse effect of the Earth's atmosphere. Since the industrial revolution took place in the western world, the concentration of carbon dioxide in the atmosphere has increased with more than 25 % (Trenberth et al., 1996). Model studies suggest that this may lead to a significant rise in the temperature of the lower atmosphere (Kattenberg et al., 1996).

The exact effects that will follow from an increase in the global temperature are very hard to predict accurately. Dramatic changes in weather patterns and a rise in sea level due to warming of the water and melting of polar ice are mentioned as possible consequences if the anthropogenic emissions of greenhouse gases do not decrease significantly (Warrick et al., 1996).

The Intergovernmental Panel on Climate Change (IPCC), organised within the framework of the United Nations, is the main authority in this field. It continuously synthesises, analyses and publishes available scientific information on climate change. Furthermore, it attempts to assess the environmental and socio-economic impacts of climate change and formulate response strategies.

1.2 The Role of Transports

The largest source of greenhouse gas emissions is the combustion of fossil fuels such as oil products and coal (Klimatdelegationen, 1995). These fuels are mainly used for direct energy production in power plants or refined to other petroleum products, many of which are used as fuels for vehicles. In 1994, the Swedish CO_2-emissions amounted to 58 Mtonnes, making Sweden responsible for about 1% of the global CO_2-emissions (Sveriges andra nationalrapport om klimatförändringar, 1997).

The transport systems of the world, which largely depend on combustion engines powered by fossil fuels, have a large responsibility for the increasing concentrations of greenhouse gases in the atmosphere. In Sweden, passenger cars are the largest separate source of CO_2 emissions from transports (Figure 1.1). The sources of N_2O- and CH_4-emissions and how they are distributed within the transport sector are displayed in Appendix B.

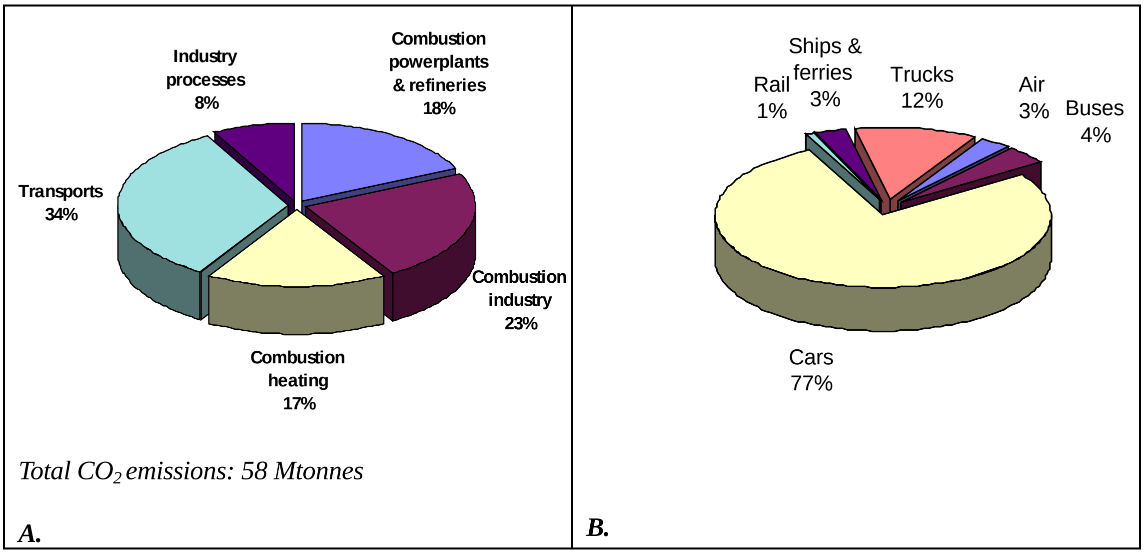

Figure 1.1 *A. Swedish sources of CO_2-emissions 1994. B. The share of the CO_2-emissions for different means of transport (Sveriges andra nationalrapport om klimatförändringar, 1997).*

1.3 The Objective of the Study

Many reports have been written concerning the environmental effects of individual means of transport, or emissions of a specific trace gas like CO_2 (e. g. Demker et al., 1994, Johansson, 1993). However, when looking for more comprehensive studies on the climatic impact of future Swedish transports we have found none.

The objective of this report is to quantitatively describe the enhancement of the greenhouse effect caused by different possible future transport systems in Sweden. Three different transport system scenarios are compared and evaluated regarding their emissions of the greenhouse gases CO_2, N_2O and CH_4 and their contribution to the greenhouse effect. The results are compared to existing estimates of how large an enhancement of the greenhouse effect the Earth can sustain without unacceptable effects on the climate and the ecosystems of the planet.

Our hypothesis is that the reductions in greenhouse gas emissions from transports suggested in Swedish transport policy will not be sufficient, i.e. suggested emission reductions will not lead to a sustainable transport system. We also want to test the hypothesis that the contribution to the greenhouse effect of CH_4- and N_2O-emissions from transports, relative to CO_2-emissions from transports, is larger than reflected in the general debate of climate change.

2. Methods

2.1 Radiative Forcing

2.1.1 How can Climate Change be Quantified?

The following chain of processes can illustrate the relationship between emissions and climate change:

emissions $\rightarrow$ increased atmospheric concentrations $\longrightarrow$ radiative forcing $\longrightarrow$
$\longrightarrow$ climate change

When assessing the effects from emissions it would be desirable if we could express these effects in climatic parameters, such as temperature rise, humidity etc. But to make predictions of such variables, general circulation models (GCMs) have to be used. Because of the complexity of the climate system the GCMs require very powerful computer systems, and the models are still afflicted with uncertainties (Kattenberg et al., 1996).

However, when relative effects from different gases and different emission scenarios are to be compared, as in this study, useful information is contained in the radiative forcing. Radiative forcing is a measure of the change in energy balance in the atmosphere, i. e. change in greenhouse effect. By calculating the radiative forcing for emissions of different gases, their different atmospheric lifetimes and characteristics in absorbing/emitting radiation are taken into account, which makes it possible to compare them with each other. Even if this does not give an answer to what climate that can be expected, it still allows for analysis of relative effects by using the quantity radiative forcing as a measure. The calculated radiative forcing should be seen as a measure of the potential climate change.

A frequently used alternative to radiative forcing when trying to assess future global warming, resulting from current anthropogenic emissions, is the concept of global warming potentials, GWPs (Albritton et al., 1995). The GWP-indexes are defined as the cumulative radiative forcing between the present and some chosen later time horizon, caused by a unit mass of gas emitted now, expressed relative to some reference gas (usually CO_2). The future global warming commitment of a greenhouse gas over the reference time horizon is the appropriate GWP multiplied by the amount of gas emitted. For example, GWPs could be used to calculate the effect of reducing current CO_2-emissions by a certain amount compared with reducing CFC-emissions, for a specified time horizon.

In this report we want to study the climatic effects of continuos emissions over a time period of several centuries. This makes the GWP-concept less suitable to use, but radiative forcing is a measure fit for this type of study. We therefore use the concept of radiative forcing to quantify the climate change induced by Swedish transports. The methods used to calculate the radiative forcing in this report are analogous to the methods described by Zetterberg (1993).

2.1.2 What is Radiative Forcing?

Radiative forcing, measured in W/m^2, can be described as the change in radiative balance at the tropopause. In other words, the change in the difference between incoming and outgoing radiation, i.e. net radiation, through the tropopause. A positive radiative forcing tends to warm the Earth’s surface, a negative radiative forcing tends to cool it. The tropopause is the boundary between the troposphere and the stratosphere. Depending on season and latitude the altitude of the tropopause varies between 8 and 18 km (Brasseur & Solomon, 1986).

Factors able to perturb the radiative balance of the Earth are called radiative forcing agents. In this report we are mainly concerned with gases which absorb IR-radiation, so called greenhouse gases. The most important greenhouse gas in the atmosphere is water vapour, but since its’ concentration in the atmosphere is not directly affected by human activities it is not treated separately in this report. However, effects of water vapour are to some extent included in the equations of radiative forcing. One should be aware that feedback mechanisms connected to climate change might well affect the concentrations of water vapour and other climate-affecting factors in the future; as an example higher temperatures will increase the evaporation of water from the oceans. Generally, such feedback mechanisms are very hard to predict and this obviously increases the uncertainties associated with the calculations of climate change. Furthermore, we do not consider the effects of chlorofluorocarbons (CFCs), or tropospheric ozone in this study. The emissions of CFCs from the transport sector are minor and the relationship between radiative forcing and the atmospheric concentrations of CFCs and ozone are still to be determined accurately. We concentrate on the three main greenhouse gases connected to transports: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Aerosols are also radiative forcing agents, but they tend to reduce the forcing, thereby having a cooling effect. Emissions of aerosols from e.g. ocean going ships could have a large local effect on the radiative forcing, but the effects are difficult to quantify on a large scale and have not been considered in this study.

2.1.3 The Relationship Between Greenhouse Gas Emissions and Atmospheric Concentrations

In order to calculate the radiative forcing caused by the emission of a greenhouse gas, for example the CO_2 emissions from a car, one needs to calculate the change in atmospheric CO_2 concentration caused by the emission. When a gas is released into the atmosphere it will immediately or after some time (e.g. after diffusion and/or dispersion in the atmosphere) start to decay. Each gas could be involved in numerous sink processes, for example chemical reactions, solution in the oceans, photolysis or biological uptake (IPCC, 1990).

The decay of a gas in the atmosphere can be described by the expression

$$m(t) = m_0 e^{-t/\tau} \tag{2.1}$$

where t is the time in years, m_0 is the mass at t=0 and m(t) is the remaining mass after t years. τ is the atmospheric lifetime of the gas, defined as the ratio of the atmospheric content to the total rate of removal (Watson et al., 1990). This time scale also characterises the rate of adjustment of the atmospheric concentrations if the emission rates are changed abruptly. A long lifetime makes the adjustment rate slow and vice versa.

As the decay of greenhouse gases involves a number of different processes it is not easily quantified, let alone described by a single value of τ. Consequently, different values for the atmospheric lifetimes of greenhouse gases can be found in the literature. We have chosen to use the values of τ recommended by the IPCC (Table 2.1).

Table 2.1 *Atmospheric lifetimes of selected greenhouse gases (Albritton et al., 1995).*

Trace Gas	*Atmospheric lifetime, τ, (years)*
*Carbon dioxide, CO_2, uptake by biosphere**	*6.993*
*uptake by ocean surface water**	*71.109*
*transfer to deep ocean water**	*815.727*
Nitrous oxide, N_2O	*120*
Methane, CH_4	*14.5*

**Corresponding mass fractions: 0.30036, 0.34278, 0.35686, respectively.*

To be able to describe the decay of CO_2 with reasonable accuracy, the IPCC suggests a sum of exponential functions of the form given in eq. 2.1. One can regard the carbon dioxide as having three separate fractions, of roughly equal sizes, each with its' own atmospheric lifetime; approximately 6, 71 and 816 years respectively. This, of course, does not mean that there are three fractions of CO_2 reacting independently but should rather be regarded as a means of describing the decaying processes of the gas. The different atmospheric lifetimes are related to different sink processes of CO_2. Rapid uptake by the biosphere causes a fast, initial decay of CO_2 which corresponds to the first, rather short-lived, fraction of CO_2. The intermediate atmospheric lifetime reflects the mechanisms which control the equilibrium in CO_2 concentrations between the troposphere and the ocean surface waters. There is a continuos exchange of CO_2 in both directions between the atmosphere and the ocean. The net flux into (or out of) the ocean is driven by the atmospheric partial pressure of CO_2 and the equilibrium partial pressure of CO_2 in the surface water. The third and longest atmospheric lifetime is determined by the exchange of carbon between the surface and deeper layers of the ocean. This exchange is accomplished mainly through transport by water motion and is rather slow.

When the remaining mass of the gas at time *t* has been computed, the corresponding change in concentration, ΔC, expressed in ppmv, can be determined using the following expression:

$$\Delta C(t) = \left(\frac{m_{gas}(t)}{M_{gas}} \middle/ \frac{m_{atm}}{\overline{M}_{air}} \right) \times 10^6 \qquad (2.2)$$

where $m_{gas}(t)$ is the remaining mass of the gas, $\overline{M}_{air}$ is the mean molar mass of air, 28.96 g mol^{-1}, M_{gas} is the molar mass of the gas and m_{atm} is the mean mass of the atmosphere, 5.136×10^{18} kg (Peixoto & Oort, 1992.). Eq. 2.2 is only correct if the added mass of our gas is negligible in comparison with the total mass of the gas in the atmosphere. For the gases discussed in this report this does not pose a problem.

2.1.4 The Relationship between Greenhouse Gas Concentrations and Radiative Forcing

The equations coupling changes in greenhouse gas concentrations to radiative forcing are fairly straightforward. They are all simplifications mainly based on empirical studies and model studies. Only recently have enough high quality observations become available to make it possible to start assessing the correctness of the models. Many details in the underlying assumptions (such as methods of handling clouds, spectral overlap of gases and feedback mechanisms) are not handled in the same way by all scientists working in this field.

The following equations relating the atmospheric concentration of a specific greenhouse gas to radiative forcing are used by Shine et al. (1990) derived from Wigley (1987) and Hansen et al. (1988). The equations are accurate to about ±10% (Wigley, 1987).

To calculate the radiative forcing ΔF_C from concentration changes in carbon dioxide, CO_2, we use the expression

$$\Delta F_{CO_2} = 6.3 \ln\left(C_{CO_2} \middle/ C_{0_{CO_2}} \right) \qquad (2.3)$$

Here C is the concentration of CO_2 expressed in parts per million volume (ppmv) and $C_{0_{CO_2}}$ is the background concentration of CO_2 in the atmosphere. The expression is valid for C<1000 ppmv.

For methane, CH_4, the relationship between atmospheric concentration and radiative forcing can be written

$$\Delta F_{CH_4} = 0.036\left(\sqrt{C_{CH_4}} - \sqrt{C_{0_{CH_4}}}\right) - \left(f\left(C_{CH_4}, C_{0_{N_2O}}\right) - f\left(C_{0_{CH_4}}, C_{0_{N_2O}}\right)\right) \tag{2.4}$$

where C_{CH_4} is the atmospheric concentration of methane, $C_{0_{CH_4}}$ is the background concentration of methane in the atmosphere and $C_{0_{N_2O}}$ is the background concentration of nitrous oxide in the atmosphere. All concentrations are expressed in parts per billion volume (ppbv). The expression is valid for C<5 ppmv. Since the absorption spectra for CH_4 and N_2O are slightly overlapping, the function f is needed to take this into account

$$f(M, N) = 0.47\ln\left[1 + 2.01\times10^{-5}(MN)^{0.75} + 5.31\times10^{-15}M(MN)^{1.52}\right] \tag{2.5}$$

where M and N are trace gas concentrations expressed in ppbv.

The corresponding equation used to derive the radiative forcing due to nitrous oxide, N_2O, can be written

$$\Delta F_{N_2O} = 0.14\left(\sqrt{C_{N_2O}} - \sqrt{C_{0_{N_2O}}}\right) - \left(f\left(C_{0_{CH_4}}, C_{N_2O}\right) - f\left(C_{0_{CH_4}}, C_{0_{N_2O}}\right)\right) \tag{2.6}$$

where C_{N_2O} is the atmospheric concentration of nitrous oxide and the other terms indexed as above. All concentrations expressed in ppbv. The expression is valid for C<5 ppmv.

2.1.5 Defining the Swedish contribution to Global Radiative Forcing

The radiative forcing resulting from emissions of any of the greenhouse gases is determined by the increase in gas concentration in relation to the atmospheric background concentration of that specific gas (eq. 2.1-2.6). Hence, the choice of background concentration is critical for the resulting calculated radiative forcing. The atmospheric concentration of all greenhouse gases have increased markedly during the last centuries, e.g. for CO_2 from 280 ppm to 358 ppm from pre-industrial time until now (IPCC, 1995). When calculating the global radiative forcing, the choice of background concentration is obvious. The global radiative forcing is always calculated as the increase in atmospheric concentration related to the pre-industrial background concentration. The question is which background concentrations that should be used when calculating the radiative forcing emanating from the Swedish transport system. There are at least three different principles possible to apply, each one resulting in different calculated radiative forcing for the same emission scenario.

1) The increases in concentration can be related to the pre-industrial atmospheric concentration, that is before there were any transports powered by fossil fuels. In this case the radiative forcing represents what would have been the result if the emissions from the Swedish transport system had been the only ones that had taken place on Earth.

2) The increases in concentration can be related to the increasing atmospheric concentrations resulting from global emissions. One then calculates how much the Swedish transport system further increases the radiative forcing. With this approach, only the marginal effect of the Swedish emissions is calculated. It implies that the rest of the world is responsible for the increasing atmospheric concentrations of greenhouse gases and minimises the moral responsibility of Sweden in this matter. That is, Sweden is regarded as unable to influence the overall development of the global society and its' use of fossil fuels.

3) It is also possible to assume that every person on Earth is equally responsible for the global greenhouse gas emissions. This principle allows us to avoid the issue of background concentrations altogether. If every person on Earth were to emit the same amounts of greenhouse gases as a person in Sweden, the global greenhouse gas emissions would amount to some 3000 times the Swedish emissions. That is if the population of Sweden is 1/1000 of the global population and if the transport sector is responsible for 1/3 of the Swedish greenhouse gas emissions, as it presently is. In this way a scenario for global greenhouse gas emissions can be calculated from a scenario for Swedish transport emissions. From this global emission scenario, the global radiative forcing can be calculated as described above. The radiative forcing resulting from Swedish transport emissions is then defined as 1/3000 of the calculated global radiative forcing.

Principle 1 is the most straightforward way to calculate the forcing but gives higher radiative forcing values than the other two principles. This approach implies that Sweden has a large moral responsibility for the global situation concerning greenhouse gas emissions. If all countries in the world would calculate their national contribution to radiative forcing in this way, the sum of all national radiative forcings would be greater than the real global radiative forcing. The approach can be motivated if worst-case effects are to be studied.

Principle 2 will lead to a lower calculated contribution to the radiative forcing than if one would have followed the first principle. This follows from the fact that an increase of one ppbv of the concentration of a gas will have a greater effect on the radiative forcing if the atmospheric concentration of the gas is low, than if the concentration is high. If all countries in the world would calculate their national contribution to radiative forcing in this way, the sum of all national radiative forcings would be smaller than the real global radiative forcing.

Using principle 2 will lead to practical problems. To study future radiative forcing in this way one has to make assumptions about how global emissions and atmospheric concentrations will develop. The accuracy of the results will depend on the accuracy of the predicted global emission scenario and how the local emission scenarios are related to the global scenario.

Principle 3 is not dependent on a separate global emission scenario. It represents a viewpoint that Sweden is neither more, nor less responsible for the greenhouse gas emissions than any other country of the world. One may regard it as way of studying the question “what would be the consequences if the global development followed the Swedish path?”

We have used all three principles and made a comparison between the effects of the different approaches.

2.2 The Model

To be able to easily calculate the radiative forcing of a transport scenario and compare different scenarios, we constructed a computer model using the application Powersim. Model input data consist of present and future transport volumes, means of transport and their specific emissions of greenhouse gases. Past Swedish emissions of greenhouse gases, also necessary for the calculations, were estimated from data on global emissions (Watson et al., 1990). The model then uses the equations described in sections 2.1.3-2.1.4 to calculate the resulting radiative forcing from a given scenario. The basic structure of the model is shown in Figure 2.1, and the entire model with equations is found in appendix C. All the input data is stored on separate Excel spreadsheets. At the onset of a simulation, data is imported from these spreadsheets by the model.

For every time step, the emitted mass is calculated for each gas and is added to the pool of anthropogenic greenhouse gases in the atmosphere. The resulting rise in atmospheric concentration, determined by the total emissions during the simulated time period and the decaying rates, is computed. By using the equations in section 2.1, the radiative forcing, in W/m^2, can be calculated for each gas. We make a distinction between greenhouse gases present in the atmosphere as an effect of Swedish transports, defined as anthropogenic greenhouse gases, and the CO_2, N_2O and CH_4 existing in the atmosphere independent of Swedish activities. Finally, the sum of the specific radiative forcings gives us the total radiative forcing. Throughout the calculations we assume that the gases are immediately well mixed into the entire atmosphere. Local Swedish climatic effects are not considered.

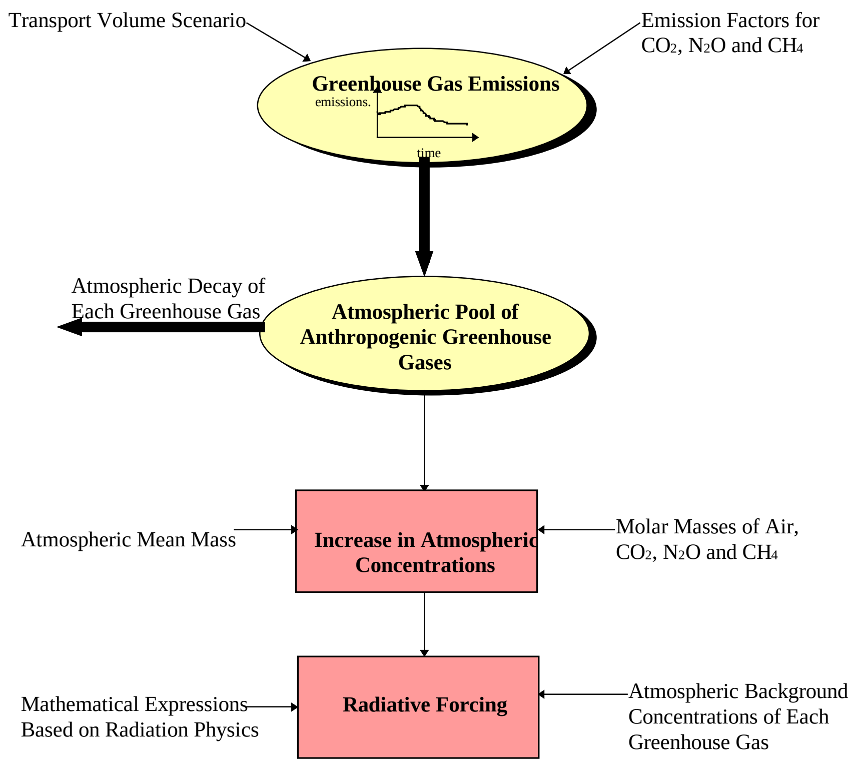

Figure 2.1 *Schematic view of the model used to calculate radiative forcing for future Swedish transport scenarios.*

2.3 Specifications of scenarios

Three different scenarios were studied with the model. Two of them are published in the final report of Kommunikationskommittén (KomKom) (in English: "Government Commission on Transport and Communications"), "Ny kurs i trafikpolitiken" (in English: "Heading for a New Transport policy") (Kommunikationskommittén, 1997), and the third scenario is based on the report "Färder i framtiden" (in English "Transport in a sustainable society - Sweden 2040") (Steen et al., 1997), published by Forskningsgruppen för Miljöstrategiska Studier (FMS) (in English: The Environmental Strategies Research Group). One of the scenarios in Kommunikationskommittén (1997) is a "Business as Usual" scenario derived for a future without changes in traffic policy and the other is a vision of the road towards a long-term sustainable transport system. The FMS-scenario starts from a vision of a sustainable Swedish transport system in 2040 and then presents a way to reach that vision.

2.3.1 The KomKom-scenarios

Both KomKom scenarios in this report are based on forecasts calculated by the Swedish Institute for Communication Analysis (SIKA). The forecasts are based on the future economy of Sweden, as predicted in government reports and official statistics, concerning population, employment, incomes and transports. The future transport volumes were calculated using different traffic models.

System conditions (Potucek & Östlund, 1993): Only domestic travels are included in passenger transports. Only domestic transports are included in air and water cargo transports. Domestic transports plus the part of international transports inside Sweden are included in cargo transports. Light-duty trucks in professional use are not included in the scenarios. Private light-duty trucks are included in cars.

Scenario A

Scenario A (Table 2.2 and 2.3) is based on the assumption that there will be no changes in traffic policy until 2020. This means that only infrastructure investments made before 1998 are included. The investments are assumed to be kept in good condition through necessary management and maintenance.

Table 2.2 *Total passenger transports in scenario A 1993 to 2020 (SIKA, 1997). Values in 10^9 passenger kilometres.*

Means of transport	***1993***	***1995***	***2005***	***2010***	***2020***
Car	*89.8*	*92.6*	*104.7*	*110.8*	*123.7*
Train	*5.7*	*6.1*	*8.0*	*9.0*	*9.5*
Aircraft	*2.9*	*2.8*	*3.6*	*4.0*	*4.3*
Bus	*9.2*	*9.5*	*10.0*	*10.2*	*10.4*
Number of passengers:					
Car (pass/car)	*1.52*	*1.52*	*1.52*	*1.52*	*1.52*
Bus (pass/bus)	*12.0*	*12.0*	*12.4*	*12.6*	*13.0*

Table 2.3 *Total cargo transports in scenario A 1993 to 2020 (SIKA, 1997). Values in 10^9 tonne kilometres.*

Means of transport	***1993***	***1997***	***2005***	***2010***	***2020***
Truck	*29.0*	*28.5*	*32.0*	*34.6*	*37.2*
Train	*19.7*	*21.1*	*23.5*	*25.2*	*27.0*
Ship	*25.2*	*24.4*	*29.1*	*32.5*	*34.9*
Ferry, trucks	*0.8*	*0.7*	*0.92*	*1.1*	*1.1*
Ferry, train	*0.2*	*0.1*	*0.2*	*0.2*	*0.2*
Average transport volume:					
Truck (tonnes/truck)	*12.6*	*13.1*	*13.1*	*13.1*	*13.1*

Scenario B

In Kommunikationskommittén (1997), a vision of what a future long-term sustainable transport system may look like is presented. The authors then propose a new traffic policy they believe will realise that vision. The environmental quality objective is that "the transport system shall contribute towards a good habitat and shall be adapted to what human health and nature can tolerate. Conservation of natural resources shall be promoted." Concerning the climatic impact of the future transport system, intermediate and long-term objectives for the emissions of carbon dioxide have been quantified (Table 2.4) according to the final report of the "MaTs"-project

(MaTs, 1996) ("MaTs" stands for a Swedish co-operation project, "Environmentally benign transport system"). MaTs suggests that the long-term objective should be reached in 2050. The long-term objective is based on a consequence analysis of one of IPCC:s scenarios for future CO_2 emissions, made by the Stockholm Environment Institute, SEI. In the IPCC scenario studied, the atmospheric CO_2-concentration stabilises at the double pre-industrial level during the first decades of the 22nd century. Emissions of other greenhouse gases (N_2O and CH_4) are assumed to be reduced at the same rate as the CO_2-emissions. Scenario B is displayed in Table 2.5 and 2.6.

Table 2.4 *Suggested intermediate and long-term objectives for reductions in CO_2-emissions from the Swedish transport system (MaTs, 1996).*

Year	***Reduction in CO_2-emissions***
1990 (Base year)	*0%*
2020 (Intermediate objective)	*-15%*
2050 (Long-term objective)	*-60%*

Table 2.5 *Total passenger transports in scenario B 1993 to 2020 (SIKA, 1997). Values in 10^9 passenger kilometres.*

Means of transport	***1993***	***1995***	***2005***	***2010***	***2020***
Car	*89.8*	*92.6*	*101.2*	*106.8*	*114.4*
Train	*5.7*	*6.1*	*8.6*	*9.8*	*10.5*
Aircraft	*2.9*	*2.8*	*3.2*	*3.5*	*3.6*
Bus	*9.2*	*9.5*	*10.1*	*10.4*	*10.8*
Number of passengers:					
Car (pass/car)	*1.52*	*1.52*	*1.52*	*1.52*	*1.52*
Bus (pass/bus)	*12.0*	*12.0*	*12.4*	*12.6*	*13.0*

Table 2.6 *Total cargo transports in scenario B 1993 to 2020 (SIKA, 1997). Values in 10^9 tonne kilometres.*

Means of transport	***1993***	***1997***	***2005***	***2010***	***2020***
Truck	*29.0*	*28.5*	*30.9*	*32.7*	*35.1*
Train	*19.7*	*21.1*	*24.8*	*27.4*	*29.5*
Ship	*25.2*	*24.4*	*29.1*	*32.5*	*34.9*
Ferry, trucks	*0.8*	*0.7*	*0.90*	*1.0*	*1.1*
Ferry, train	*0.2*	*0.1*	*0.18*	*0.2*	*0.2*
Average transport volume:					
Truck (tonnes/truck)	*12.6*	*13.1*	*13.1*	*13.1*	*13.1*

2.3.2 The FMS-scenario, scenario C

The FMS-scenario was developed using backcasting-methodology (Steen et al, 1997) which gives a different approach compared to how the KomKom-scenarios were developed. The objective of a backcasting scenario is not to present *likely* scenarios, but *possible* future scenarios. One aims at a vision, a picture of the future, which really will solve a specific problem, in this case the negative climatic impact from the transport system. Once the goal and time scale are set, the study concerns requirements important to reaching that goal.

The FMS-report presents a future Swedish transport system that would be compatible with sustainable development. The authors define sustainable development as: the effects of human activities shall be limited to what the nature can withstand in the long run, resources shall be preserved for the needs of future generations and the consumption of resources shall be globally equally divided (per capita). They have chosen 2040 as the year when their vision is to be realised (Table 2.7 and 2.8).

FMS makes the assessment that energy consumption is the most critical factor in reaching a sustainable transport system. The reason for this is primarily the emissions of carbon dioxide from fossil fuels. Their scenario is based on the amount of energy that would be available for the Swedish transport system in a sustainable future where energy consumption is globally equally divided. The calculation of the allowed amount of energy was based on the assumption that Sweden will have 1/1000 of the global population in 2040. This resulted in that the transport system has to reduce its energy consumption to 1/3 of today’s levels to reach sustainability. Energy supply in this scenario is based almost entirely on renewable resources like e. g. hydropower, solar energy and biofuels.

System conditions (Steen et al., 1997): All travels performed by people resident in Sweden are included in passenger transports. This means that e.g. their international travels by air also are included. Only domestic transports are included in road and rail cargo transports. Water cargo transports include both domestic transports and import.

Table 2.7 *Total passenger transports in scenario C 1995 to 2040 (Steen et al, 1997). Values in 10^9 passenger kilometres.*

Means of transport	*1995*	*2040*
Car	*85*	*36*
Electric car	*0*	*20*
Ferry	*4*	*3*
Pleasure boats (TWh)	*0.8*	*0.8*
Train	*9*	*23*
Aircraft	*20*	*12*
Bus	*9*	*22*

Table 2.8 *Total cargo transports in scenario C 1995 to 2040 (Steen et al, 1997). Values in 10^9 tonne kilometres.*

Means of transport	*1995*	*2040*
Truck	*33*	*15*
Train	*19*	*22*
Ship	*100*	*55*
Ferry	*4*	*2*

2.4 Input Data and Underlying Assumptions

2.4.1 Emission Factors

Together with the predicted transport volumes, the emission factors determine how much of a gas will be emitted into the atmosphere in the future. Thus they are very important for the future radiative forcing. There are many uncertainties associated with almost every emission factor used in this report, especially concerning how the emission factors will change with time. We have used several sources of information (see Appendix A), since there is no work covering all the gases and all means of transport treated in this report. The emission factors for CO_2 and CH_4 seem reliable whereas corresponding data for N_2O have a much larger range of uncertainty. An example is the N_2O emission factor for gasoline powered cars where Cooper et al., (1992), report values from the literature ranging from 2 to 520 mg/vehiclekm. The emission factors for each gas, mean of transport and year together with references and comments are given in Appendix A. In cases where available data have been contradictory, uncertain or incomplete, we have made best estimates based on our own general knowledge.

2.4.2 Transport volumes

The transport volumes given in section 2.3 were used together with the emission factors to produce input emission data to the model. As the specifications of the scenarios only provided transport volumes for a few specific years, linear interpolation was used to produce continuos time series of transport volumes. For scenario C we also had to estimate a change from fossil fuels to renewable ones (Appendix B). The CO_2-emissions from the original scenarios are displayed in Figure 2.2.

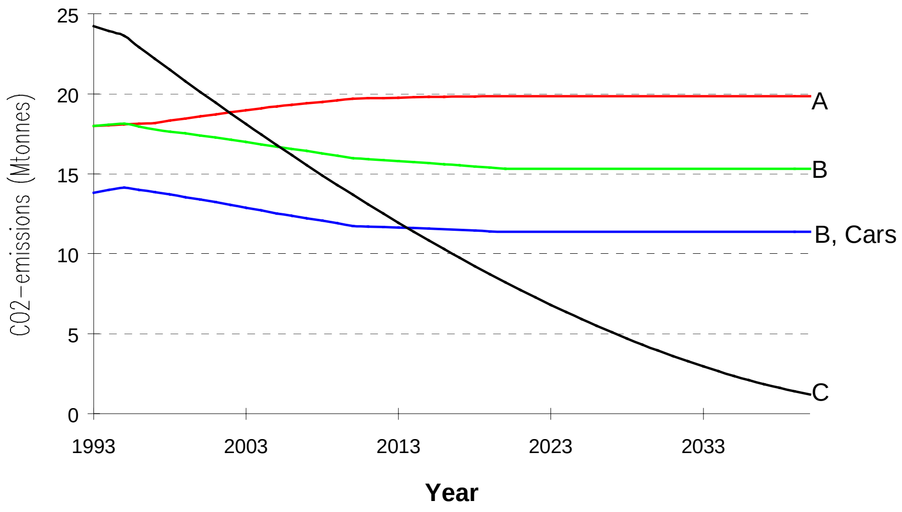

Figure 2.2 CO_2-emissions for original scenarios.
A: The comparison scenario.
B: The scenario suggested by KomKom
C: The FMS-scenario.

Our intention was to study long-term climatic effects of different future transport systems, so we therefore set the simulation limit to the year 2300. Since the scenarios were only specified until 2020 and 2040 we had to make extrapolations until 2300. The following extrapolations of corresponding scenarios were made (Figure 2.3):

- **A.** The emissions after 2020 were kept constant at the same level as in 2020.
- **B1.** The emissions after 2020 were kept constant at the same level as in 2020.
- **B2.** The emissions after 2020 were gradually reduced until 2050, reaching 40% of 1990 emissions in 2050. After 2050, the emissions were kept constant at the same level as in 2050.
- **B3.** The emissions after 2020 were gradually reduced until 2050, reaching 40% of 1990 emissions in 2050. After 2050, the emissions were gradually reduced until 2200, reaching the level corresponding to the IPCC S550-scenario (see section 2.4.3) in 2200 and thereafter following the IPCC S550-scenario.
- **C.** The emissions after 2040 were kept constant at the same level as in 2040.

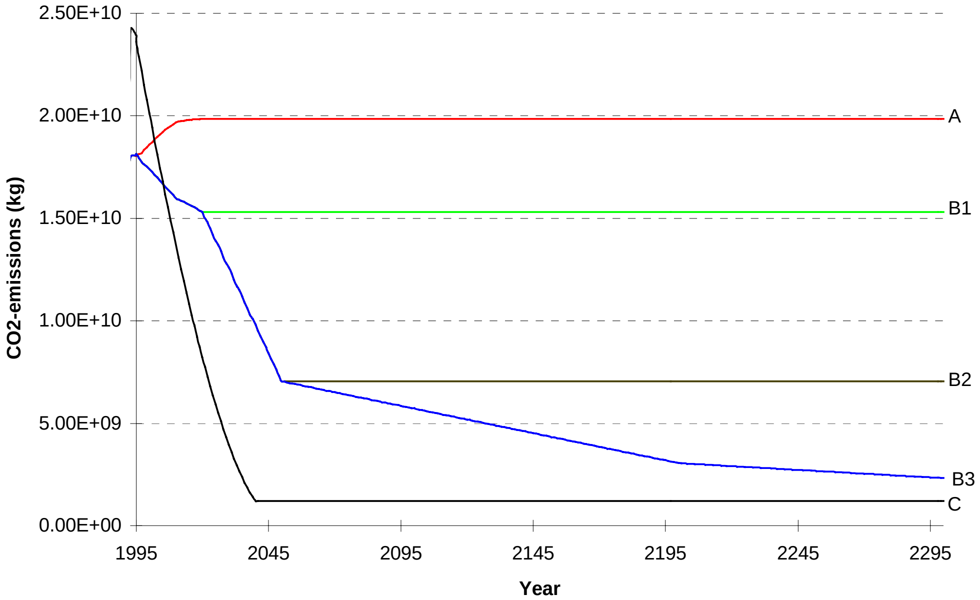

Figure 2.3 *CO_2-emissions for different scenarios.*
A: The comparison scenario with constant CO2-emissions after 2020 at the 2020 level.
B1: The scenario suggested by KomKom with constant CO2-emissions after 2020 at the 2020 level.
B2: Same as B1, but with 60% emission reduction until 2050, thereafter constant emissions.
B3: Same as B2, but with emissions corresponding to the IPCC S550-scenario after 2200.
C: The fms-scenario

2.4.3 What is a Sustainable Transport System?

In order to be able to put the radiative forcing resulting from our simulations in a global perspective, we defined a sustainable level of radiative forcing. The definition was based on a consequence analysis of future atmospheric greenhouse gas concentrations, performed by the Stockholm Environment Institute (SEI) (Rijsberman & Swart, 1990). SEI defined an atmospheric concentration of 400 - 560 ppm CO_2-equivalents as an upper limit beyond which the risks of grave damage to ecosystems, and of non-linear responses, are expected to increase rapidly. That limit corresponds well to the IPCC S550-scenario (Schimel et al., 1995) (Figure 2.4 and 2.5), stabilising the atmospheric CO_2-concentration at 550 ppm in the beginning of the 22nd century. With this as a starting point, we defined a sustainable radiative forcing and corresponding CO_2-emissions for future Swedish transport systems. The sustainable radiative forcing was defined as 1/3000 of the stabilised global forcing resulting from the S550-scenario, based on the assumptions that Sweden will have 1/1000 of the global population in 2050 (SCB, 1994 and UN, 1996). Furthermore, we assume that the transport system will be responsible for 1/3 of the Swedish CO_2-emissions in the future, as it is today (Sveriges andra nationalrapport om klimatförändringar, 1997).

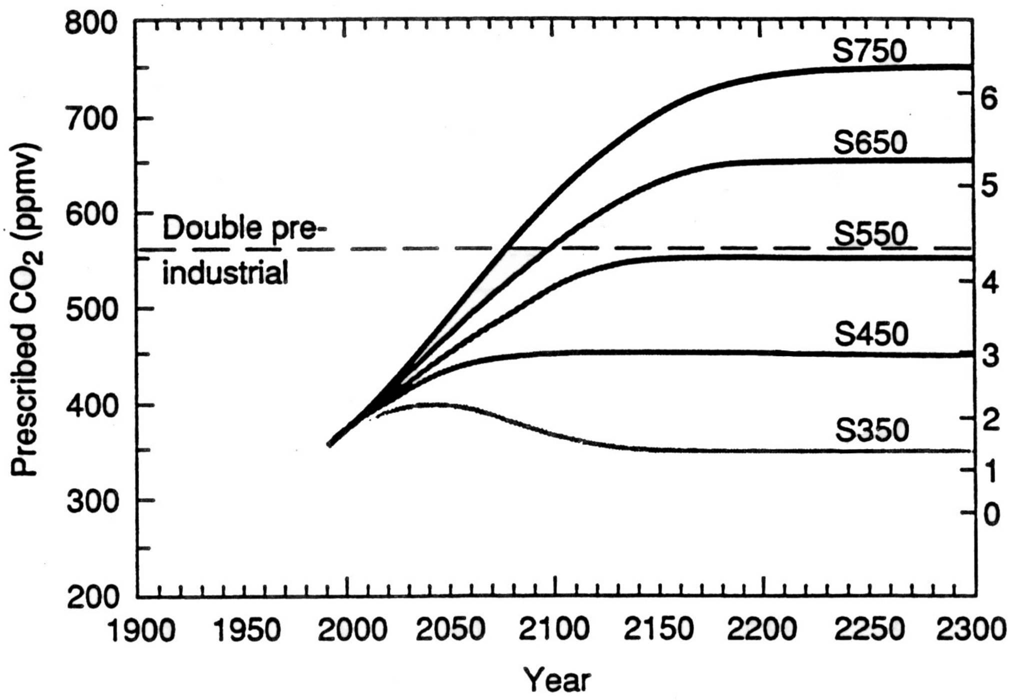

Figure 2.4 *Profiles of atmospheric CO2-concentration leading to stabilisation at 350, 450, 550, 650 and 750 ppmv. The radiative forcing resulting from the increase in CO_2 relative to pre-industrial level is marked on the right hand axis. Note the non-linear nature of the relationship between CO_2 concentration change and radiative forcing (IPCC 1994).*

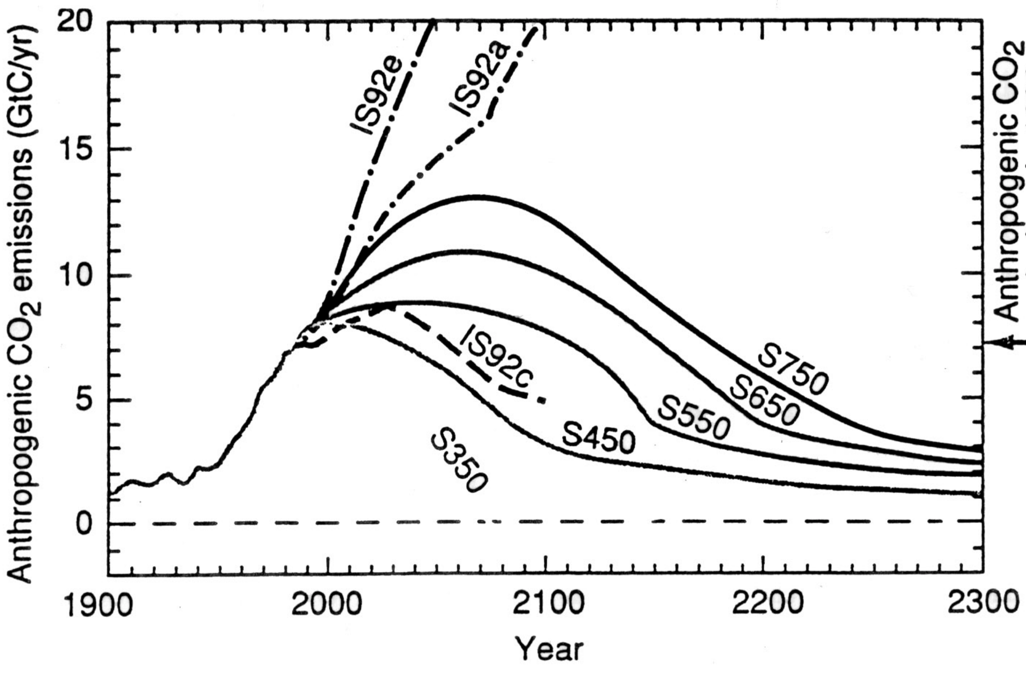

Figure 2.5 *Anthropogenic CO_2-emissions leading to stabilisation at concentrations of 350, 450, 550, 650 and 750 ppmv following the profiles shown in Figure 2.4 The negative emissions for stabilisation at 350 ppmv are an artefact of the particular concentration profile imposed (IPCC ,1994).*

3. Results

3.1 The relative importance of CO_2, CH_4 and N_2O

The contribution of CH_4 and N_2O emissions from Swedish transports to the increase in radiative forcing showed to be very small in relation to the CO_2-emissions in all scenarios (exemplified in Figure 3.1 for scenario A). As a consequence of this, all the following results are based on CO_2-emissions only.

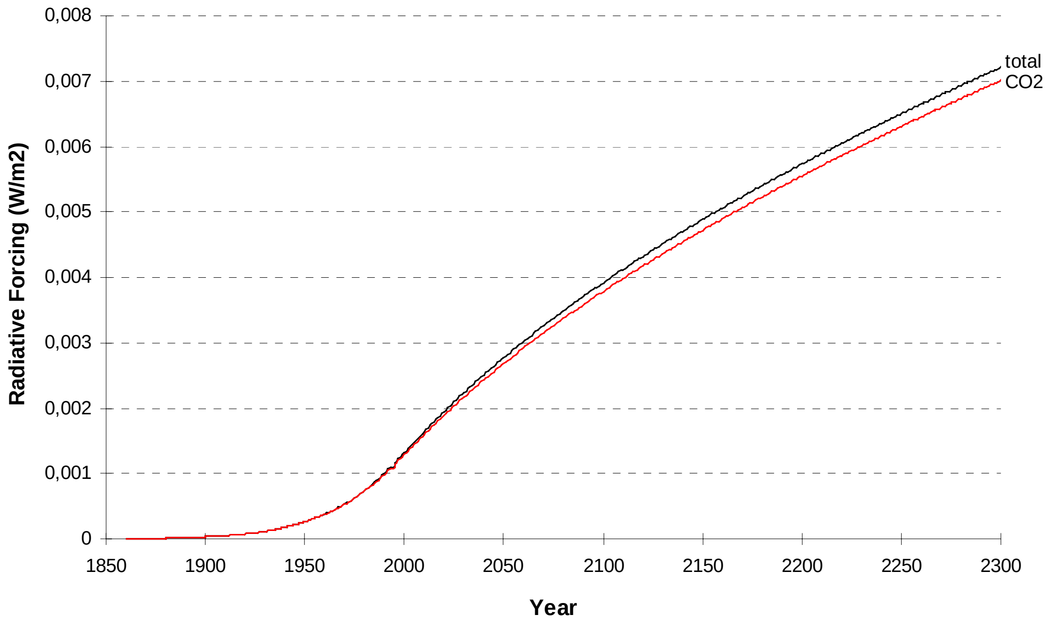

Figure 3.1 *Total radiative forcing and radiative forcing calculated for CO_2-emissions only. The comparison scenario, A, was used with constant greenhouse gas emissions after 2020 at the 2020 level. Pre-industrial background concentrations.*

3.2 Radiative Forcing when using Pre-Industrial Background CO_2-Concentration

If the pre-industrial CO_2-concentration is used as background concentration, all emission scenarios, except scenario C, will in the long run result in a forcing greater than what we have defined as sustainable (see section 2.4.3.), (Figure 3.2). Scenario C will give a forcing that first rises above the sustainable level, but then rather rapidly decreases and stabilises at an acceptable level. If no changes in transport policy are assumed to take place (scenario A), the radiative forcing will continue to increase dramatically. This is also the case if the goals of KomKom for 2020 are achieved, followed by constant emissions at the 2020 level (scenario B1). Note that scenario B2, which fulfils the long-term goals of KomKom, will give increasing radiative forcing even after the goals have been reached. The CO_2-emissions have to be reduced according to scenario B3 to reach a stabilisation of the radiative forcing. The emission reductions, compared to emissions in 1990, in scenario B3 corresponds to an 83% reduction until 2200 and 87% until 2300.

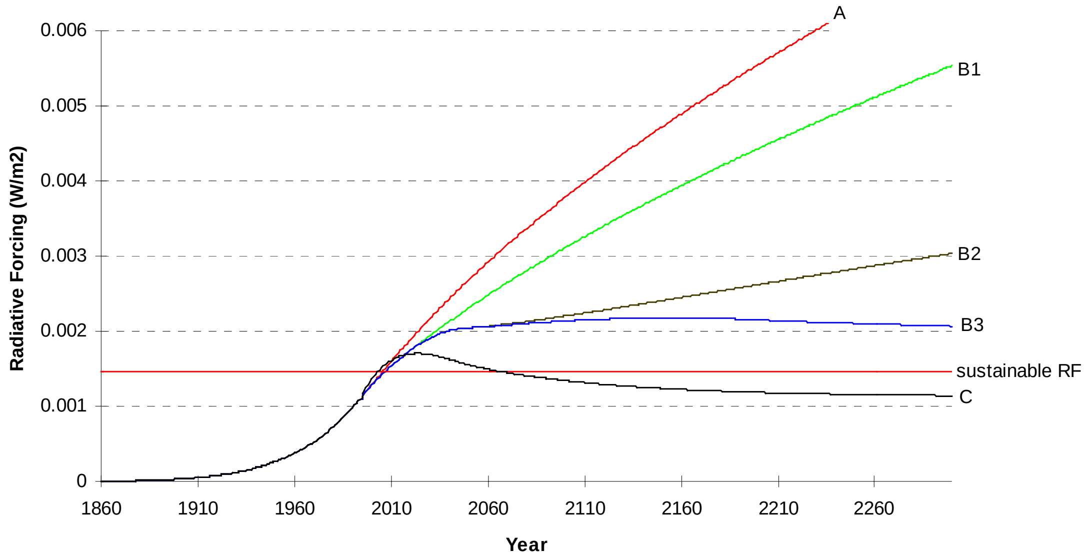

Figure 3.2 *Radiative forcing from CO_2-emissions for the different scenarios. Pre-industrial background CO_2-concentration (285 ppmv).*
A: The comparison scenario with constant CO_2-emissions after 2020 at the 2020 level.
B1: The scenario suggested by KomKom with constant CO_2-emissions after 2020 at the 2020 level.
B2: Same as B1, but with 60% emission reduction until 2050, thereafter constant emissions.
B3: Same as B2, but with the same emissions as allowed by the IPCC S550-scenario after 2200.
C: The fms-scenario.

3.3 Radiative Forcing when using Increasing Background CO_2-Concentration

When we calculated the radiative forcing with increasing background CO_2-concentrations according to the IPCC S550-scenario, all scenarios except A and B1 gave sustainable radiative forcing (Figure 3.3). The tendencies of the radiative forcing are the same as in Figure 3.2 but the final radiative forcing in Figure 3.3 are half of the final radiative forcing in Figure 3.2. Scenario B2 gives increasing radiative forcing also with increasing background concentration, and the radiative forcing exceeds the sustainable level at the end of the simulated time period.

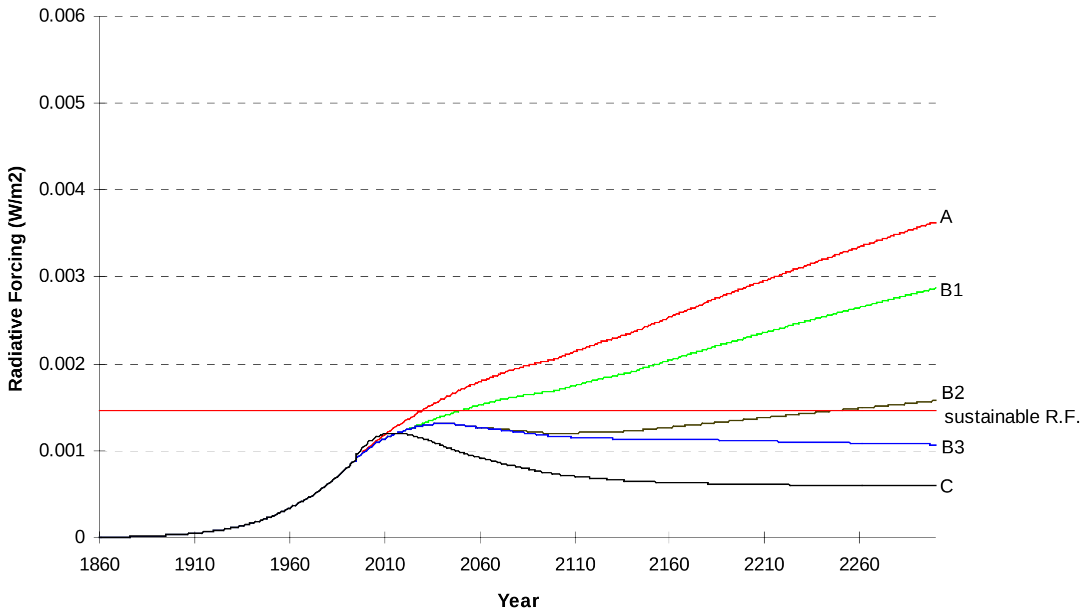

Figure 3.3 Radiative forcing from CO_2-emissions for different scenarios. Increasing background concentration according to the IPCC S550-scenario.
A: The comparison scenario with constant CO_2-emissions after 2020 at the 2020 level.
B1: The scenario suggested by KomKom with constant CO_2-emissions after 2020 at the 2020 level.
B2: Same as B1, but with 60% emission reduction until 2050, thereafter constant emissions.
B3: Same as B2, but with the same emissions as allowed by the IPCC S550-scenario after 2200.
C: The fms-scenario.

3.4 Radiative Forcing when assuming Equal Global Responsibilities

When calculating the radiative forcing according to principle 3 (as described in section 2.1.4), the radiative forcing comes to lie in between the results displayed in Figure 3.2 and 3.3 (Figure 3.4). Scenarios B3 and C give sustainable radiative forcings, while scenarios A, B1 and B2 do not give radiative forcings within the sustainability level.

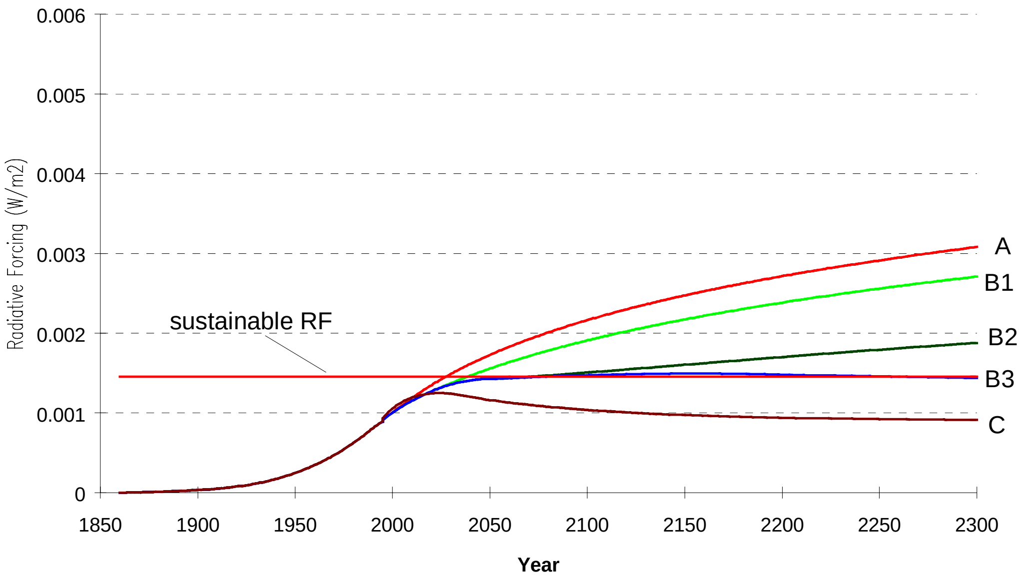

Figure 3.4 *Radiative forcing from CO_2-emissions for different scenarios. Every person on Earth is assumed to be equally responsible for the CO_2-emissions (principle 3).*
A: The comparison scenario with constant CO_2-emissions after 2020 at the 2020 level.
B1: The scenario suggested by KomKom with constant CO_2-emissions after 2020 at the 2020 level.
B2: Same as B1, but with 60% emission reduction until 2050, thereafter constant emissions.
B3: Same as B2, but with the same emissions as allowed by the IPCC S550-scenario after 2200.
C: The fms-scenario.

3.5 Uncertainties in N_2O-Emissions

In Figure 3.1 we showed that N_2O and CH_4 contributed very little to the total forcing, but since the range for N_2O-emission factors were so great (see section 2.4.1.), we also studied the forcing that would be the result of scenario B3 if N_2O-emission factors were ten times higher. The results show that N_2O then would contribute with about 20% to the total forcing in 2050 with constant pre-industrial background concentrations (Figure 3.5), and would then definitely not be negligible in comparison with CO_2.

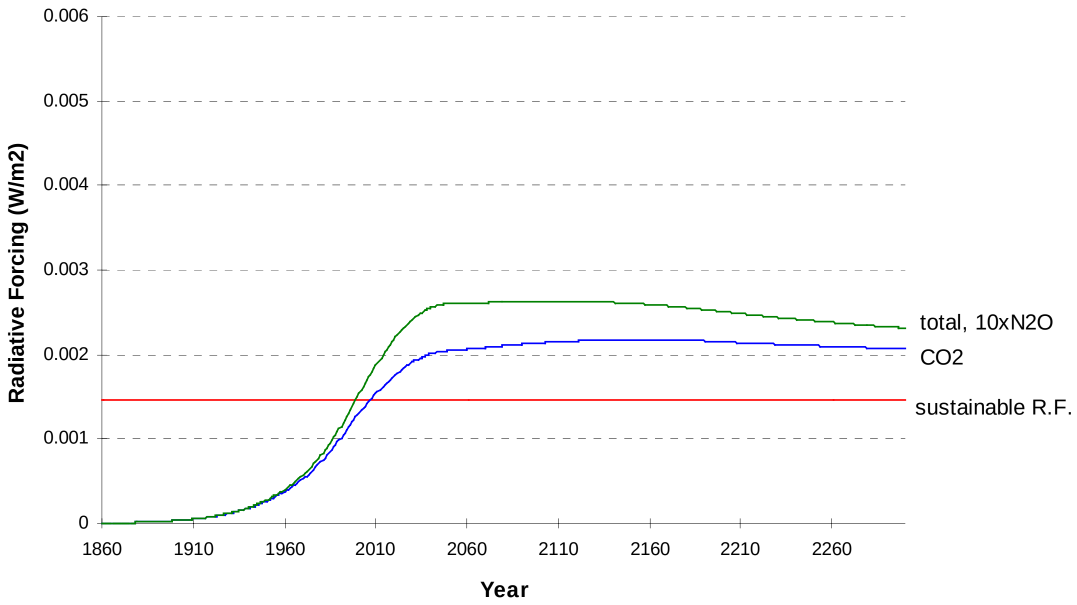

Figure 3.5 *Radiative forcing for scenario B3. Radiative forcing due to CO_2-emissions and total radiative forcing with ten times the default N_2O-emission factors. N_2O-emissions are reduced proportional to CO_2-emissions. Pre-industrial background concentrations.*

4. Discussion

4.1 Climatic Impact

All our results show that at present the radiative forcing emanating from the Swedish transport sector is rising rapidly. If the development continues as in the comparison scenario, where no changes in traffic policy are assumed, the Swedish contribution to the enhancement of the greenhouse effect will increase significantly over the next century. Note that this is the case even though in our simulations the emissions do not increase after 2020. If the global development follows the same path as outlined in the Swedish comparison scenario, major changes in the climate of the Earth seem likely.

The B1 scenario, implying a 15% decrease in CO_2 emissions by 2020 compared to the levels of 1990, does also show alarming results. The radiative forcing resulting from the scenario is more than twice the sustainable even if one tries to marginalise the Swedish contribution to the global emissions by using the most forgiving way of defining the background concentrations of greenhouse gases.

Even if the long-term goal of KomKom, a 60% reduction in greenhouse gas emissions, is achieved, the radiative forcing will still be unacceptable according to principles 1 and 3. The radiative forcing will also continue to increase. To reach acceptable levels even greater reductions are required.

In scenario B3, the emissions continue to decrease even after the long-term goal of KomKom have been reached. In such a scenario, the radiative forcing does no longer increase after 2100. If we use principle 3 in the calculations, the stable level of radiative forcing will be the same as the sustainable radiative forcing since scenario B3 coincides with what is defined as sustainable emissions in section 2.4.3.

It is not surprising that scenario C, developed by FMS, results in radiative forcing well below the sustainable level. The starting point of their work is to present a sustainable transport system. Their main objective is to show ways of realising this goal, something we have not discussed at all in this report.

It is difficult to predict how much the atmospheric concentrations of greenhouse gases can rise without seriously changing the climate of the Earth. What the exact consequences will be for a given scenario is even harder to predict. Lack of knowledge of possible future feedback mechanisms such as changes in cloud cover and changes in biomass uptake of greenhouse gases add further to the uncertainties concerning our future climate. Consequently, it is impossible to give an exact and indisputable definition of what is a sustainable human impact on the atmospheric system. However, considering the precautionary principle and what the effects might be if we exceed the limits of nature in this case, our definition of what is a sustainable radiative forcing, is, if anything, daring.

Of course, it might be possible that the transports should be allowed to have a larger share of the total greenhouse gas emissions in the future than they have today. Mobility of people and goods may be given a higher priority than what our assumptions reflect. In such a scenario, transports could be allowed higher emissions than our defined sustainability level. This illustrates the heart of the whole issue of global warming: we have to choose what we want to use the resources of the world for. If we want to use a larger share of the available resources for transports than we do today, that is possible of course, as long as we are willing to take the consequences concerning other sectors of society. Even so, there is little doubt that transports today consume more fossil fuels than what is sustainable in a long-term perspective. What priority one chooses to give transports should, and will be, discussed in the future. Such a discussion is, however, beyond the scope of this study and would not alter the main results and conclusions in this report.

As of today, the debate concerning greenhouse gas emissions has mainly been focused on CO_2. Our results do not show that N_2O or CH_4 will have a significant impact on the future radiative forcing due to Swedish transports. For N_2O the reason is the relatively low emission levels. For CH_4, it is also due to the short atmospheric lifetime of the gas. It is important to note, though, that the data on emission factors for N_2O are unsatisfactory and in many cases contradictory. If the default values we have used prove to be too low, which is not out of the question, the significance of N_2O can be considerably larger than what our results imply. Hence it is important to obtain more reliable data on the emissions of N_2O. We can thus reject our hypothesis that CH_4 contribute more to the enhancement of the greenhouse effect due to transports than previously believed. It also seems unlikely that N_2O emissions from transports will seriously affect the enhancement of the greenhouse effect in the future, but we cannot reject our hypothesis in this matter on the grounds of data available today.

The three principles of calculating the Swedish contribution to the global radiative forcing presented in this report represents different views on what moral responsibility Swedish transports should be given in a global perspective. As a consequence, the choice of principle is partly a political decision.

If principle 1 or 2 is used, the results of the radiative forcing calculations depend greatly on the background concentration. The final radiative forcing resulting from principle 2 is about half of the radiative forcing resulting from principle 1. That corresponds to a doubling of the background CO_2-concentration according to Table 2.2. When comparing different scenarios with each other, this does not pose a problem. The relative climatic impact of different scenarios is not affected by the choice. However, when comparing the results, in absolute figures, with the sustainable forcing, a more complex situation arises. Scenario B3 for example, leads to a radiative forcing high above the sustainable level using principle 1, but gives an acceptable radiative forcing using principle 2. Unfortunately, it is not possible to say that one of the principles gives more correct results than another.

The third principle of calculating the Swedish contribution to the global radiative forcing provides a way around the problem with the choice of background concentration. By studying what would be the consequences if the global development followed the Swedish path we can concentrate on the question if the Swedish transport system is sustainable or not in a global perspective. We believe this to be the central matter of interest, and principle 3 to be the most relevant approach to the problem. Hence we can conclude that reductions according to scenario B3 are necessary if we want to achieve a transport system that is sustainable in a long-term perspective, assuming equal global responsibilities concerning greenhouse gas emissions.

The methodology used in this study has both advantages and short-comings. It is best used in long-term, strategic studies, and may provide answers to questions like: What will the result be, 200 years ahead, if we reduce emissions by 60% in 40 years? What will happen if it takes 60 years instead? The method is not as fit for tactical studies, like "Is it better to put efforts in replacing 5% of gasoline cars with methanol cars, than replacing 10% of truck transports with train transports?". Since this latter type of study has to be more detailed concerning characteristics for the different means of transportation the studied period of time must be shorter.

4.2 Uncertainties

There are many uncertainties associated with climate predictions in general. Since we base our studies on the theory of radiative forcing and climate change, all the uncertainties connected to that field of science will apply to our work as well. The most important factor for our results and conclusions is probably the difficulty to predict feedback mechanisms in the climate system. However, a thorough uncertainty analysis of the theory of radiative forcing and climate change is beyond the scope of this study.

In addition to the uncertainties connected with the theory of climate change, there are other uncertainties associated with the methods used in this study. We use possible scenarios of the transport system to study long-term processes and use long time scales in our simulations. It is of course extremely difficult to predict what our transport systems will look like 300 years ahead, let alone say how large the emissions of greenhouse gases will be then. As a consequence, the exact figures of future greenhouse emissions and the resulting radiative forcing presented in this report should not be the main focus of interest for the reader. Instead, the results should be used to investigate the general direction of the development and what measures are needed to achieve a sustainable transport system.

4.3 Is a Sustainable Transport System Possible to Achieve?

It is interesting to view our results in the light of the general debate surrounding transport policy. There are many different opinions on how large reductions in greenhouse gas emissions the Swedish transport sector needs to undertake and how the reductions should be realised. The differences in opinions become particularly clear in the debate between government authorities and various interest groups. The debate easily becomes infected since the different parties look at transports in different ways. For example, the measures suggested by KomKom have been heavily criticised for the negative effects the measures might have on welfare and employment. Many of the bodies that have considered KomKom's proposal do not think it is worth risking jobs to reach the environmental goals set by KomKom (Svenska vägföreningen, 1997).

Because of the strong interests connected to the transport sector and the emotions often involved in the debate surrounding it, it seems to be very difficult to reach an agreement on how emissions can be reduced to the extent that is necessary. Conventional strategies for reducing emissions, e.g. regulations and taxes, give because of this only marginal effects compared to what is needed.

The results show that very large emission reductions are necessary to reach a level of radiative forcing acceptable in a long-term perspective. The transport system is responsible for a large part of the total Swedish greenhouse gas emissions, and passenger cars are currently responsible for almost 80% of the emissions from transports (Figure 1.1). Consequently, there is much to gain in reducing the car emissions. This can be achieved partly by introducing new fuels based on renewable resources. In our opinion though, what is really needed is not just a program for making our cars less harmful to the environment. What we need is a new vision of what our future transport systems should look like. Today, traffic jams, accidents and pollution are natural parts of everyday life in many cities of the world. These things considered, we firmly believe that a vision of an effective, long-term sustainable transport system suited to people's needs and preferences must include new infrastructure solutions and not just cleaner cars.

Generally we believe that the backcasting methodology is more suitable than conventional methods when one works with long-term scenarios. In such scenarios, the development of the factors affecting the results is hard to predict. Furthermore, it is often difficult to anticipate and see the possibilities in the future. Conventional methods start with the current situation and look at ways of changing it with the means of today. As a consequence, they do not provide as wide a spectrum of possible changes as the backcasting methodology does. Furthermore, the solutions offered by conventional methods are often apprehended as negative since they are based on the idea that people should change their way of living without changing their preferences. This often means that people will have to reduce an activity they perceive as positive, e.g. driving their car. The backcasting methodology, in contrast, starts by asking the question "What do we want and what are our needs?" and goes on to ask "How can we realise these goals?". This means that it is easier to have a positive approach to the problem and it will be easier to come across with a message to realise the goals set by people's preferences. In our opinion, the question of how our future transport systems should be constructed is an excellent opportunity to use the backcasting methodology.

5. Conclusions

The future transport policy suggested by KomKom will not lead to a long-term sustainable transport system. The climatic impact of the suggested scenario will be larger than what is sustainable. The transport system presented by FMS will be sustainable.

The climatic impact of the transport system is dominated by CO_2-emissions. The climatic impact of N_2O and CH_4-emissions seems to be minor compared to CO_2-emissions. However, data on N_2O-emission factors are incomplete.

The definition of background greenhouse gas concentrations is partly a political choice and affects the calculated radiative forcing markedly.

6. Acknowledgements

There are many persons who deserve to be mentioned and thanked for their support and cheerfulness, and for helping us through hard times and periods of grief and sorrow. Because of the limited space on this sheet, we can´t mention them all. We would, though, like to mention a few persons who have meant more to us than anyone else. First of all we would like to thank guru-of-atmospheric-science-conqueror-of-mountains-and-our-spiritual-leader Prof. Lasse for always being there for us. Without You this project had never been possible. Lars-Christer and Allan, it may seem impossible that all the wisdom on Earth can be found in two single persons, but by getting to know you, we have found out that this actually is true. Sade, Sting and Bo, you have supplied a bottomless well to get inspiration from. Last, but definitely not least; Göran, thanks a lot for the hurtses!

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APPENDIX A, Emission factors

Table 6.1 *CO_2 emission factors, passenger transports. Scenarios A and B.*

	1993	1996	2005	2010	2020	References & Comments
Car Scen. A (g/vkm)	234	230	216	209	193	SIKA,1997
Car Scen. B (g/vkm)	234	232	188	167	151	SIKA,1997
Bus (g/vkm)	988	910	884	850.2	767	SIKA,1997
Train (g/passkm)	2.5	2.5	2.5	2.5	2.5	Andersson, 1994
Air (g/passkm)	190	190	190	190	143	SIKA,1997

Table 6.2 *CO_2 emission factors, cargo transports. Scenarios A and B.*

	1993	1996	2005	2010	2020	References & Comments
Truck (g/vkm)	936	910	910	858	767	SIKA,1997
Rail (g/tkm)	5.9	5.9	2.95	2.02	1.08	SIKA,1997
Truckferry (g/tkm)	62	62	59	57.5	56	SIKA,1997
Railferry (g/tkm)	290	290	280	270	260	SIKA,1997
Ship (g/tkm)	18.3	18.3	16.8	16.5	16.1	SIKA, 1997

Tale 6.3 *N_2O emission factors, passenger transports. Scenarios A and B..*

	1993	1996	2005	2010	2020	References & Comments
Car Scenario A (g/vkm)	0.028	0.035	0.044	0.044	0.041	IPCC, 1997. N_2O emissions assumed to be proportional to fuel consumption. Only fossil N_2O considered. Fraction of cars equipped with 3-way catalyst considered.
Car Scenario B (g/vkm)	0.028	0.033	0.038	0.027	0.032	Same as above
Bus (g/vkm)	0.030	0.028	0.027	0.026	0.023	Same as above
Train (g/passkm)	0.001	0.001	0.001	0.001	0.001	Lundgren, 1992 via data on energy consumption in Andersson, 1994.
Air (g/passkm)	0.014	0.014	0.014	0.014	0.014	Derived from Luftfartsverket, 1995 and IPCC, 1997.

Table 6.4 *N_2O emission factors, cargo transports. Scenarios A and B.*

	1993	1996	2005	2010	2020	References & Comments
Truck (g/vkm)	0.030	0.029	0.029	0.028	0.025	IPCC, 1997. N_2O emissions assumed to be proportional to fuel consumption. Only fossil N_2O considered.
Rail (g/tkm)	0.00042	0.00042	0.00042	0.00042	0.00042	Lundgren, 1992. Trains powered by fossil fuels not included.
Truckferry (g/tkm)	0.0017	0.0017	0.0016	0.0016	0.0015	Derived from IPCC, 1997. N_2O emission factors expected to decrease at the same rate as CO_2 emission factors. Only fossil N_2O included.
Railferry (g/tkm)	0.0079	0.0079	0.0076	0.0073	0.0071	Same as above
Ship (g/tkm)	0.00050	0.00050	0.00046	0.00045	0.00044	Same as above

Table 6.5 *CH_4 emission factors, passenger transports. Scenarios A and B.*

	1993	1996	2005	2010	2020	References & Comments
Car Scenario A (g/vkm)	0.045	0.036	0.021	0.019	0.016	IPCC, 1997. CH_4-emissions assumed to be proportional to fuel consumption. Only fossil CH_4 considered. Fraction of cars equipped with 3-way catalyst considered.
Car Scenario B (g/vkm)	0.045	0.032	0.018	0.015	0.013	Same as above
Bus (g/vkm)	0.060	0.055	0.054	0.052	0.047	IPCC, 1997. CH_4emissions assumed to be proportional to fuel consumption. Only fossil CH_4 considered.
Train (g/passkm)	0.00036	0.00036	0.00036	0.00036	0.00036	Lundgren, 1992 via data on energy consumption in Andersson, 1994
Air (g/passkm)	0.0048	0.0048	0.0048	0.0048	0.0048	Derived from Luftfartsverket, 1995 and IPCC, 1997.

Table 6.6 CH_4 *emission factors, cargo transports. Scenarios A and B.*

	1993	1996	2005	2010	2020	References & Comments
Truck (g/vkm)	0.060	0.059	0.058	0.055	0.049	IPCC, 1997. CH_4 emissions assumed to be proportional to fuel consumption.
Rail (g/tkm)	0.00014	0.00014	0.00014	0.00014	0.00014	Lundgren, 1992. Trains powered by fossil fuels not included.
Truckferry (g/tkm)	0.0042	0.0042	0.0040	0.0039	0.0038	Derived from IPCC, 1997. CH_4 emission factors expected to decrease at the same rate as CO_2 emission factors.
Railferry (g/tkm)	0.016	0.016	0.015	0.015	0.014	Same as above
Ship (g/tkm)	0.0017	0.0017	0.0016	0.0016	0.0015	Same as above

Table 6.7 CO_2 *emission factors, passenger transports. Scenario C.*

	1993	2020	2040	References & Comments
Car (g/MJ)	73.0	40.6	6.72	IPCC, 1997 (gasoline) and Blinge et al., 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel.
Electric Car (g/MJ)	5.83	5.83	5.83	Andersson, 1994.
Bus (g/MJ)	74	40.9	6.39	IPCC, 1997 (diesel) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel.
Ferry (g/MJ)	77.6	42.8	6.39	Same as above.
Pleasure boats (g/MJ)	74.0	40.9	6.39	Same as above.
Train (g/MJ)	5.83	5.83	5.83	Andersson, 1994.
Air (g/MJ)	72.8	60.7	51.0	Derived from Luftfartsverket, 1995 and IPCC, 1997. Based on an assumption of a 30% reduction in fuel consumption by 2040. This is the estimated potential of improvement as of today (Greene & Archer in Steen et al., 1997).

Table 6.8 *N_2O emission factors, passenger transports. Scenario C.*

	1993	2020	2040	References & Comments
Car (g/MJ)	0.011	0.010	0	IPCC, 1997 (gasoline) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel and fraction of cars equipped with 3-way catalysts.
Electric Car (g/MJ)	0.0024	0.0024	0.0024	Derived from Lundgren, 1992
Bus (g/MJ)	0.0030	0.0015	0	IPCC, 1997 (diesel) and Blinge, 199x (methanol). Emission factor dependent on the introduction of methanol as a fuel and fraction of cars equipped with 3-way catalysts.
Ferry (g/MJ)	0.0020	0.0010	0	Same as above.
Pleasure boats (g/MJ)	0.0020	0.0010	0	Same as above.
Train (g/MJ)	0.0024	0.0024	0.0024	Derived from Lundgren, 1992
Air (g/MJ)	0.0030	0.0024	0.0021	Derived from Luftfartsverket, 1995 and IPCC, 1997. Based on an assumption of a 30% reduction in fuel consumption by 2040. This is the estimated potential of improvement as of today (Greene & Archer in Steen et al., 1997).

Table 6.9 *CH_4 emission factors, passenger transports. Scenario C.*

	1993	2020	2040	References & Comments
Car (g/MJ)	0.019	0.0051	0.0031	IPCC, 1997 (gasoline) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel fuel and fraction of cars equipped with 3-way catalysts.
Electric Car (g/MJ)	0.00085	0.00085	0.00085	Derived from Lundgren, 1992
Bus (g/MJ)	0.0060	0.0037	0.0014	IPCC, 1997 (diesel) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel . See fig. 2.XXX
Ferry (g/MJ)	0.0060	0.0037	0.0014	Same as above.
Pleasure boats (g/MJ)	0.0050	0.0032	0.0014	Same as above.
Train (g/MJ)	0.00085	0.00085	0.00085	Derived from Lundgren, 1992
Air (g/MJ)	0.0020	0.0017	0.0014	Derived from Luftfartsverket, 1995 and IPCC, 1997. Based on an assumption of a 30% reduction in fuel consumption by 2040. This is the estimated potential of improvement as of today (Greene & Archer in Steen et al., 1997).

Table 6.10 *CO_2 emission factors, cargo transports. Scenario C.*

	1993	2020	2040	References & Comments
Truck (g/MJ)	74	40.9	6.39	IPCC, 1997 (diesel) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel.
Rail, cargo (g/MJ)	5.83	5.83	5.83	Andersson, 1994.
Ferry, cargo (g/MJ)	77.6	42.8	6.39	IPCC, 1997 (diesel) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel.
Ship (g/MJ)	77.6	42.8	6.39	IPCC, 1997 (diesel) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel.

Table 6.11 *N_2O emission factors, cargo transports. Scenario C.*

	1993	2020	2040	References & Comments
Truck (g/MJ)	0.0030	0.0015	0	IPCC, 1997 (diesel) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel.
Rail, cargo (g/MJ)	0.0024	0.0024	0.0024	Derived from Lundgren, 1992
Ferry, cargo (g/MJ)	0.0020	0.0011	0	IPCC, 1997 (diesel) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel.
Ship (g/MJ)	0.0020	0.0011	0	IPCC, 1997 (diesel) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel.

Table 6.12 *CH_4 emission factors, cargo transports. Scenario C.*

	1993	2020	2040	References & Comments
Truck (g/MJ)	0.0060	0.0037	0.0014	IPCC, 1997 (diesel) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel.
Rail, cargo (g/MJ)	0.00085	0.00085	0.00085	Derived from Lundgren, 1992
Ferry, cargo (g/MJ)	0.0060	0.0037	0.0014	IPCC, 1997 (diesel) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel.
Ship (g/MJ)	0.0060	0.0037	0.0014	IPCC, 1997 (diesel) and Blinge, 1997 (methanol). Emission factor dependent on the introduction of methanol as a fuel.

APPENDIX B, Miscellaneous underlying data

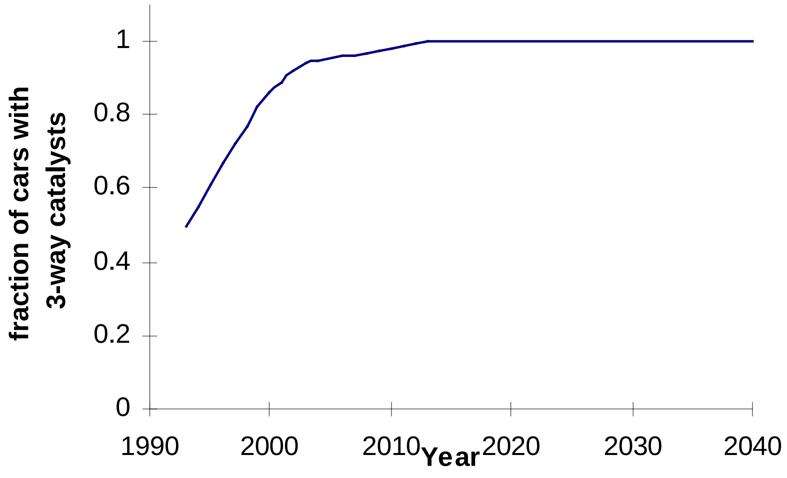

Figure 6.1 *Fraction of passenger cars with 3-way catalysts from 1990 to 2040 (Brandel & Sjödin,1995).*

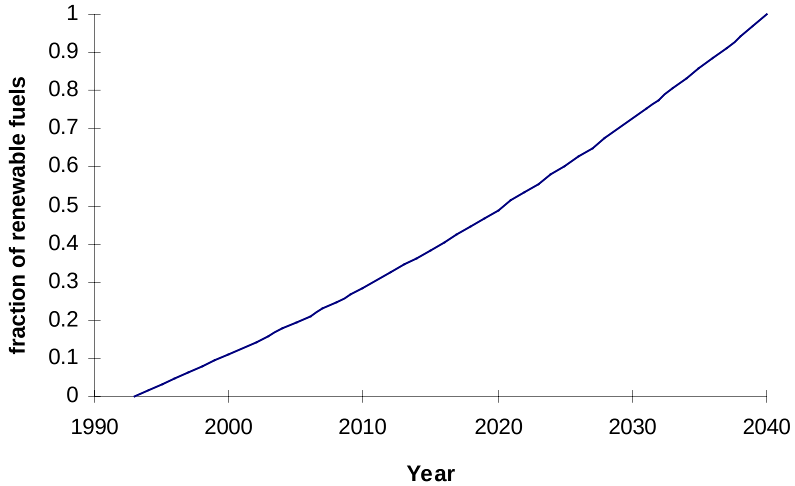

Figure 6.2 *Assumed development from use of fossile fuels towards use of renewable fuels.*

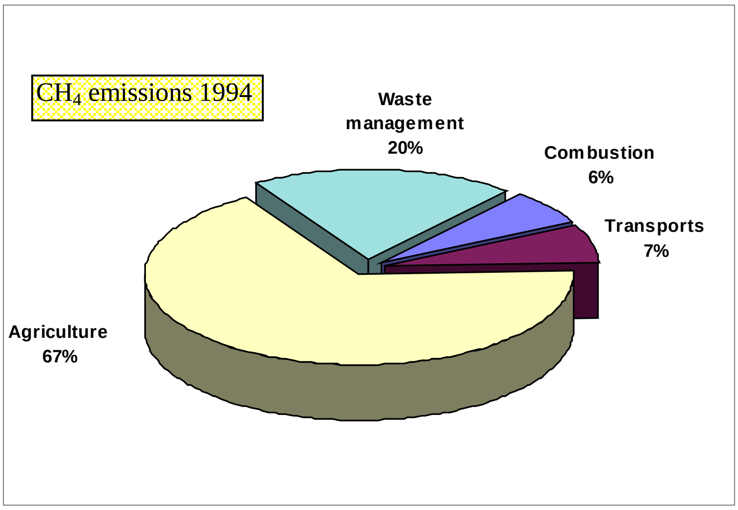

Figure 6.3 *Swedish emissions of methane, CH_4 in 1994 (Sveriges andra nationalrapport om klimatförändringar, Ds 1997:26, 1997)*

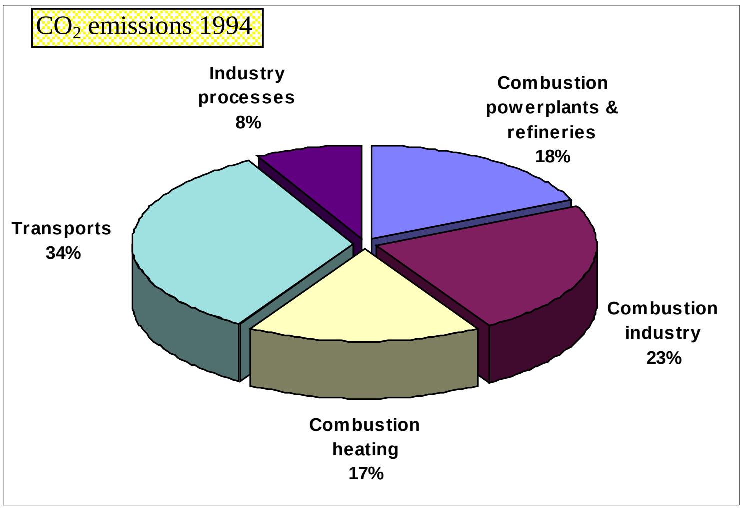

Figure 6.4 *Swedish emissions of carbon dioxide, CO_2, in 1994 (Sveriges andra nationalrapport om klimatförändringar, Ds 1997:26, 1997)*

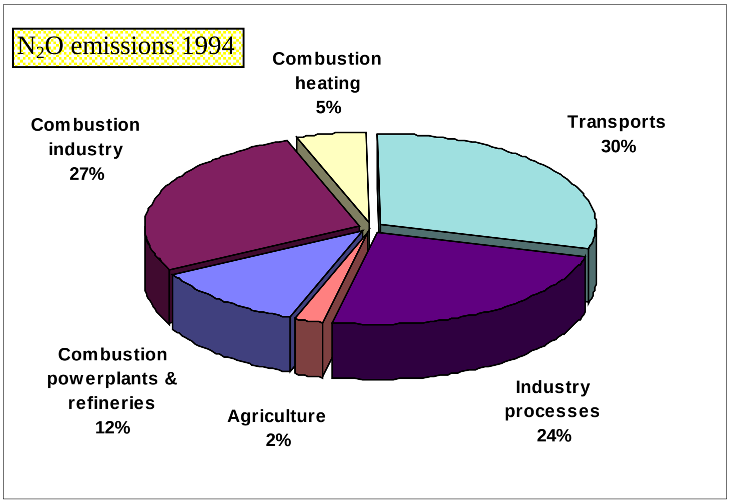

Figure 6.5 *Swedish emissions of nitrous oxide, N_2O, in 1994 (Sveriges andra nationalrapport om klimatförändringar, Ds 1997:26, 1997)*

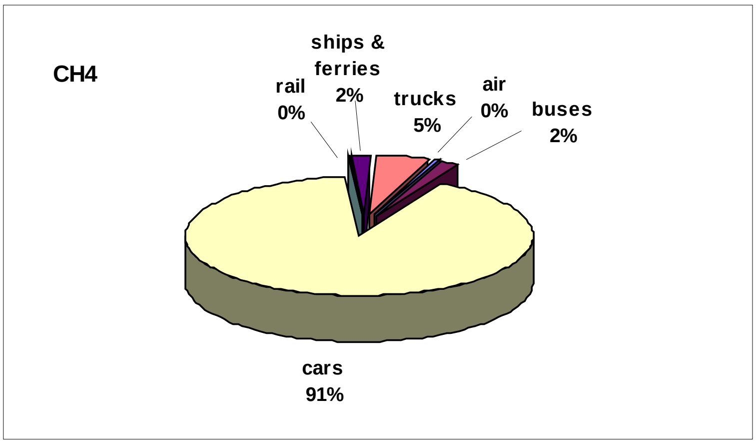

Figure 6.6 *Swedish emissions of methane from the transport sector in 1994. Based on the emission factors given in this report and the transport volumes given by KomKom.*

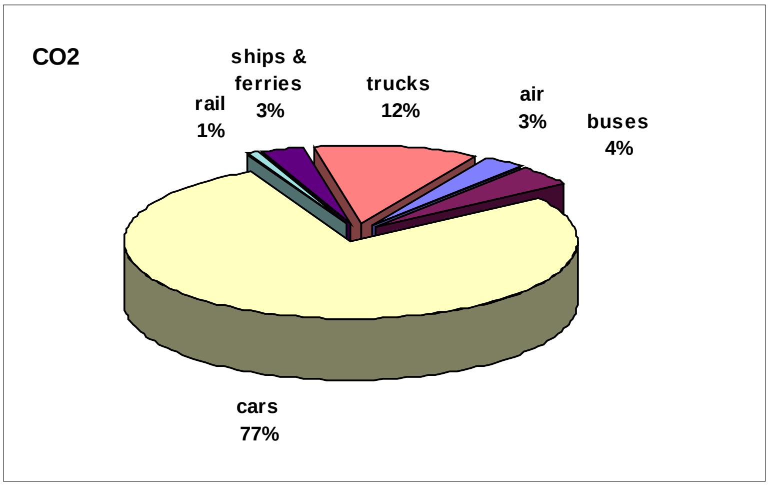

Figure 6.7 *Swedish emissions of carbon dioxide from the transport sector in 1994. Based on the emission factors given in this report and the transport volumes given by KomKom.*

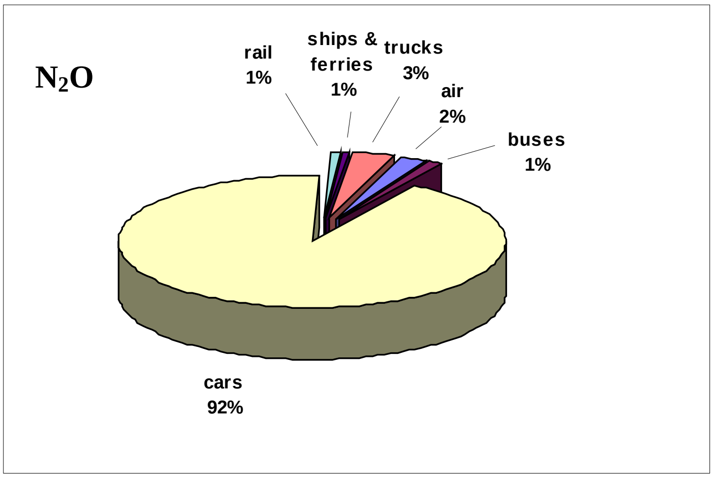

Figure 6.8 *Swedish emissions of nitrous oxide from the transport sector in 1994. Based on the emission factors given in this report and the transport volumes given by KomKom (1997).*

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