

Robèrt, Markus; R., Daniel Jonsson

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Assessment of Policy Instruments Toward a Sustainable Traffic System -A backcasting approach for Stockholm 2030

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Assessment of Policy Instruments Toward a Sustainable Traffic System

A backcasting approach for Stockholm 2030

Markus Robèrt and R.Daniel Jonsson

Department of Infrastructure
Royal Institute of Technology, Stockholm

Abstract

Our intention is to highlight the future requirements and expectations on new mobility management alternatives and other sustainability measures (e.g. telecommuting, car-sharing, road tolls, CO₂-taxes and renewable fuel systems) assisting the reaching of a long-term sustainability target of greenhouse gas emissions at the year 2030. We will employ the traffic forecasting model SAMPERS and the traffic assignment model EMME/2 in order to investigate the effect from specific changes to the traffic network of Stockholm 2030, e.g. the environmental and socioeconomic impact from reduced number of commute trips (from more frequent telecommuting), reduced car ownership (from increased car sharing and ride-matching), and new price structures and restrictions on private vehicle travel. In connection to this, we also quantify negative side effects (so-called rebound effects) coupled to efficiencies in the traffic network. We use a backcasting influenced appraisal framework in order to assess the impact from the specific policies in relation to the United Nation's (IPCC) requirements for a sustainable level of CO₂-emissions. The findings from this study point at the inevitable need for at least a 50% renewable fuel mix in the traffic system if reaching the target 2030. Single-handedly, travel demand measures are insufficient to accomplish the CO₂-emission target for 2030. Nevertheless, reducing traffic volumes by just a few percent might contribute to savings in emission costs, accident costs and aggregate travel time costs in the traffic system.

1. Introduction

In this study we investigate strategies consistent with Stockholm's target for greenhouse gas emissions 2030ⁱ. The intention is to develop feasible paths from today to the desired emission target. We use the traffic demand model SAMPERS and the traffic assignment model EMME/2 (for further references see Johansson (2001)ⁱⁱ and Beser and Algers (2001)ⁱⁱⁱ), by which we experiment on two alternative types of policy measures contributing to achieving the emission target: a) reduced traffic volumes from a hypothetical successful launch of mobility management services (car-sharing, ride-matching, telecommuting, meeting policies, videoconferencing, public transport) or specific travel demand measures (TDM) such as traffic tolls, car-free streets, increased fuel taxes, and free fare public transport, and b) increased share of renewable fuel vehicles and fuel efficiency regulations on private vehicles in the traffic system.

A central question we pose in this study is: how effective are mobility management services, in comparison to other types of sustainability measures, in reaching the target? To answer this question properly for the year 2030, where large uncertainties regarding e.g. fuel prices and technological development exist, we test alternative levels of TDM and compare it to hypothetical levels of reduced traffic volumes and car ownership in the region.

To incorporate the sustainability target for 2030 and how to reach this state in the future from the situation of today, we use a backcasting approach (Robinson, 1982)^{iv}, where forecasting is applied to derive concrete states and paths in the backcasting framework. Forecasting and backcasting are different approaches in the context of analysing complex systems. Forecasting on the one hand means to make statements regarding the future based on explicit or implicit assumptions from the present situation and model how changes affect future development. Backcasting on the other hand is a strategic problem-solving framework, searching the answer of *how* to reach specified outcomes in the future. The idea of synthesising forecasting into a backcasting framework is developed in other studies (for references see Robèrt (2003)^v, Höjer (1998)^{vi} and Höjer and Mattsson (2000)^{vii}).

The idea of a framework when dealing with sustainability has also been developed in the EU project PROSPECTS (May et. al., 2003)^{viii}, geared towards helping cities with guidance on how to use planning to tackle the issue of sustainability. One of the main points from PROSPECTS is that careful use of an appraisal framework is an essential part of the planning process. Planning styles may vary, but it is nonetheless always necessary to assess differences between alternative solutions.

In the evaluation of different sustainability paths derived in this study, we consider emission costs and accident costs coupled to the traffic flows. Litman (2004)^{ix} point out the necessity of including traffic safety and health aspects when evaluating various TDM and mobility management services. In this study we will assume a direct relationship between traffic volumes and accident costs (Lindberg, 2005)^x. According to Litman (2004), each percentage of mileage reduction in the traffic network might imply even a relatively larger saving in crash-costs since often more than one vehicle is involved in traffic accidents.

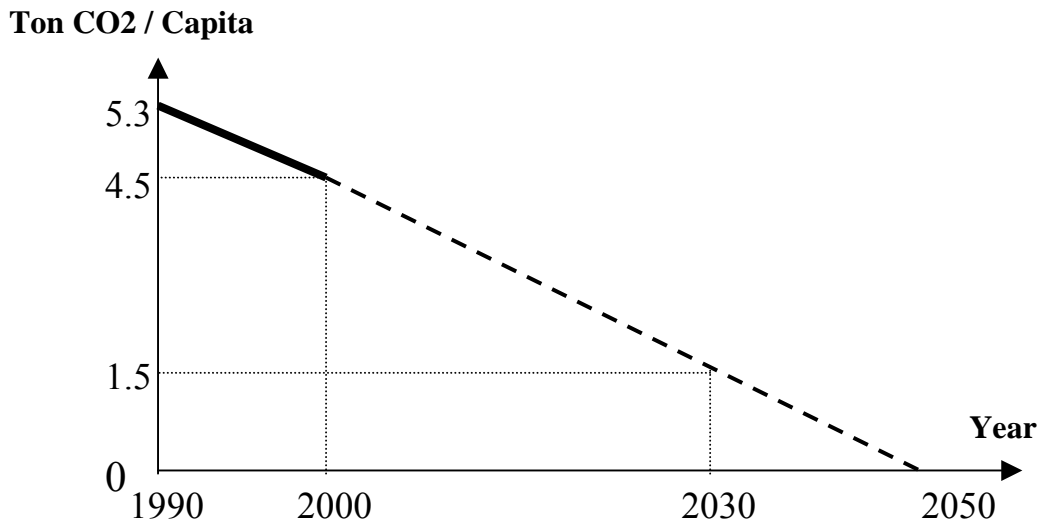


Figure 1. *Graphic construction of targets for Stockholm's action programme against greenhouse gas emissions. The emission target for 2030 and 2050 is based on an extrapolation of the CO₂-reduction rate between 1990 and 2000.*

The Stockholm action programme against greenhouse gas emissions

Stockholm reached the target of not increasing the level of greenhouse gas emissions from the year of 1990 (5.3 ton/capita) to the year 2000 (4.5 ton/capita). The intention is now to continue this positive development toward the United Nations recommendations for a stable level of CO₂ in the atmosphere (Stockholm action programme against greenhouse gas emissions, 2003). According to the UN Intergovernmental Panel on Climate Change (IPCC), this long-term target would be achieved if reducing emissions of greenhouse gases to 1.5 ton/capita. This would mean that the Stockholm inhabitants would have to reduce present levels of greenhouse gas emissions by 2/3 (about 70%) in average. This sustainable level of greenhouse gas emissions should be reached about the year of 2030 if extrapolating the emission reduction development between the levels of 1990 and 2000. This would still have an impact on climate change, but to an extent that would be possible for the society and the environment to adapt to. The vision is to continue this reduction rate till the year of 2050 –a situation when Stockholm would have got rid of all use of fossil fuels, i.e. an extrapolation of the reduction rate between 1990 and 2000 would result in zero emissions at the year of 2050 (see figure 1 above).

In section 2 the conceptual, backcasting influenced appraisal framework applied for this study is presented. In section 3 we present the results from the different types of target-oriented changes, consistent with target achievement 2030. Finally, a discussion and the conclusions make up sections 4 and 5 respectively.

2. Development of the framework

An appraisal framework of some kind is necessary in almost all planning settings. Let us say that the city officials are contemplating a change to the transport system. At a minimum the effects of the proposed change should be compared to what would happen when nothing is done. For that comparison to be useful there needs to be some structure to how the two outcomes are described. Ideally, there would be not only two but a range of alternatives to compare. In this section we will lay out a

framework influenced by backcasting techniques that facilitates comparisons of different strategies for attaining a sustainable transport system.

The term “backcasting” refers to a planning approach that departs from a vision of future success, followed by looking back and seeking strategies or “feasible paths” to get there by. According to Dreborg (1996)^{xi}, backcasting is particularly useful when:

- The problem studied is complex, affecting many sectors and levels of society;
- There is a need for a major change;
- Dominant trends are part of the problem;
- One of the reasons for the problem is externalities, i.e. problems that the market does not treat properly;
- The time perspective is long enough to allow for deliberate choices.

When developing backcasting paths toward a sustainable traffic system of Stockholm 2030, the idea is to make decision makers iteratively (or preferably democratically) sort out the most effective set of strategies in order to reach target fulfilment. How should the new mobility services, together with other TDM be implemented in reality according to factors such as economic feasibility, present traffic situation, public opinion, etc? By modelling the traffic system at large, pitfalls such as unexpected rebound effects and sub optimizations could be avoided.

Simon (1962) distinguishes two fundamentally different descriptions when constructing problem formulations in complex systems: *state descriptions* and *process descriptions*. Simon states: “The former characterize the world as sensed; they provide the criteria for identifying objects, often by modelling the objects themselves. The latter characterize the world as acted upon; they provide the means for producing or generating objects having the desired characteristics”. Simon (1962) extends his reasoning, claiming that these two descriptions are generally adopted in the context of problem oriented analysis of complex systems: “There is now a growing body of evidence that the activity called human problem solving is basically a form of means-end analysis that aims at discovering a process description of the path that leads to a desired goal”. Schoemaker (1993)^{xii} touches upon an adjacent matter when introducing the terminology of “snapshot scenarios” and “chain scenarios”. While the former represents an endpoint scenario (e.g. a desirable image of the future), the latter describes the sequence of events that led to that state. According to List (2004)^{xiii}, despite the fact that the chain scenarios are essential in the sense of forming strategic intermediate steps towards the long-term goal, still these scenarios are scarce in research literature so far.

Clear parallels can be drawn from Simon’s state and process descriptions to the concept of backcasting. While the former refers to any well-defined problem formulation, the latter is primarily used in the context of social planning and environmental research. In the backcasting framework, the desired target and the present situation correspond to Simon’s state descriptions, whereas the feasible paths leading between the desired target and the present situation correspond to the process descriptions.

By what method should the components of the traffic system be analyzed in order to find feasible ways to a more sustainable development? One approach would simply be to forecast the emission reductions from e.g. new mobility services, based

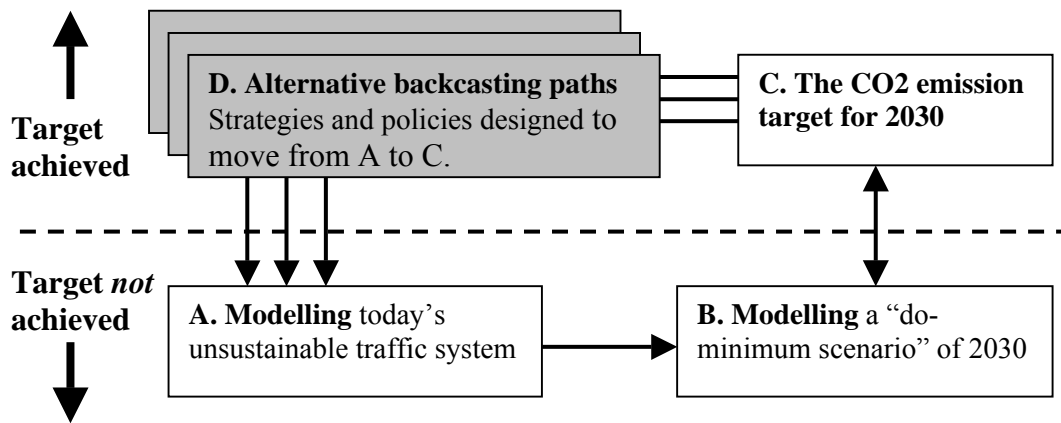



Figure 2. A structural backcasting framework. The state descriptions (A-C) and the backcasting paths (D) are treated separately in order to avoid aggregation of the analysis.

on market demand and present conditions, extrapolate the results and (most likely) find that the predictions do not match the CO₂ target for Stockholm 2030. The question of how the CO₂ target might be achieved would then not be fully explored, since this only gives us the gap between the desired target and the expected development. In addition, we have not touched upon the issue of what processes or measures that could bring the two situations closer.

A more blem-oriented approach for seeking the answer to our question would be to integrate three state descriptions (A→B→C) in the order presented in the backcasting framework in figure 2. Incorporating the target achievement (state description C) in the framework makes it possible to “count backwards” how to reach this state from the present situation (state description A). In state description C the ultimate requirements on the traffic system are modelled in relation to the “do-minimum scenario” (B). The alternative backcasting paths (D) represent various practical solutions, bridging the gap between the two state descriptions A and C.

State description A: Initially we investigate specific key parameters of the unsustainable traffic system of today, such as e.g. absolute traffic volumes, share of private car, public transport and goods transport, present greenhouse gas emission levels, fuel prices, CO₂-taxes, in vehicle time costs, emission costs and accident costs generated in the traffic system.

State description B: Here we carry out a traditional “do-minimum-forecast” of the traffic situation at the year 2030 if no specific target-oriented actions are taken. Here we incorporate socio economic aspects like predicted population growth, socio economic growth, expected modifications to the road network and more efficient fuel combustion standards.

State description C: The emission target is formulated by the Intergovernmental Panel of Climate Change (IPCC) as a CO₂-level per capita of 1.5 tons. For Stockholm this would correspond to about a 70% reduction of present greenhouse gas emissions per capita. Using state description B as a reference point, we model

the emission quantities needed to reach target fulfilment. To arrive at state description C, *above* the threshold line in figure 2, CO₂ –emissions from the traffic system must reach 0.35 ton/capita.

The three state descriptions presented in figure 2 constitute solid platforms in the backcasting framework. Each state is characterised by a range of *indicators*, describing the key elements of the planning objectives (e.g. traffic volumes, emissions and socio economic costs). Obviously, the emission target is necessary, whereas other indicators may be used to produce a richer picture of the alternative future states. The idea of modelling these state descriptions is to, as far as possible, “quantify what is quantifiable” with the intention of assessing the impact from each policy measure.

The backcasting paths D: The process descriptions, or backcasting paths, in figure 2, consist of concrete measures or strategies, consistent with the requirements for target achievement in state description C. When forming the backcasting paths we experiment with the assumptions regarding changes to state description B. The forecasting model is employed to assess the impact from the various policy measures implemented.

Since consequences and effects from integrating new mobility services into the traffic system are hard to assess, the backcasting paths including assumed levels of reduced traffic volumes are less strict and quantitatively exact. However, they provide guidance on hypothetical advantages linked to adoption of these services. This, in turn, could stimulate initiatives to develop and integrate these alternatives as part of a sustainable transport system. A motive for using a backcasting approach is that we decouple the state descriptions and the analysis of different alternative process descriptions (backcasting paths).

There are three prominent motives for developing a backcasting-influenced framework in this study: Firstly, it reduces the level of aggregation of the complex problem formulation. The reduced level of aggregation, allowing more strict derivation of the specific state descriptions, implies a higher level of stability to the total framework. The state descriptions serve as “solid ground” or “stable reference points”, between which the more uncertain backcasting paths could be drawn. Secondly, stakeholders (here, Stockholm municipality) could assess the effectiveness of different measures in relation to each other and sort out the most economically, socially and politically efficient path fulfilling the requirements for target achievement. In addition, there might be consequences on other aspects than CO₂-emissions, such as accidents or in vehicle time. Thirdly, if it is hard to determine the exact effect from mobility management services and TDM in practice, we could analyze the *relative* importance of the different measures, i.e. settle what changes posed on the traffic system has the *greatest* impact on target achievement, and what changes are of minor importance. From that information, decision makers could assess what practical measures leading to state description C should be prioritized over the other. The bottom line with this reasoning would be that we might have a clue of which *type* of practical measures should be prioritized over the other, even though the exact quantities are more difficult to assess.

We create a *set* of alternative backcasting paths leading to state description C. This resembles much of Robinson’s (2003)^{xiv} description of a “second generation of

backcasting”, where he suggests alternative scenarios in the backcasting framework, all in principle consistent with the long-term target but where none is prioritized to the other in advance. This is advisable since it allows decision makers and stakeholders to select the most feasible one according to existing circumstances (e.g. budget constraints, economic payback, public opinion, political climate, etc.). Gibs (1999)^{xv}, stress the importance of creating multiple scenarios in sustainable urban planning, since sustainable policy making always involves different partners and coalitions. Private companies, environmental groups, transport providers, local authorities, housing associations, technology manufacturers and investors all have a part in the planning process towards a desirable sustainable city (Guy and Marvin, 1999)^{xvi}.

The rationale for decoupling the analysis of the state descriptions and the process descriptions of the backcasting framework (see figure 2) is consistent with Robèrt (2003), using forecasting in order to select strategies for sustainable development. In state description C we set the ultimate principles for a sustainable level of traffic related greenhouse gases, according to e.g. absolute traffic volumes and proportion of renewable fuel vehicles in Stockholm 2030. By what means the mobility services and TDM could meet these conditions (selection of backcasting paths) corresponds to the derivation of the most efficient tools and how to best coordinate them for target fulfilment.

The framework is developed to assess the effectiveness of various policy measures, aiming at reaching a sustainable level of CO₂ emissions. First it is worth pointing out that this study does not intend to fully explore the political feasibility or economic efficiency of the policies, since we are mainly interested in different policies’ leverage with respect to the CO₂ target. Second, a natural extension to the present study would be to test various combinations of policy measures. However, introducing combinations increases the number of possible paths quickly. If we were to test all combinations of the eight tested travel demand measures (tables 8 - 11 in appendix) we would end up with 96 combinations. Presenting them in tabular form would not be useful, so it would become necessary to form some kind of ranking system. It is usually done by assigning weights to each indicator and then summing them up in an objective function (Minken et. al. 2003^{xvii}, Jonsson 2003^{xviii}). It is important to point out that the intention, when formulating an objective function, is not primarily to let the appraisal framework find the optimal solution, but to aid decision makers in their processing of large amounts of information. Consequently, such objective functions must be formulated with care, within a larger planning process, with involvement from decision makers and stakeholders.

Strategies for Stockholm

The traffic forecasting system SAMPERS is used to study how different policy measures can be used to get from today’s situation (state description A), to a sustainable future (state description C). The measures we study directly through SAMPERS fall into the following two categories:

Travel demand measures (TDM) include such things as:

- Increased fuel prices or mileage-based user charges, e.g. mileage based insurance systems (DeCorla-Souza and Whitehead, 2003)^{xix}.
- Free fare public transport

- Traffic tolls
- Car-free streets in the city centre

The second group of measures is centred on *fuel technology*, in particular:

- The effect of a renewable fuel goods transport system.
- The effect of a certain share of renewable fuels in private vehicles in Stockholm.
- Regulation on fuel-efficient vehicles (i.e. smart cars) in Stockholm, including the potential *rebound effect* from more efficient fuel consumption in vehicles. Here we derive the net effect from reduced emissions per vehicle in relation to a potential increase in vehicle use (from reduced fuel price/km).

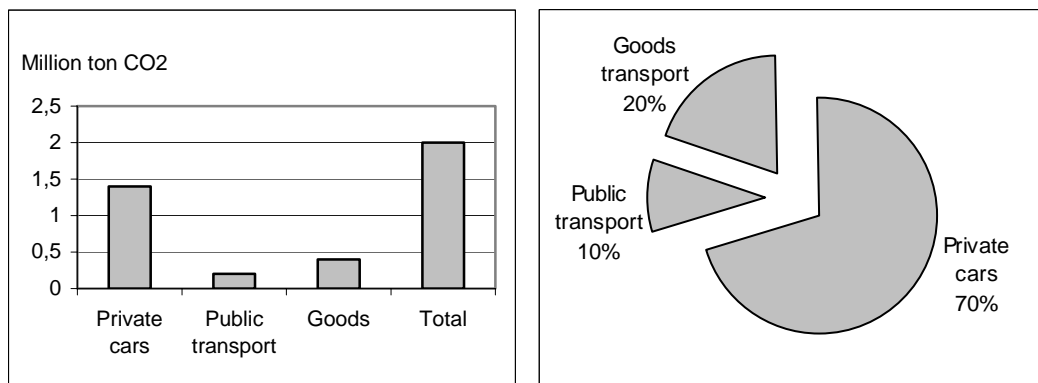
Increased share of renewable fuel vehicles will play a central role in the formulation of feasible backcasting paths. With a sufficiently high renewable fuel mix in the traffic system the target will always be reached. Thus, the renewable fuel mix required in each backcasting path, serves as an effectiveness measure of the other policies included in each specific backcasting path. The lower the required renewable fuel mix, the more effective is the specific policy measure tested. Most backcasting paths derived in this study include a renewable fuel mix of about 50-60% –a mix that we assume reasonable for 2030 (Droege, 2002^{xx}, Urry, 2004^{xxi}, Campbell and Laherrere, 1998^{xxii}). To make the emission target for 2030 sensible, we assume that the public transport system is entirely renewable fuel driven. Buses are assumed to be using fuel cell technology, and the electricity to rail traffic is produced from renewable sources of energy - a process that has already been set in motion in Stockholm.

It is not straightforward to quantify the exact adoption rate or effect from various combinations of mobility management services in the future. Instead we estimate the effect from specific *assumptions* regarding these services. Effects associated with increased future adoption of new mobility management alternatives are assessed indirectly. The intention is to give a qualitative argument on the potential impact a mobility management service can have on some key indicators of the system. We have experimented with four different potential impacts:

- The aggregate emission reduction from an X% reduction of total private vehicle trips in Stockholm, calculated on vehicle and emission standards in the traffic system of 2030.
- The emission impact from reducing the number of work commute trips and local business trips by X%.
- The emission effects from an X% reduced car ownership in Stockholm.
- Local effects from reducing commuting volumes by X% between Stockholm and the largest telecom business district in Sweden (Kista), caused by an assumed succesful implementation of company travel plans in the area (e.g. telecommuting programs at companies etc). In relation to this we will give a quantitative measure of the potential rebound effects caused by reduced travel times in the traffic network.

Different levels of X are tested to explore the possible range of impacts from mobility management services.

Figure 3. *The emission level of today, distributed at three transport sectors.*



In summary, we have developed a target-oriented framework, geared to assess the effectiveness of alternative policy measures (mobility management services and travel demand measures), on condition that Stockholm's target for greenhouse gas emissions is achieved. The results are presented in the next section. Bear in mind that the analysis would have to be enhanced with cost estimates and a more detailed view of where costs and benefits go, in order to answer questions on political or economic feasibility.

3. Results

We use the traffic forecasting model SAMPERS (for technical details see SIKA, (2001)^{xxiii} to generate the demand for each policy setting. The travel demand is assigned to a network with EMME/2. The effects from the transport system in terms of emissions and accidents are based on the flow on each individual road link. The effect model is presented in the appendix. This chapter presents the findings from the modelling work.

3.1 The present situation (State description A)

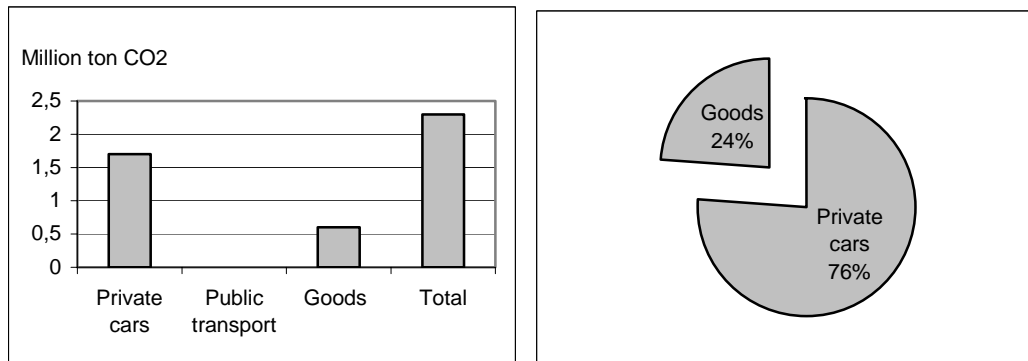
Figure 3 presents the proportions of CO₂ equivalents in Stockholm county at the present situation (state description A). Evidently, private car traffic corresponds to 70% of the slightly more than 2 million tons CO₂ equivalents emitted from the traffic system of Stockholm per year.

CO₂ equivalents from the public transport system are 0.2 million tons at present. This figure will be eliminated in all 2030 scenarios where we assume a renewable fuel driven public transport system. A 70% CO₂ reduction per capita corresponds to a CO₂-equivalent level of 0.35 tons per capita (Table 1 in the Appendix).

3.2 “Do-minimum” scenario of 2030 (State description B)

Figure 4 presents the proportions of CO₂ equivalents in the do-minimum scenario of 2030 (state description B). This is a prediction of the CO₂ equivalent level at 2030 if disregarding the emission target. In this scenario we assume that the public transport system is entirely renewable fuel driven.

Figure 4. The annual emission level in a “do-minimum scenario” of the year 2030. The public transport system is assumed using renewable fuels exclusively.



In state description B, private car kilometres and adherent accident costs has increased with 28% in comparison to state description A. This traffic increase is mainly due to the fact that we assume an economic growth of 2% per year (implying e.g. increased car ownership) and a population increase from 1.8 million today to 2.4 million until 2030 (Carle, 2000)^{xxiv}. Nevertheless, the CO₂-equivalent level is just 7% higher in 2030 than today because of the drastic renewable fuel assumption of the public transport system. In addition, we have assumed more effective combustion and emission standards in future vehicles, implying that emissions per unit of fuel are assumed to be lower in the 2030 prediction (Biding and Lindqvist, 2005). Evidently, because of the population increase, the per capita measure is lower in 2030 than today. However, the CO₂-equivalent level must be reduced with 63% to attain the emission target of 0.35 tons per capita (Table 2 in Appendix).

3.3 Backcasting paths to target achievement

This section presents feasible paths to the desired target of greenhouse gas emissions at the year 2030 (given in state description C, see Table 3-11 in Appendix). Each of the backcasting paths incorporates a certain level of renewable fuel in order to reach the target of 0.35 ton CO₂-equivalents per capita. We have chosen the levels of policy variables with consideration to the following two criteria: a) we aim at a renewable fuel mix close to 50% since we assume this is a fair assumption for technical feasibility of renewable fuel technology at the year of 2030, and b) we try to keep within the model's trusted range. Since the demand model is estimated on cross-sectional data, it is likely that the forecasts will become less reliable the further away from that state we go.

3.3.1 Implementation of new alternatives

In this section we experiment with changes to the traffic system that could be associated with a successful implementation of mobility management alternatives. We test the aggregate CO₂ reduction effect from reducing 10%, 20%, 30% of a) all private car trips, b) only commute- and local business trips, and c) specific levels of car-ownership. The difference in magnitude between a) and b) are small, revealing that work commute and local business trips (i.e. work related travel) are the far most important travel categories with private car. The impact from reducing car-ownership follows almost exactly the same pattern as reducing work-related travel. Still a renewable fuel mix in the range 51% to 61% is needed in these backcasting paths in order to reach target fulfilment of greenhouse gas emissions.

Yet, seen from an economic perspective, reducing private vehicle kilometres only to a marginal extent implied significant savings in accident costs and emission costs. Reducing all private vehicle trips by 10% corresponds to 750 million SEK savings of accident costs and 360 million SEK savings of emission costs, implying a total annual socioeconomic saving of 1.11 billion SEK. The corresponding figure from reducing work commute and local business trips only is 760 million in total. Only the most radical reduction level (30% of all private vehicle trips) would come close to the aim of a 50% share of renewable fuel mix. This would correspond to a total saving of accident- and emission costs of 3.25 billion SEK, a figure that is probably out of reach to achieve in reality but which shows the economic potential of reducing traffic volumes.

In addition to savings in emission and accident costs, one could expect potential savings from road users reductions in total in vehicle time costs. However, it is not straightforward to give a fair estimate of in vehicle timesavings from reduced traffic volumes since we do not have information of how the timesavings are used. Nevertheless, just to give a hint of the potential savings associated with reduced traffic volumes, we calculated the aggregate monetary in vehicle timesaving from the 10% reduction of work commute trips, using 120 SEK/hour for average hourly wage in Sweden (SIKA, 2002)^{xxv}. This would correspond to a monetary saving of 568 million SEK for Stockholm County.

To give a fair estimate of the potential rebound effect from reducing traffic volumes locally, we tested the effect from reducing work commute trips by 30% between Stockholm and Sweden's largest telecom-business district (a district potentially fulfilling the conditions for a high telecommuting frequency). The 30% reduction of work commute trips implied an average travel time reduction of about 1%. This in turn resulted in a rebound effect of 3%, i.e. 3% of the reduced vehicle kilometres are lost due to a latent private vehicle demand. Naturally, a 30% reduction of commute trips from Stockholm to this single destination implied just a marginal effect on the total road network of Stockholm (2% reduction).

3.3.2 Travel demand measures (TDM)

In this section we test the effect from changing the price structure between private car and public transport. As expected, the drastic increases of fuel price would have a significant impact on private vehicle travel. However, doubling fuel prices would still require a mix of renewable fuels of 58% in order to reach state description C. The most substantial impact per unit of price increase observed in this study would be to increase fuel costs from 0.8 SEK/km to 2 SEK/km. This would reduce CO₂ emissions by 21%, which would require a mix of renewable fuel vehicles of 53% in Stockholm County. However, only a marginal relative emission impact of just 6% is evident if increasing fuel price from 2 SEK/km to 3 SEK/km.

Somewhat surprisingly, free fare public transport did not cause a substantial impact on reduced private vehicle mileage and adherent CO₂ emissions. Making public transport free of charge implied just a 4% reduction of CO₂ emissions in comparison to state description B. The reason for this is that this policy mainly caused a shift from walking and cycling to public transport.

We tested the impact from implementing traffic tolls similarly to what is planned for Stockholm in January 2006. Our tolls would consist of a fee of 20 SEK at peak

hours and 10 SEK at off-peak hours for entering the Stockholm city centre by private car (a circle of radius 3 km). This would correspond to 0,5% of the total area of Stockholm county (6519 square kilometres). This would lead to a 9% reduction of CO₂-emissions and a 59% renewable fuel mix in order to reach the emission target.

We also tested the effect from enforcing a car-free inner city centre by closing down the most central streets in Stockholm from private vehicle traffic (an inner city centre of about 1km radius, corresponding to 0,05% of Stockholm county). This would lead to a 4% reduction of CO₂-emissions and a required renewable fuel mix of 61% in order to reach the emission target.

Finally, it would be technically possible to enforce fuel-regulations on private vehicles. Several cities (e.g. London and Paris) are considering introducing policies against “fuel-guzzlers” and subsidise “fuel-sippers”. In this study we test the effect from an average 30% and 50% fuel efficiency standard in private vehicles. As expected, this would have a considerable effect on prospects for target achievement. However, because of the improved fuel efficiency standard, car users get a reduced kilometre cost implying a clear increase in vehicle kilometres. For instance, we noticed that halving fuel consumption in private vehicles implies an adherent CO₂ - rebound effect of almost 10%, i.e. a tenth of the positive emission reducing effect is lost as a result of the price effect from a cheaper kilometre cost. In spite of this drastic fuel efficiency regulation, still a renewable fuel mix of 53% and 44% respectively is needed in order to reach the CO₂-reduction target.

4. Discussion

Evidently, the traffic system will be strongly dependent on renewable fuel systems in order to fulfil the requirements of a sustainable level of greenhouse gas emissions in state description C. All backcasting paths created in this study show that, in spite of the radical policy measures enforced, a renewable fuel mix of at least 50% is generally needed to accomplish the emission target. The findings in this study are in accordance with a sustainability scenario created by Stockholm municipality (1995)^{xxvi}. Also in that study, only the most radical scenarios, assuming positive expectations on technological developments of renewable fuel systems and environmental engagement met the IPCC- sustainability requirements.

It is hard to assess the future development and adoption rate of specific mobility management services. However, in this study we experiment with the macroscopic effect from hypothetical levels of reduced private car trips, commute trips and car-ownership –all associated with potential future adoption rates of mobility management services. The results indicate that on condition that mobility management services could bear it's own expenses in the long run, these services might fill a certain meaning since even modest reductions of traffic volumes contribute to savings in traffic related costs to the society. In addition, mobility management services might induce new travel patterns and in some cases even stimulate the development of renewable fuel systems (as seen in some car-sharing fleets and public transport systems today). However, economic feasibility, investment costs and practical implementation are left beyond the scope of this study. We focus on the potential effectiveness of the various mobility management services and TDM as tools for reaching the emission-target for 2030, and a few adherent positive side effects. Nevertheless, to make a complete cost benefit

analysis of the different policy alternatives, each of the positive economic side effects presented in this study must be weighted against investment costs and maintenance costs for both short and longer time frames.

Examples of mobility management services, hypothetically assisting the conditions in state description C are car-sharing, ride-matching, telecommuting, meeting policies, videoconferencing and public transport. The Swedish national road administration (SNRA, 2003)^{xxvii} conducted a national survey revealing that about 20% of Swedish households are interested in joining a car-sharing facility. SNRA (2003) further refer to a study by Muheim (1998)^{xxviii}, concluding that the potential for car-sharing in Switzerland is almost 10%, a figure that, according to SNRA (2003) could be used with caution even for Sweden. Regarding the potential CO₂ reduction, SNRA (2003) conclude that one CS-vehicle substitutes approximately 5 private cars and implies about 380 kg CO₂ reduction per car-sharing member (or 6600 tons CO₂ reduction per car-sharing vehicle and year).

Naturally, the potential for mobility management services is higher in a densely populated city like Stockholm than in Sweden in general. Robèrt (2005)^{xxix} conducted a stated preference survey in one of Stockholm's larger business districts (Nacka Strand) and identified potential win-win situations where both the employees and the employer would save travel expenses from an extended use of new mobility management alternatives. More than half of the respondents stated that they were willing to substitute present car- and taxi trips with mobility management services such as car-sharing and ride matching. The employees were also positively disposed toward more frequent telecommuting. Even though telecommuting was well implemented at the companies, a majority of the sample stated they were willing to telecommute even more than at present (Robèrt and Börjesson, 2005)^{xxx}. Arnfalk (2002)^{xxxi} refers to two alternative predictions of future telecommuting potential in Stockholm, concluding that telecommuting has the potential to substitute work commute in the range of 6% (Paavonen, 2000)^{xxxii} to 25-30% (City of Stockholm, 1995)^{xxxiii}.

SNRA (2003) conclude that the greatest strength of mobility management services (e.g. car-sharing) is probably of a structural nature, facilitating use of public transport and inducing more effective car use. The exact substitution rate is therefore hard to predict, especially in a future scenario, since it depends on the interaction with other travel modes, changed travel patterns and new price structures. It is likely that the adoption rate of new mobility management alternatives increases in relation to the TDM tested in this study (e.g. increased fuel prices and traffic tolls).

What proportions of the specific mobility services and other TDM must be required to fulfil the reduction levels experimented upon in this study, and in specific, what measures should be prioritized over the other? Based on the forecasts mentioned above, and from our results from the business district in Stockholm, a reduction of work-related travel of at least 10% (from all types of mobility management alternatives) might be a fair assumption for 2030. The results in this study show that work related travel corresponds to the far most substantial part of private vehicle kilometres. Consequently, testing attitudes and preferences towards new travel policies and new mobility alternatives at companies are of great importance in order to incorporate mobility management alternatives as an efficient TDM (Robèrt,

2003)^{xxxiv}. Company travel plans (i.e. development of more sustainable work related travel) might play an essential role for sustainable development (Robèrt, 2005, Rye, 2002^{xxxv}, Coleman, 2000^{xxxvi}).

As expected, a clear fuel price sensitivity was evident. However, the effect from making public transport free of charge was perhaps not as substantial as expected. Brown et al, (2003)^{xxxvii} show, in a before- and after study, a vast impact on mode choice from fare-free public transport in Los Angeles. Public transport to the university of California (UCLA) increased by 56% and solo-driving fell by 20%. Perhaps the differences in results between these two studies could be explained from that Stockholm has a relatively higher share of public transport.

Both traffic tolls and enforcement of a car-free city centre implied just a minor effect on reaching the emission target (merely a 9% reduction from the introduction of traffic tolls and a 4% reduction from the car-free city centre). Yet, considering that the area enclosed by traffic tolls in this study only cover 0,5% of Stockholm county (Stockholm, 2004)^{xxxviii}, and that the car-free city centre would cover only about 0,05%, these two travel demand measures highlight the relative large impact from actions taken locally in the most congested part of the traffic network. Naturally, since traffic tolls and car-free streets in the city centre are limited to just the core of Stockholm county, it is difficult to compare the CO₂-reduction effect from these measures to other TDMs tested in this study. The largest impact from traffic reducing measures in the city centre is probably seen in reduced walking/cycling accidents and from increased health and comfort aspects from cleaner air in the city. This in turn, corresponds to savings in emission- and accident costs (e.g. savings in emission and accident costs from traffic tolls would amount to 1.14 billion SEK).

Apparently, two different types of rebound effects were detected. Firstly, our experiment with reducing traffic volumes locally between Stockholm and a large business district, revealed a latent car demand filling part of the vacant space in the traffic network. This 3% rebound effect does not appear substantial enough for giving up the idea of telecommuting as a traffic reducing policy, at least on the margin. However, telecommuting might also be coupled to other types of rebound effects discussed in literature (Mokhtarian, 1997^{xxxix}, TDM encyklopedia, 2004^{xl}, Arnfalk, 2002^{xli}).

Secondly, in consistency with (Jones, 1993)^{xlii}, (Greene et al, 1999)^{xliii} and (Berkhout et al, 2000)^{xliiv} the results in this study indicate a rebound effect of about 10% from the fuel efficiency regulation. Nevertheless, since the fuel efficiency regulation appeared to be quite effective in reducing emissions, the 10% loss is not likely to ruin the chances for this policy to be part of a strategy set toward the emission target 2030. In addition, from the fuel price sensitivity detected, both types of rebound effects are likely to be counteracted by fuel taxes and other TDMs elaborated with in this study.

5. Conclusions

At a first glance, from a pure emission reduction point of view, mobility management services and TDMs seem to bring just a modest impact on reaching the CO₂ –target in comparison to the required share of renewable fuel vehicles 2030. In spite of the drastic regulations experimented with in this study, a renewable fuel

mix of at least 50% is required in order to reach target fulfilment. However, from a more holistic point of view the traffic reducing policies might contribute *indirectly* to target achievement since a) even small reductions of traffic volumes might imply large savings in traffic related costs from emissions, accidents and in vehicle times. If these savings could help launch more expensive renewable fuel systems, which evidently are crucial in all attempts to reach target achievement, mobility management and TDMs would play a significant role, b) mobility management services such as e.g. car-sharing might assist and complement public transport, making this alternative more attractive, thus reducing the need for private car, and c) mobility management services such as e.g. car sharing are well suited as starting ground for renewable fuel vehicles (a trend that is seen in many car-sharing manufacturers already, e.g. Sunfleet), and finally d) “many a little makes a mickle”. Changing travel habits and emissions just a little here and there might be worthwhile from a larger perspective where synergy effects might arise. It is hard to foresee future development of new innovative transport alternatives, especially in the case where some of the TDM tested in this study are implemented. A snowballing effect could take place if user rates reach a certain threshold level, i.e. more car-sharing vehicles, ride-matching commuters or videoconference facilities increases the attractiveness of the services, implying a positive feedback loop. In addition, it is likely that the price relationship between fossil fuels and renewable fuels will shift till the year 2030. The price sensitivity of increased kilometre costs detected in this study indicates that a changed price balance between fossil- and renewable fuels would favour the development of renewable fuel vehicles substantially.

Future potential and development of mobility management services and adoption of renewable fuel vehicles needs further research. In this study we have employed a traffic forecasting system where mobility management services or renewable fuel vehicles are not incorporated as alternatives to traditional travel modes. Instead we estimate the *potential* impact from these travel alternatives by reducing certain proportions of total traffic volumes, work related travel and car-ownership. Our assumptions concerning potential substitution rates of mobility management services are based on former research and literature studies, showing that there is a hypothetical potential for mobility management alternatives (including public transport) to cut traffic volumes in the approximate range of 10-20% in the future. Of course, in order to investigate the future impact from these new travel alternatives in detail, there is need to extend existing traffic forecasting models by incorporating these new travel alternatives. For this to be realized, extensive market research must be carried out (which is presently planned in Stockholm). Nevertheless, the effect calculations from reduced traffic volumes presented in this study, showing substantial savings in emission- and accident costs, indicate that there is reason to bring these services into the discussion of efficient paths toward a sustainable traffic system and that it might be worthwhile considering subsidies to mobility management initiatives, e.g. company travel plans. Moreover, we conclude that if the aim were to derive the most optimal *combination* of travel policies, the number of alternative backcasting paths would have been innumerable and it would have been necessary to introduce some sort of ranking system (e.g. optimizing an objective function over all feasible policy sets).

APPENDIX

The effect model

We derive the emissions generated in the traffic network from the following relationship:

$$E_h = \sum_i \sum_j \sum_k f_{ik} l_i \lambda_k^v e_j \quad (1)$$

E_h = emission from the traffic network at one hour in the traffic network of Stockholm

i = link number

f_{ik} = vehicle flow of type k (private cars, light lorries, heavy lorries, trailer lorries) on link i per hour

l_i = length of link i

λ_k^v = emission factor for vehicle type k at vehicle speed v

e_j = one unit of a certain emission (CO_2 , NO_x , HC, SO_2 , particles)

To calculate λ_k^v for CO_2 –emissions, we use a formula applied by the Swedish national road administration (2001)^{xlv}. This expression is supplemented with a factor compensating for the greenhouse contribution from other exhaust gases (SNRA, 2004)^{xlvi}:

$$\text{CO}_2 \text{ –equivalents} = (\text{equivalentfactor}) * (\text{dieselmixfactor}) * (\text{fuelconsumption}) \quad (2)$$

equivalentfactor = (1/0.965)

dieselmixfactor = (0.88*2.36+0.14*2.54)

The first term transforms CO_2 - emissions to CO_2 - equivalents. The second term compensates for different proportions of petrol-driven and diesel-driven vehicles in the traffic network.

When calculating the costs for the emitted gases, we use standard values developed by the Swedish national road administration (Biding and Lindqvist, 2005)^{xlvii}. The emission costs per hour (C_h) are then derived from a similar expression as eq.1:

$$C_h = \sum_i \sum_j \sum_k f_{ik} \lambda_k^v l_i e_j \sigma_{ij}, \quad (3)$$

where σ_{ij} is the socio economic cost for emitting one unit of gas e_j at link i . Since the term σ_{ij} is link-based, higher emission costs could be assigned low-speed roads in the city centre where more people get exposed to the toxic exhaust fumes.

To calculate daily and yearly emissions from the traffic network of Stockholm, we use an approximation applied by the Swedish national road administration (Biding and Lindqvist, 2005):

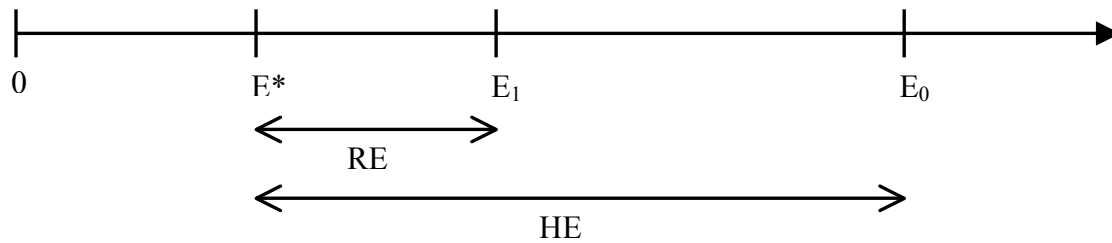
$$E_{\text{year}} = 365 * (4E_h^{PH} + 10E_h^{OPH}) \quad (4)$$

where E_h^P is emission per hour at peak hours, and E_h^{OP} emission per hour at off-peak hours.

Estimation of the rebound effect

In figure 1 below we visualize the rebound effect graphically. E_0 is the emission level or level of traffic volumes before the efficiency change is introduced (in this study caused by reduced fuel consumption or reduced traffic volumes). The rebound effect is then the difference between the emission level after the efficiency change is introduced (E_1), and the emission level that would have been achieved in a hypothetical scenario where the transport demand is held constant in spite of the efficiency change (E^*). Figure 1 below visualizes the absolute quantitative size of the rebound effect (RE). The relative rebound effect (RRE) is the ratio between the rebound effect (RE) and the hypothetical effect (HE), expressing the extent of the rebound effect in relative terms. The RRE is the standard definition to the rebound effect, most commonly expressed in percent (Berkhout et al, 2000)^{xlviii}.

Fig. 1.



E_0 = Energy reference level without the energy efficiency (today)

E_1 = Energy level achieved after efficiency is introduced

E^* = Energy level achieved in a virtual scenario without rebound effects

$RE = E_1 - E^*$

$HE = E_0 - E^*$

$RRE = RE / HE = (E_1 - E^*) / (E_0 - E^*)$

Results

State description A

Table 1.

Effect estimations (per year)	Private cars	Stockholm traffic system
CO ₂ -equivalents (million tons)	1.46	2.11
CO ₂ -equivalents per capita (tons)	0.81	1.17
NO _x (ktons)	2.72	10.00
HC (ktons)	3.58	4.98
Particles (ktons)	0.034	0.295
SO ₂ (ktons)	0.031	0.044
emission costs* (billion SEK)	2.59	4.40
private car kilometres (billion km)	6.15	
accident costs (billion SEK)		7.00

*Socio economic costs for CO₂, NO_x, HC, Particles, SO₂

State description B

Table 2.

Effect estimations (per year)	Private cars only	Stockholm traffic system
CO ₂ -equivalents (million tons)	1.72	2.27
CO ₂ -equivalents per capita (tons)	0.72	0.94
NO _x (ktons)	0.96	3.13
HC (ktons)	1.35	2.11
Particles (ktons)	0.028	0.070
SO ₂ (ktons)	0.036	0.048
emission costs (billion SEK)	2.74	4.13
private car kilometres (billion km)		7.87
CO ₂ exceeding target (million tons)		1.42
accident costs (billion SEK)		8.96
CO ₂ increase in comparison to A		7%
Required renewable fuel mix		63%

Backcasting paths to state description C

Reduced traffic volumes

Table 3. *Reduction of private car trips*

Level of reduction	10%	20%	30%
CO ₂ -equivalents from total traffic system (million tons)	2.07	1.87	1.70
CO ₂ -equivalents from total traffic system per capita (tons)	0.86	0.78	0.71
CO ₂ -equivalents exceeding target achievement (million tons)	1.23	1.03	0.86
Annual emission cost (billion SEK)	3.77	3.40	3.09
Annual accident cost (billion SEK)	8.21	7.46	6.80
CO ₂ reduction compared to state description B	-8%	-17%	-24%
Required renewable fuel mix to reach target fulfilment	59%	55%	51%

Table 4. *Reduction of work commute and local business trips*

Level of reduction	10%	20%	30%
CO ₂ -equivalents from total traffic system (million tons)	2.13	1.99	1.88
CO ₂ -equivalents from total traffic system per capita (tons)	0.89	0.83	0.78
CO ₂ -equivalents exceeding target achievement (million tons)	1.29	1.15	1.04
Annual emission cost (billion SEK)	3.88	3.63	3.43
Annual accident cost (billion SEK)	8.45	7.95	7.53
CO ₂ reduction compared to state description B	-5%	-12%	-16%
Required renewable fuel mix to reach target fulfilment	61%	58%	55%

Table 5. *Reduction of car ownership*

Level of reduction	10%	20%
CO ₂ -equivalents from total traffic system (million tons)	2.14	1.98
CO ₂ -equivalents from total traffic system per capita (tons)	0.89	0.83
CO ₂ -equivalents exceeding target achievement (million tons)	1.30	1.15
Annual emission cost (billion SEK)	3.90	3.61
Annual accident cost (billion SEK)	8.44	7.86

CO ₂ reduction compared to state description B	-6%	-13%
Required renewable fuel mix to reach target fulfilment	61%	58%

Table 6. *Reduced commuting to Kista*

30% reduction of private car commuting to Kista	
CO ₂ -equivalents from total traffic system (million tons)	2.23
CO ₂ -equivalents from total traffic system per capita (tons)	0.93
CO ₂ -equivalents exceeding target achievement (million tons)	1.39
Emission cost (billion SEK)	4.06
Accident cost (billion SEK)	8.80
Private car kilometres (billion km)	8.59
CO ₂ reduction compared to state description B	-2%
Required renewable fuel mix to reach target fulfilment	62%
Calculated rebound effect (increased traffic volumes caused by reduced travel times)	3%

Travel demand measures

Table 7. *Increased fuel price*

Fuel price (base level = 0.8 SEK/km)	1.5 SEK/km	2 SEK/km	3 SEK/km
CO ₂ -equivalents from total traffic system (million tons)	2.02	1.79	1.68
CO ₂ -equivalents from total traffic system per capita (tons)	0.84	0.74	0.70
CO ₂ -equivalents from total traffic system per capita (tons)	1.18	0.94	0.84
Annual emission cost (billion SEK)	3.69	3.26	3.07
Annual accident cost (billion SEK)	7.98	7.06	6.57
CO ₂ reduction compared to state description B	-11%	-21%	-26%
Required renewable fuel mix to reach target fulfilment	58%	53%	50%

Table 8. *Free fare public transport*

CO ₂ -equivalents from total traffic system (million tons)	2.19
CO ₂ -equivalents from total traffic system per capita (tons)	0.91
CO ₂ -equivalents exceeding target achievement (million tons)	1.34
Annual emission cost (billion SEK)	4.00
Annual accident cost (billion SEK)	8.69
CO ₂ reduction compared to state description B	-4%
Required renewable fuel mix to reach target fulfilment	61%

Table 9. *Traffic tolls*

CO ₂ -equivalents from total traffic system (million tons)	2.07
CO ₂ -equivalents from total traffic system per capita (tons)	0.86
CO ₂ -equivalents exceeding target achievement (million tons)	1.22
Annual emission cost (billion SEK)	3.77
Annual accident cost (billion SEK)	8.18
CO ₂ reduction compared to state description B	-9%
Required renewable fuel mix to reach target fulfilment	59%

Table 10. *Increased fuel efficiency in private cars*

Efficiency level	30%	50%
CO ₂ -equivalents from total traffic system (million tons)	1.78	1.49
CO ₂ -equivalents from total traffic system per capita (tons)	0.74	0.62
CO ₂ -equivalents exceeding target achievement (million tons)	0.94	0.65

Annual emission cost (billion SEK)	3.38	2.92
Annual accident cost (billion SEK)	9.15	9.47
CO ₂ reduction compared to state description B	-21%	-34%
Required renewable fuel mix to reach target fulfilment	53%	44%
calculated CO ₂ rebound effect (total traffic system)	6%	10%

Table 11. *Car-free city centre*

Car-free city centre		
CO ₂ -equivalents from total traffic system (million tons)		2.17
CO ₂ -equivalents from total traffic system per capita (tons)		0.90
CO ₂ -equivalents exceeding target achievement (million tons)		1.32
Emission cost (billion SEK)		3.95
Accident cost (billion SEK)		8.61
Private car kilometres (billion km)		8.40
CO ₂ reduction compared to state description B		-4%
Required renewable fuel mix to reach target fulfilment		61%

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