Mobility Management and Climate Change Policies

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Doctoral Thesis in Infrastructure
with specialisation in Planning and Implementation

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Abstract

Globally, the transport system faces a paradigmatic shift where, in addition to increased local traffic problems, climate change and depletion of fossil oil reserves will foster a successive transition to renewable fuels and a need for more resource-efficient mobility management and communication alternatives. Foresighted countries, cities or companies taking the lead in adapting to these tougher conditions might well not only solve those problems, but also turn the problems into business advantages. This thesis is based on six studies that attempt to develop future strategies based on rigorous principled emission and energy efficiency targets and to modulate the impact of travel policies, technical components and behaviours in economically advantageous ways. The modelling frameworks developed throughout the thesis build on a target-orientated approach called backcasting, where the following general components are applied: (1) target description at a conceptual level *i.e*. the potential for sustainable energy systems, emissions, costs, behavioural patterns, preferences, *etc*.; (2) mapping of the current situation in relation to target description; and (3) modelling of alternative sets of policies, technologies, behaviours and economic prerequisites to arrive at target achievement. Sustainable travel strategies are analysed from two main viewpoints. The first four studies focus on company travel planning, where behavioural modelling proved to be an important tool for deriving target-orientated travel policies consistent with employee preferences. The latter two studies focus on strategies and preconditions to meet future emission targets and energy efficiency requirements at a macroscopic regional level by 2030. Backcasting's role as a generic methodology for effective strategic planning is discussed.

Keywords: *Strategic Sustainable Development (SSD), Backcasting, Greenhouse gas emissions, Traffic planning, Company travel planning, Mobility Management, ICT.*

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Stockholm, December 2007

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List of papers:

1. **Backcasting and econometrics for sustainable planning - Information technology and individual preferences of travel**
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2. **Incentives and policies toward car-sharing and ride-matching**
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3. **Company incentives and tools for promoting telecommuting**
   Robèrt, M. and Börjesson, M. (2006). Environment and Behavior 38, 521-549.

4. **A model for climate target-oriented planning and monitoring of organisations' travel and climate change policies**
   Robèrt, M. (2007). International Journal of Sustainable Transportation, 1:4, 1-17.

5. **Assessment of transport policies toward future emission targets**
   Robèrt, M. and Jonsson, R.D. (2006). Journal of Environmental Assessment Policy and Management, 8:4, 1-28.

6. **Biofuels in the energy transition beyond peak oil**
   Robèrt, M., Hultén, P. and Frostell, B. (2007). Energy 32:11, 2089-2098.

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1 Introduction

The overall aim of this thesis was to devise and evaluate sustainability strategies of the urban transport system in general, and business and commuter travel in particular. Traffic planners all over the world face the same type of urban transport dilemma of how to strategically plan for maximising urban mobility, while at the same time minimising the associated emissions, congestions and accidents.

Transport accounts for 31% of energy use in the EU, where emissions from road traffic account for about 23% of total CO_2-equivalents and are expected to increase (European Environmental Agency, 2004; European Commission, 2005). Because of the rapid growth and dominant use of fossil fuels, and the transport sector's need for relatively refined fuels, may prove the transport sector to be the most difficult to monitor and the most difficult to include in emission trading programmes – in particular as regards private vehicle travel (Coussan *et al*., 1997; STEM, 2005). Besides economic, social and ecological impacts originating from expanding traffic infrastructure, urban sprawl, and use of land in the expanding renewable energy sector, we also se many other local problems from inefficient traffic systems and increasing traffic loads. Examples are congestion and undesirable increases in travel times, stress, respiratory diseases, cancer and accidents (Department of Health, 2004; WHO, 2006). Furthermore, there are indications that we might well be approaching a tipping point where unexpected climate shifts appear as the cause of the global temperature increase. From this perspective it is important that no energy sector lags behind in the search for strategies preventing climate change. The need for good examples is even more crucial in a situation where new economies enter the market (primarily China and India).

Achieving future emission targets and managing the coming transition to renewable fuels will place heavy demands on future production and manufacturing processes to make those efficient as regards energy, land use and other resources. Consequently, the competition for renewable fuels will increase in the future (Åkerman and Höjer, 2006) and most likely there will be limitations in supply, at least in the coming decades (Azar *et al*., 2003; Iglesias and Apsimon 2004). Thus, efficient energy use, both in the transport sector and in other sectors of the society, is a prerequisite for a smooth transition to a renewable fuel system where unexpected synergy effects and benefits from economies of scale could be discovered.

In order to avoid hasty headlong decisions at a later date, when requirements on energy efficiency are likely to become even more acute, it is important to analyse road-users' acceptance and potential market shares of alternative travel modes. World-wide, there are numerous examples of cities introducing various forms of *mobility management* solutions in order to encourage citizens to choose more resource-efficient travel alternatives. Mobility management represents the 'software' in the traffic infrastructure, improving integration of public transport, walking and cycling in the road network, encouraging collective car use (*e.g.* car sharing or ride matching), finding ways to substitute physical travel for virtual means of communication (*e.g.* videoconferencing and teleworking) and developing new standards for intelligent transport systems in order to monitor flow and reroute traffic (McCullough, 2004).

The company perspective

Companies are potential key players in the development of mobility management and a sustainable transport system and may chose different means to exploit this potential by a) Analyse employees' travel behaviour and their willingness to adopt more resource-efficient travel alternatives in the creation of target-orientated travel policies; and b) use the aggregated results from the analysis of employee preferences to open a market-orientated dialogue with actors regarding employee criteria for choosing more resource-efficient travel alternatives. However, a problem when discussing sustainability terms in private companies is that the time perspective is generally considered too long (see *e.g.* the Brundtland Commission's definition[1]). Thus, an obvious precondition for implementing sustainable travel policies targeting *e.g.* emission reductions in private companies is that the sustainable long-term emission target is transferable to short-term and mid-term targets that can serve as flexible platforms towards the longer term (Ny *et al.*, 2006). Such shorter targets should give sufficient return on investment, in a sufficiently short time, to sustain the transition, including the indirect value from increased work efficiency among employees, improved public relations and promotion of own products or services. Furthermore, the successful launch of company travel policies is strictly dependent on the social dimension of sustainability, concerning employee acceptance of alternative travel behaviour. This relationship, entailing all three dimensions of sustainability, is illustrated in Figure 1, where the emission target could be perceived as the 'tip of the iceberg', entirely dependent on the development of the lower segments (economic feasibility and employee acceptance). This bottom-up approach formed the basis for the backcasting frameworks developed at a company level in this thesis.

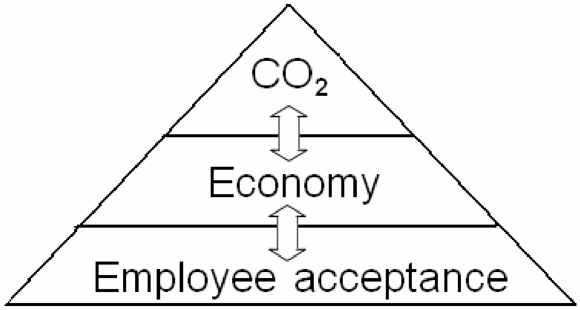

Figure 1. *The feasibility of emission reductions for a profit-maximising company is strictly dependent on the economic payback, which in turn demands employee acceptance of the alternative travel policies.*

To date, sophisticated traffic modelling techniques and travel choice analyses have been developed mainly to provide cost benefit assessments of new infrastructure investments and optimised private vehicle traffic, where the focus is often placed on objectives such as traffic flows and vehicle times, while overlooking others, such as improved mobility for non-drivers. All energy sectors (where the transport sector sets a good example) might well approach a paradigmatic shift where limits for emissions and energy use will meet stricter conditions in the future.

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[1] "A sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs (UN, 1987)"

Thus, the challenge for future traffic planners and company managers aiming to achieve long-term environmental, economic and social sustainability is to incorporate all these dimensions, where the first constitutes the upper limit in the planning process in order not to harm the others in the long-term perspective. However, this does not necessarily mean that we need to reduce economic growth and quality of life. On the contrary, by taking boundaries for natural capital into account at an early stage in the planning process, decision-makers could well create a win-win situation by being one step ahead in the global adaptation to a more resource-efficient economy when the demand for best practice and know-how is growing, and this might well be turned into a market advantage.

From this perspective, the original objectives of this thesis are twofold:

1. To identify potential win-win situations from more resource-efficient travel, both at a regional level and from a company perspective, and to demonstrate how the three dimensions of sustainability (environment, economy, social aspects) could move in parallel.

2. To develop tools for policy assessments based on the target-orientated approach of backcasting (see section 2.1), where traffic modelling in general and discrete choice modelling in particular (see section 2.2) provide strength in the identification and evaluation of strategies consistent with conceptual targets for sustainability.

One of the key findings in this thesis was that, regardless the size of the system (*e.g.* a company or a city region), a structured policy assessment framework that measures quantitative improvements from alternative policy decisions at an early stage in the planning process is of considerable importance. Such a framework can be used to prioritise and make efficiency assessments between alternative strategies, solve strategic problems related to trade-offs in the planning situation, and avoid unexpected rebound effects from simplistic mono-dimensional solutions. Furthermore, it can identify driving factors (*e.g.* cost reductions or improved work conditions for employees) that might encourage and finance more far-reaching sustainability targets further ahead. In particular, for private companies intermediate sub-targets coupled to short-term payoffs are essential to meet targets over longer time frames.

The structure of the thesis

The thesis consists of six studies, reported in papers 1-6. Although all these studies touched upon the issue of sustainable travel and mobility management, the perspective differed to some extent. The first three studies, which analysed mobility management from a company perspective at Ericsson in Nacka Strand, were produced during the IT boom when great attention and expectations were linked to the potential substitution effect of IT on physical travel and the extent to which IT would become the universal panacea for the unsustainable transport system. The fourth study also focused on mobility management from a company perspective, but with empirical support from three other large companies (Swedbank, TeliaSonera and Länsförsäkringar). Although IT was still utilised as an important ingredient in the creation of company travel policies in the fourth study, the focus was shifted to a broader range of mobility management strategies to achieve company climate targets, where a model was developed to transform emission targets to policy-related changes in employee travel behaviour. Studies five and six analysed strategies to achieve a sustainable transport system from a regional perspective, where mobility management together with various forms of travel demand measures filled an important role in the strategic toolbox toward emission and energy efficiencies at a macro orientated scale.

1.1 Climate change and peak oil

Globally, the current transport system faces a double dilemma: climate change and the approaching peak in fossil fuel production. In the next two sections, these two catalysts toward a more energy-efficient and renewable fuel-driven transport system are reviewed.

1.1.1 Evidence of global warming – a summary based on IPCC reports

The United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) established the Intergovernmental Panel on Climate Change (IPCC) in 1988. The purpose was to gather research world-wide on climate change and to provide policy-makers and decision-makers with effective strategies to counteract such change. Many hundred scientists world-wide are involved in providing the IPCC with climate-related research.

According to the IPCC (IPCC 2001, 2007), 'The atmospheric concentration of carbon dioxide (CO_2) has increased by 31% since 1750. The present CO_2 concentration has not been exceeded during the past 420,000 years and likely (90-95% confidence level) not during the past 20 million years. The current rate of increase is unprecedented during at least the past 20,000 years. It is not possible to estimate the exact influence of human use of fossil fuels and the greenhouse effect. However, when comparing historical temperature trends at earth's surface with the increased concentrations of human emissions of greenhouse gases during the last century, a strong correlation is evident (Figure 2). Palaeo-atmospheric data, *e.g.* from trees, corals and sediments and from air trapped in ice over hundreds of millennia, are providing information about climate history on earth.

The upper left graph of Figure 2 shows the temperature of earth's surface during the past 140 years. Evidently, there is a clear temperature increase starting at the time of the industrial revolution – pointing at a causal relationship between temperature and human activities (use of fossil fuels). During this period, the surface temperature of earth has increased by 0.6 ± 0.2°C. In the lower left-hand graph of Figure 2, the average temperature during the last millennium points to a relatively steady state during the time before the industrial revolution. The blue curve represents the year-by-year average and the black curve represents the 50-year average. The grey region is the 95% confidence level representing uncertainties in measurements before the instrumental age, based on proxy variables (glacier layers, *etc*.). The IPCC has concluded that, with a 90-99% confidence level, the 1990s was the warmest decade and 1998 the warmest year of the millennium. Based on global model simulations, the IPCC further predicts that the coming century will be the warmest century in 10 000 years (90-99% confidence level).

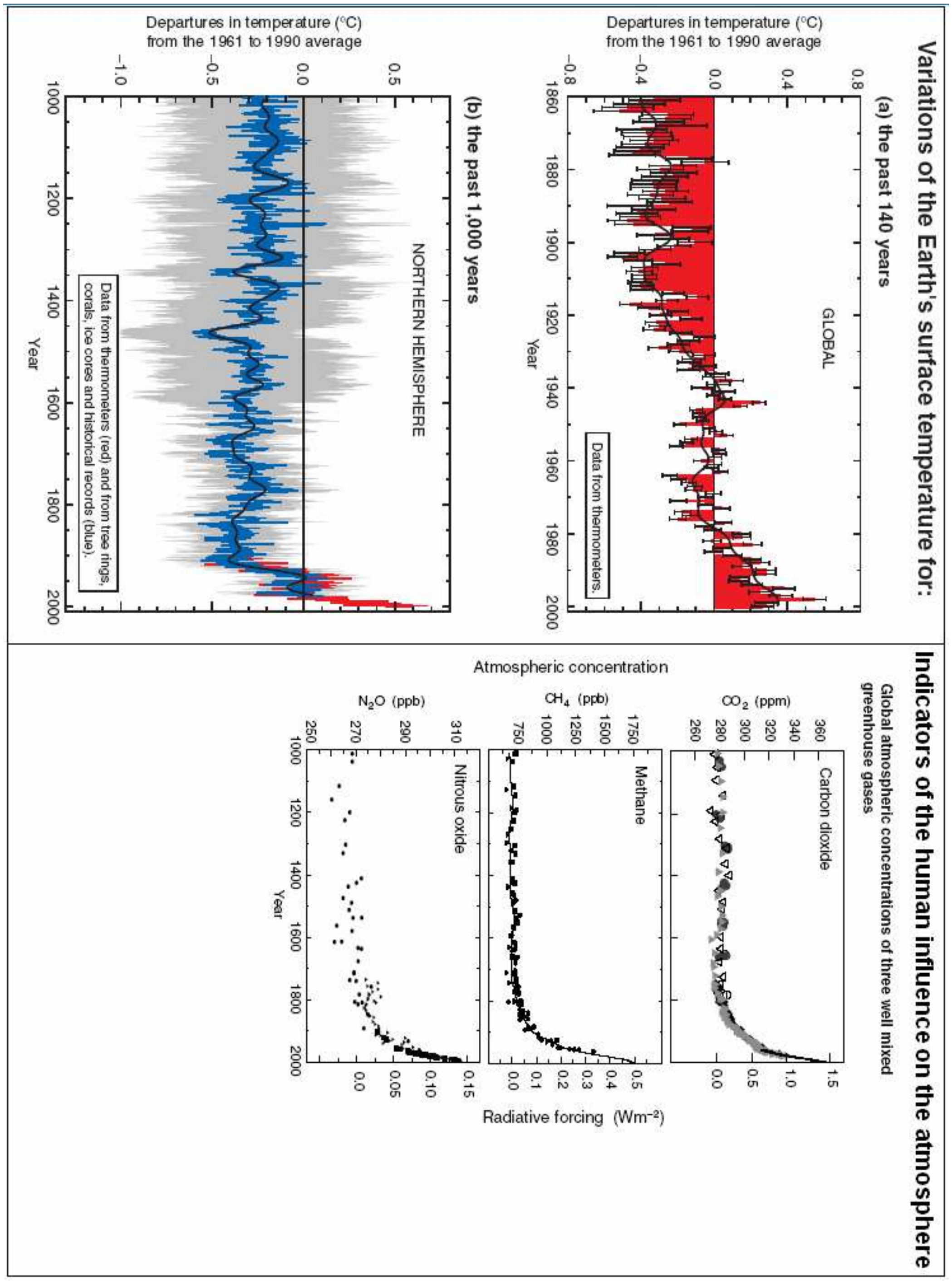

Figure 2. *Variations in the surface temperature of earth and the concentrations of atmospheric greenhouse gases. The graphs are adapted from IPCC (2001).*

The three right-hand graphs in Figure 2, representing concentrations of greenhouse gas emissions during the last millennium, indicate a substantial increase in emissions from human activities during the industrial era. The IPCC have concluded that this increased concentration of greenhouse gas emissions is mainly caused by combustion of fossil fuels (99% confidence level). The rest (about 10- 30%) is predominantly due to changes in land use, especially deforestation. As the concentration of CO_2 increases, land and water will take up a decreasing fraction of CO_2, causing a net increase in greenhouse gases in the atmosphere. Hypothetically, this net increase in greenhouse gases might reach a threshold level, where global temperature increases in an uncontrollable, self-propelled positive feedback loop. The exact point at which this tipping point would cause a collapse in the climate system is not known. It is believed that the rapid creation of the Sahara desert, about 5 500 years ago, was caused by such a collapse, where deforestation exceeded a certain threshold level.

Carbon cycle models indicate that stabilisation of atmospheric CO_2 concentrations at 450 ppm would require global anthropogenic CO_2 emissions to drop below the 1990 level within a few decades and to continue to decrease steadily thereafter. According to the target defined in the Kyoto protocol (UNFCCC, 2007), the EU-15 nations have decided to create a ‘bubble’ that involves a collective reduction in emissions of 8% below 1990 levels by 2008-2012. Eventually CO_2 emissions will need to decline to a very small fraction of current emissions.

1.1.2 Peak oil – will fossil resource constraints accelerate the attainment of future emission targets?

There are reasons to believe that the required rate of reduction in greenhouse gases reviewed in the previous section might not be too unrealistic, because cheap production of fossil fuels might cease well within this century. Depending on the assumed growth in demand for oil during the next few years, the global peak in fossil oil and gas production might occur already in the time period 2008-2018 (Robelius, 2007). This would induce a breaking point where demand for oil would exceed supply in the first half of this century, resulting in substantial price increases for fossil fuels (Campbell and Laherrere, 1998; Droege, 2002; Aleklett and Campbell, 2003; Urry 2004;). Taking these predictions into account, future emission targets might be more easily attained because of the depletion of fossil resources, and the question would then be more of the character ‘What measures should be taken in order to make the transition to renewable fuels as non-problematic as possible?’ Thus, the approaching energy transition is both a question of *mitigation,* as well as question of *adaptation.*

Even though the exact time frame for the depletion of easily accessible fossil fuels is a matter of discussion, one thing is clear: there might be reason to be risk-averse and take precautions even at an early stage, before energy prices move toward instability. Unless we prepare for the shift to a more sustainable traffic system in time, the transformation might be devastating (Purcell, 2000). The search for feasible paths to a sustainable traffic system is even more urgent considering the explosive traffic expansion that is underway in the developing countries as these strive to reach the same standard of living as the developed countries (Wegener, 1996).

The global peak of fossil oil production (Figure 3) in combination with rapid economic growth in the developing world implies tightened requirements on technological efficiency and restricted use of energy in all sectors of society (Aleklett and Campbell, 2003; Robèrt *et al*., 2007). Future competition for energy resources and associated increased energy prices will most likely influence future car use and travel patterns in a more energy-efficient direction. In addition, there are also constraints on other natural resources apart from fossil fuel, *e.g.* metals and encroachment on ecosystems by traffic infrastructure (for references see Ny *et al*., 2006; Robèrt *et al*., 2007).

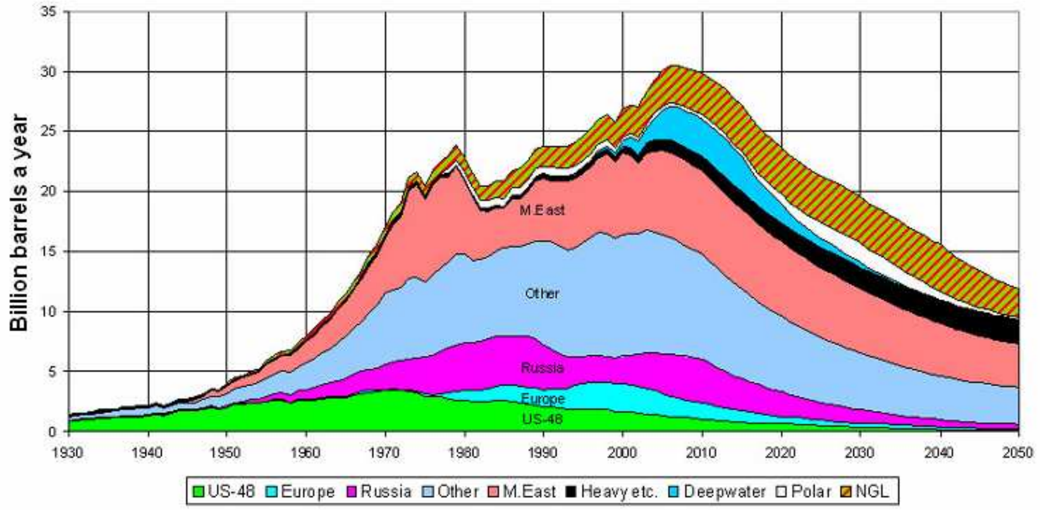

Figure 3. *Graphical presentation of global peak oil. Figure adapted from Aleklett and Campbell (2003).*

1.2 Mobility management and company travel plans

Future emission targets and limited energy resources will probably drive the price balance between fossil and renewable types of energy to a successive transition toward renewable energy sources (*e.g.* biomass, wind, hydro and solar power). These energy sources will all play an important role in the production of renewable fuels such as ethanol, methanol, biogas and hydrogen (Nonhebel, 2005; Worldwatch Institute, 2006; Schäfer *et al*., 2006). These energy sources need to satisfy future transport demand in competition with other uses of land. In order to avoid local problems such as congestions and health-related problems, while at the same time not infringing personal mobility, energy-efficient vehicles and mobility management services will most likely have an increasing importance in the future (Robèrt and Jonsson, 2006; Robèrt *et al*., 2007; Poudenx and Merida, 2007).

In many cities in industrialised parts of the world, more cost-efficient and energy-efficient urban mobility is encouraged through subsidised company travel plans and specific mobility management initiatives targeting less car-dependent personal travel (Rye, 1999; Newson, 2000; Robèrt, 2007). The concept of travel plans is referred to as an efficient measure to reduce employee commuting by private car and business travel within companies. It is defined as a package of measures developed by an employer to encourage employees, visitors or customers to switch to more economically and environmentally efficient forms of transport (both commuter travel and business travel). Turning sustainable development into win-win strategies may be a deliberate part of sustainable market-orientated traffic planning for private companies. There is an urgent need for companies to set good examples and show that mitigating the environmental impact does not necessarily conflict with short-term economic growth. Thus, from a traffic planning perspective aimed at climate targets, it is crucial to identify potential incentives to companies considering travel plan initiatives.

There is an obvious potential for IT as a cornerstone in resource-efficient company travel plans. Moving electrons will always be more energy-efficient and cost-efficient than transporting people. Arnfalk (2002) distinguishes two potential efficiency improvements from use of IT in the transport sector:

- *Substitution, which* implies that an electronic application partially or fully replaces a trip, *e.g.* telecommuting instead of commuting to work, electronic mail instead of posted letters or videoconferencing instead of face-to-face meetings.

- *Efficiency improvement*, where IT technology helps provide the same service with less transportation efforts, *e.g.* in the form of car-sharing or ride-matching systems facilitated by IT.

In many scenarios concerning the role of IT in sustainable development (*e.g.* Höjer, 2000), great importance has to be attributed to service users if the scenarios are to be realised. Thus, when analysing the impact of IT on sustainable travel, it is important to start out from the key players in the context, the potential users of these travel alternatives (*i.e.* to analyse individual preferences).

In the early days of telecommuting and virtual communication, there was great confidence in technological substitution rates and future development and adoption of telecommuting (*e.g.* Nilles, 1988). However, potential *rebound effects* (*i.e.* negative side effects) from fuel use efficiencies and IT applications is a well-known dilemma (Newman and Kenworthy, 1989; Whitelegg, 1993; Mokhtarian, 1997). Greening *et al*. (2000) review numerous estimates of the magnitude of the rebound effect from different types of energy-consuming activities (electricity, heating, cooling and automotive transport). For the transport sector, a general estimate of the rebound effect falls within the range of 10-30% takeback of the original energy saving (Jones, 1993; Greene *et al*., 1999; Portney *et al*., 2003; Litman, 2003, 2007). Berkhout *et al*. (2000) claim that rebound effects are often overestimated and arrive at a magnitude of 0-15%. However, increased fuel prices would induce a shift toward more fuel-efficient vehicles and renewable fuel vehicles without the development of undesirable rebound effects (Wachs, 2003). Such increases might be a natural consequence of peak oil and future climate constraints, stimulating a successive adoption in coming decades of more eco-efficient alternatives to private car travel, such as eco-driving, public transport, car sharing, carpooling and virtual means of communication.

2. Modelling of sustainable travel strategies

2.1 The backcasting approach

The concept of backcasting is a strategic target-orientated approach generally applied when planning in complex systems (Robinson, 1982; Dreborg, 1996; Höjer and Mattsson, 2000). This approach is well applied on any level of sustainable transport research. Applying principle targets (Robèrt, 2000; Ny *et al.*, 2006), *e.g.* emission reduction targets or targets for energy demand, rather than scenario planning and relatively fixed images of the future allows greater flexibility in the planning process where many decision makers are involved and many possible investment paths might comply with principle targets. It is often easier (and smarter) to agree on early investments that are flexible with regard to principle targets, and re-evaluate as the process unfolds and technical evolution keeps changing the conditions, than to agree on relatively specific distant futures. Priority is given to such early investments that can (i) tackle existing circumstances (*e.g.* budget constraints, economic payback, public opinion, political climate, *etc*.) *as well as* (ii) serve as flexible platforms for various investment paths towards compliance with the principle target.

Regardless of the size of the system (company, region, global community), the backcasting approach is well suited for integrating policymakers from different angles in the dialogue, since it may keep rigorous track of objectives while still leaving room for discussions and re-evaluations at the level of detail as progress is made. In creating an illustrative map of state descriptions, between which feasible backcasting paths could be drawn, decision-makers are inevitably confronted with the questions: a) Where would we like to go, *i.e.* what target is set for the future?; b) Do the present conditions meet with the target?; c) Where are we heading if no target-orientated actions are taken?; and d) What are the most efficient strategies to reach target fulfilment and what measures should be prioritised over others, considering key aspects such as the emission reduction potential, long- and short-term economic payback, individual preferences and social aspects? Efficiency assessments and strategic planning often involve many stakeholders serving different roles in the planning process (*e.g.* local transport providers, the municipal authority, company leadership, purchase managers, staff managers and environmental managers at the company). Hence, from a planning perspective it is crucial that all actors share a common vision of target achievement, but viewed from different angles (emission reductions, cost savings, health aspects, increased use rates of mobility management services).

2.2 Discrete choice modelling

2.2.1 Utility functions and the logit model

Since the aim from a company policy perspective is to find ways to influence an employee’s behaviour (*e.g.* towards choosing a new, more energy-efficient travel alternative), it is necessary to identify the conditions in which the individual is willing to do this. Let us take the example of investigating the potential to replace taxis with car-sharing for local business trips. The two alternatives are associated with some more or less attractive attributes (*e.g.* travel times, travel prices, certain conveniences), which we assume give a certain pleasure or, in microeconomic terms, *utility*. In our econometric models this utility is used to create the *utility function* in order to estimate the choice probability between the alternatives. The general modelling procedure is pictured in Figure 4 below, using the example of estimating the choice probability between the two alternatives car-sharing and taxi. In order to derive the choice probability between car-sharing and taxi, we use the associated attributes of the two services (*e.g.* travel time, travel cost, type of booking system, *etc.*), and various socio economic and work related factors that might influence the choice probability. The choice probabilities can ultimately be used to derive likely market shares over the total population, as dependent on the individual's perception of the adherent attributes (see Thomas, 1997, Louviere *et al.*, 2000; Greene, 2000).

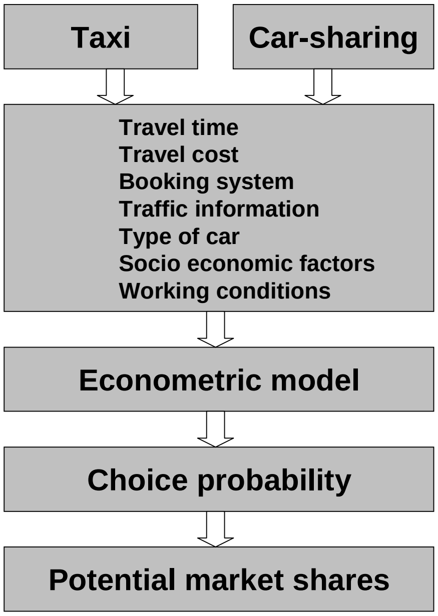

Figure 4. *Graphical representation of the modelling procedure when deriving the choice probability and the market shares between two alternatives.*

In econometrics, binary choice models are used to predict the probability that travel mode *a* is preferred to travel mode *b* (Ben-Akiva and Lerman, 1985). As discussed, each of the two choices *a* and *b* could be associated with some known attributes, giving the utilities U_a and U_b. The probability of choosing mode *a* instead of mode *b* is then the probability that U_a is greater than U_b:

$$P_a = P(U_a > U_b) \qquad (1)$$

The utility for an individual to choose alternative *i*, having *K* attributes, can be expressed as an additive linear function of the different attributes x_{ki} with the weights β_{ki}:

$$U_i = \alpha_i + \beta_{1i}\, x_{1i} + \beta_{2i}\, x_{2i} + .. + \beta_{Ki}\, x_{Ki} + \varepsilon_i \ , \qquad i = a, b \qquad (2)$$

The variables x_{ki} represent quantifiable attributes, such as time consumption, cost, or different comfort aspects associated with each alternative. The core of discrete choice analysis is to estimate the weighting or preference parameters β_{ki}. By collecting data from people's choices between the different feasible alternatives, the $ß_{ki}$ parameters can be estimated in the models. The $ß_{ki}$ parameters reflect the respondents' perceived importance of each specific attribute (*i.e.* the $ß_{ki}$ parameters weigh the influence of each attribute on the choice probability). The term α_i stands for the 'alternative specific constant', also termed the 'intercept parameter'. This constant compensates the utility function for hidden attributes, not included in the model. The term ε_i in equation (2) is called the *random* component or the disturbance. This term represents attributes that cannot be measured explicitly and that vary among individuals, *e.g.* measurement uncertainties and model misspecifications. The assumption of the density distribution of these disturbances is what determines the type of choice model.

Since utility is a subjective measure, the modeller must consider the uncertainties of not capturing the individual's *true* utility function in the models. If we assume that the utility function could be partitioned into one observable part V_i and one error term ε_i, we could treat the former with greater confidence and the latter with special caution.

Equation (2) could now be expressed in vector form as:

$$U_i(\mathbf{ß}_i)= \alpha_i + \mathbf{ß}_i\mathbf{X}_i + \varepsilon_i = V_i(\mathbf{ß}_i) + \varepsilon_i \qquad (3)$$

Here, $\mathbf{ß}_i = (ß_{1i}, ß_{2i},\ldots ß_{Ki})$ is the preference parameter vector, and $\mathbf{X}_i = (x_{1i}, x_{2i},\ldots x_{Ki})$ is the attribute vector, containing the different attributes affecting the choice between the alternatives. $V_i(\mathbf{ß}_i)$ is called the *systematic* component of the utility (*i.e.* the part of the utility that is known to the modeller).

Using equations (1) and (3), the probability of choosing mode *a* could be expressed as:

$$P_a = P(V_a(\mathbf{ß}_a) + \varepsilon_a > V_b(\mathbf{ß}_b) + \varepsilon_b) \qquad (4)$$

Substituting $V(\mathbf{ß})$ *for* $V_a(\mathbf{ß}_a) - V_a(\mathbf{ß}_a)$ and ε *for* $\varepsilon_a - \varepsilon_b$, equation (4) can be formulated as:

$$P_a = P(V(\mathbf{ß}) < \varepsilon)= \int_{-\infty}^{V} f(\varepsilon)d\varepsilon \qquad (5)$$

Equation (5) is recognised as the distribution function of $V(\mathbf{ß})$, derived through integration of the density function $f(\varepsilon)$. In Figure 5 below, the density function is represented by the grey curve and the distribution function by the black curve, asymptotically approaching unity as the difference between the utility of alternative *a* and *b* increases (represented by $V(\mathbf{ß})$).

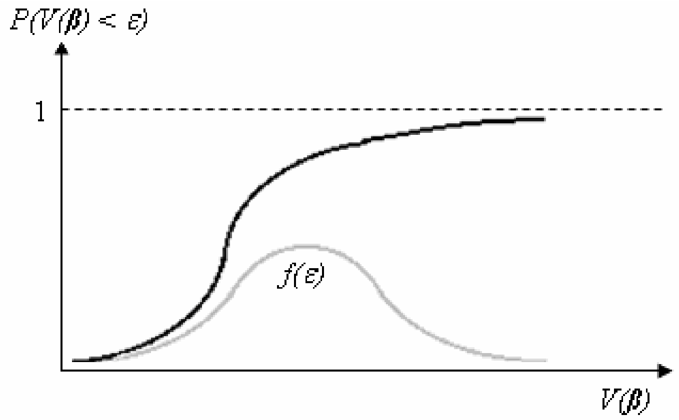

Figure 5. *The distribution function (black curve) expresses the probability that alternative a is chosen over alternative b, as dependent on the relative difference in the systematic utility of the two alternatives (represented by V(**ß**)). The distribution function is the integral of the density function f(ε) (grey curve).*

It is obvious that the probability of choosing mode *a* increases as the difference between the systematic utilities increases (*i.e.* the probability of choosing alternative *a* is larger when the utility V_a is greater than V_b). When the difference between the systematic utilities reaches extreme negative values, the probability will approach values close to zero, whereas high positive values must imply probabilities close to one.

Before the probability of choosing alternative *a* can be derived from equation (5) above, some assumptions regarding the distribution of the error term ε_i have to be made. If we assume that ε_i is identically and independently Gumbel-distributed (similar to the normal distribution), we arrive at the *logit model*, which is easy to treat analytically (equation 7 below). In the present applications, binary logit models were used in situations where we wanted to test the potential for a new transport alternative as a substitute for one of the older ones, *e.g.* car-sharing versus taxi or ride-matching versus private car. In cases where the decision-maker had more than two feasible alternatives, we generalised the above reasoning to yield a choice set, denoted $C = \{1 \ldots J\}$. The choice set contains a number of different alternatives. The notation for making choice *i* from the choice set *C* of *J* alternatives is then stated as:

$$P_i = P(U_i > U_j,\ \forall i, j \in C, j \neq i) \qquad (6)$$
$$= P(V_i + \varepsilon_i > V_j + \varepsilon_j,\ \forall i, j \in C, j \neq i)$$

The probability of choosing alternative *i* is given by the multinomial logit model (MNL) as:

$$P_i\,(\boldsymbol{\beta}) = e^{V_i(\beta_i)} / (\textstyle\sum_{j \in C} e^{V_j(\beta_j)}), \qquad \boldsymbol{\beta} = (\beta_1, \ldots \beta_J) \qquad (7)$$

Equation (7) reduces to the binary logit model if $J = 2$. It also defines a proper probability measure since

$$0 <= P_i(\boldsymbol{\beta}) <= 1 \text{ and } \textstyle\sum_{i \in C} P_i\,(\boldsymbol{\beta}) = 1 \qquad (8)$$

We applied maximum likelihood methods for estimating the parameters of the logit models throughout the studies in this thesis. The models were individually programmed in the programming language Ox. The programming code of the mixed logit model is presented in an appendix to the third paper.

2.2.2 Taste variations and the mixed logit model

One property of the multinomial logit model is the assumption that the preference parameters are constant for all individuals in the population. This assumption implies that the valuation of attributes is aggregated to one average preference vector ***ß***, representing all individuals' tastes (*i.e.* individual tastes within the population are assumed not to vary so we estimate the same ***ß*** for all individuals). This restriction was eliminated in the mixed logit model (MXL), where we instead allowed the preference vector ***ß*** to vary over the population with the normally distributed density function $f(\beta|\theta)$. Here $\theta = (\beta_{mean}, \beta_{sd})$ represents the mean value (β_{mean}) and the standard deviation (β_{sd}). The aim is then to estimate the parameters of θ. Figure 6 shows the density function of ***ß*** in one dimension.

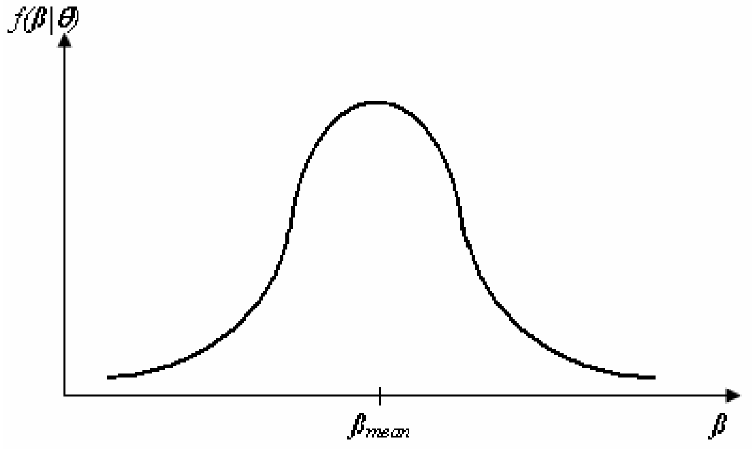

Figure 6. *The density function of* ***ß*** *in one dimension.*

The utility function in equation (2) is then provided with an extra term, incorporating the effects of the standard deviation over the population of n individuals:

$$U_i(\beta_i) = \alpha_i + (\beta_{i,mean} + \mu\beta_{i,sd})X_i + \varepsilon_i\,, \qquad \beta_i = (\beta_{i,mean} + \mu\beta_{i,sd}) \qquad (9)$$

where μ is N(0,1)-distributed and ε_{ni} is identically and independently Gumbel-distributed with zero mean.

The choice probability given by equation (7) must thei ß porate the density function $f(\beta|\theta)$, to handle the distribution of the choice vector. The mixed logit formula is the choice probability in equation (7), integrated over all possible values of ***ß***, over the density function $f(\beta \mid \theta)$:

$$\mathrm{L}_i(\theta) = \int P_i(\beta)\, f(\beta|\theta) d\beta \qquad (10)$$

The parameters θ cannot be estimated directly through a log-likelihood procedure as with standard multinomial logit models but must instead be estimated by numerical simulation. A mixed logit model can be found in the third study (Paper 3), where we built a mixed logit model in order to derive employees' valuations of a flexible office, compatible with telecommuting.

The more complex model specification of the mixed logit model also involves certain drawbacks. First it demands a higher quality of data, which limits the applicability of this model to larger samples of data and more thoroughly constructed survey methods. We experienced these problems when estimating the models in Paper 3. Here, as opposed to the multinomial logit model, the mixed logit model failed to converge to stable values in some of the estimations. A second drawback with the mixed logit model is that it is still not generally utilised, which makes the results less comparable and interpretable by other researchers.

2.2.3 Limitations in discrete choice modelling

The statistical models used in this study have limitations. First, it is not a natural law that human beings behave as rational utility maximisers, and even if this were the case, we could never expect to capture all the essential elements of the individuals' perceived utility. The models only serve as approximations of reality, and as a consequence, the results should not be interpreted as an absolute truth. As discussed in the previous sections, tastes vary between individuals and some elements of the utility are not even possible to include in our models. Nevertheless, the behavioural models might still have a certain meaning, if the results obtained are interpreted with caution. For instance, even if the models do not manage to predict the exact impact of the attributes on the choice probability between the different alternatives, they could probably tell us something about the *relative* importance of the different attributes.

Furthermore, insight into employees' behavioural response if confronted with new hypothetical transport alternatives is not the only element essential for sustainable transport development. As discussed in Papers 1 and 4, this aspect is only *one* of the elements in the backcasting framework making the long-term target feasible. There are innumerable factors affecting the final outcome of alternative company policies such as future technological developments, energy prices, political decisions and legislation. However, if all these aspects were to be included in an aggregated analysis, the results would rely to a large extent on uncertain, external factors more or less impossible to predict. On the other hand, independently deriving the employees' criteria for accepting the new alternatives (revealed in Papers 2 and 3) might even trigger the further development of these external factors (*e.g.* creation of new, more far-reaching company policies and political initiatives).

2.3 Modelling policy effects at a macroscopic scale

In Papers 5 and 6 we modelled policy effects at a macroscopic scale for the transport system of Stockholm County in 2030. We applied the transport forecasting model system SAMPERS (Johansson, 2001; Beser and Algers, 2001) and EMME/2[2] in order to derive travel demand, traffic flows of different vehicle types and velocities at each link in the traffic network as dependent on various target-orientated policy measures. The SAMPERS and EMME/2 combination is frequently used by the Swedish National Road Administration for *e.g.* valuation assessments of potential infrastructure investments, in particular in the Stockholm region. This reduces the risk of errors, and adds to the confidence that the models will produce valid results.

We built a specially designed effect model in order to derive final emissions and energy quantities, in vehicle times, accidents and socio-economic costs (Figure 7).

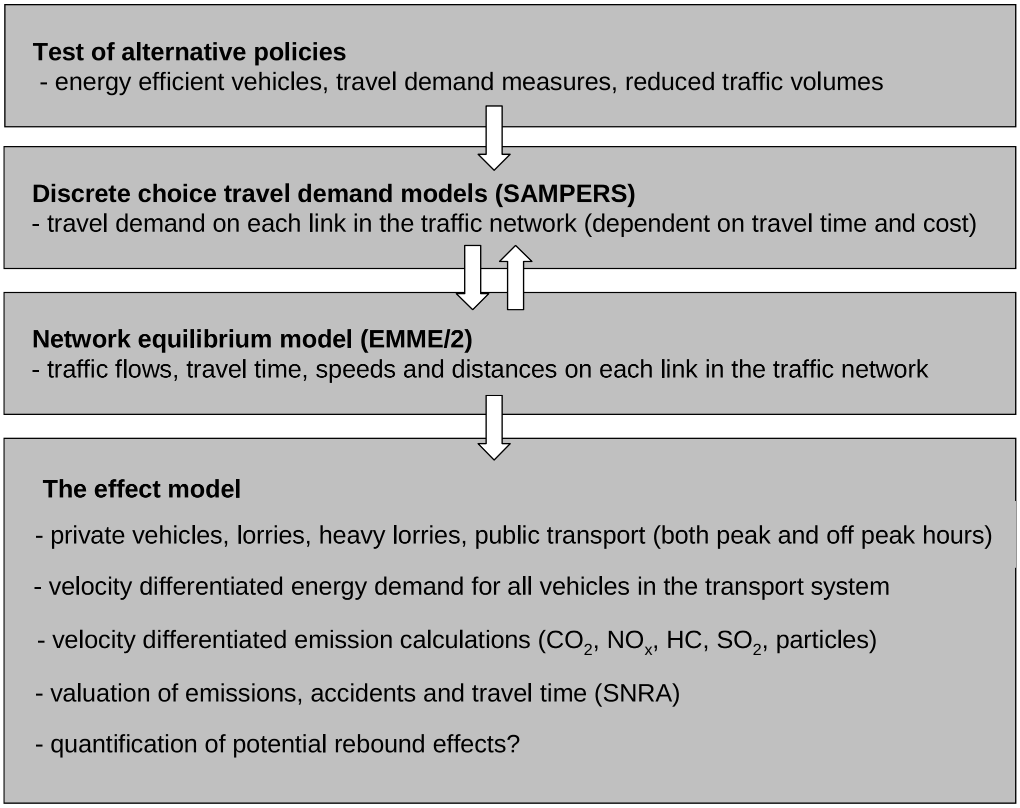

Figure 7. *The modelling system SAMPERS and EMME/2, supplemented with an individually designed effect model applied to assess emission levels, energy demand and socio-economic costs in the transport system of Stockholm County.*

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[2] Information available from INRO, http://www.inro.ca.

The modelling system generates traffic flows at each road link. We derived the emissions generated in the road network from the following relationship:

$$E_j^* = \sum_i \sum_k f_{ik}^* l_i \alpha_j \beta_k \gamma_{jk} (v_i^*) \qquad (11)$$

where:

E_j^* = emission per hour of each of the gases, represented by index *j* (CO_2, NO_x, HC, SO_2, particles), from the transport network in Stockholm. The superscript* represents peak hours (PH) and off-peak hours (OPH).

i = link number

k = vehicle type (private cars, light lorries, heavy lorries, trailer lorries).

f_{ik}^* = flow of vehicle type *k* on link *i* per hour.

l_i = length of link *i*.

α_j = factor transforming CO_2 emissions into CO_2 equivalents (SNRA, 2004), = 1 for other emissions.

β_k = factor compensating for different proportions of petrol-driven and diesel-driven private vehicles in the road network for vehicle type *k* (Biding and Lindqvist, 2005)[3], = 1 for lorries.

$\gamma_{kj}(v_i^*)$ = emission factor per km for gas *j* for vehicle type *k* at vehicle speed *v* at link *i* for peak hours and off peak hours, respectively (Biding and Lindqvist, 2005).

To calculate daily and yearly emissions from the transport network of Stockholm, we used an approximation applied by the Swedish National Road Administration (Biding and Lindqvist, 2005):

$$E_{j,year} = 365 * (4E_j^{PH} + 10E_j^{OPH}) \qquad (12)$$

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

When calculating the costs for the emitted gases, we used standard values developed by SIKA (2002) and Persson and Lindqvist (2003).

The emission costs per hour C_h^* are then derived from a similar expression to equation 11:

$$C_h^* = \sum_i \sum_k \sum_j f_{ik}^* l_i \beta_k \gamma_{kj} (v_i^*) \sigma_{ij} \qquad (13)$$

where:

σ_{ij} = socio-economic cost of emitting gas *j* at link *i*.

The term σ_{ij} is link-based, allowing us to assign relatively higher emission costs at low-speed roads in the city centre than in more peripheral areas (as a consequence of more people being exposed to the toxic exhaust fumes in densely populated areas).

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[3] For reference, please contact the authors.

Total socio-economic costs from *emissions*, *accidents* and *in vehicle time* generated in the road network per year are finally derived from:

$$C_{tot} = C_{emission} + \lambda(f) + \sum_i f_i^{year} \frac{l_i}{v_i}\delta \tag{14}$$

C_{tot} = costs from emissions, accidents and in vehicle time.

$C_{emission}$ = emission costs per year (derived through equation 12, using C_h^* instead of E_h^*).

$\lambda(f)$ = accident costs, assumed proportional to vehicle flows *f* in the road network.

f_i^{year} = traffic flow per year at link *i*.

δ = 120 SEK/hour for average hourly wage in Sweden (SIKA, 2002).

When deriving energy quantities in Paper 6, we used equation 11 in which E_j^* was substituted with energy demand per hour.

The transport analysis system SAMPERS and EMME/2 does not incorporate travel modes other than car, public transport, bicycle and walking. Thus, the model system must be developed further for testing future market shares of mobility management services (such as car-sharing or alternative fuel vehicles), as dependent on fuel prices and various travel demand measures. Since most of these mobility management alternatives are still in their infancy, the only way is to estimate the *potential* impact from these travel alternatives by replacing certain proportions of total transport volumes with these modes.

3. Overview of appended papers

Paper 1. *Backcasting and econometrics for sustainable planning - Information technology and individual preferences of travel*

This paper gives a description of an IT-related research project in a business district outside Stockholm, together with a problem formulation of the analysis. Paper 1 also paves the way for using the results and findings from the two following empirical papers from a company policy perspective, prioritising sustainable travel policies consistent with employee acceptance.

In Paper 1 we present the idea of backcasting, an analytical framework generally applied when planning in complex systems (Robinson, 1982). Backcasting is particularly useful in a system consisting of several independent components, when the aim is to reach a successful predetermined target. The initial step is to sketch the desired long-term target and then, with regard to the present conditions, derive feasible paths between the desired and the present situations. A main advantage with backcasting is that it allows the planner (or group of planners) to create sub-targets that are flexible and robust with regard to long term objectives and thus may work as stepping stones in the planning process. In the research in Nacka Strand, we treat the analysis of potential changes of employee travel behaviour as an explicit sub-target and show econometric modelling to be a useful tool for dealing with uncertainties related to future individual behaviour.

Some elementary methodology from the field of econometric discrete choice theory is also presented in Paper 1. By using econometric modelling we treated the individuals as rational ‘utility maximisers’, always choosing the alternative that seemed to be the most desirable from an objective point of view. A desirable long-term target in Nacka Strand would for instance be an acceptable rate of uptake of the alternative services, in order to make implementation of renewable fuel technologies economically feasible. This would be a win-win situation where both environmental and economic gains are achieved. Of course, in order for this to be realised, components other than individual choice conditions must also be considered (*e.g.* company policies, practical feasibility, technological developments, *etc.*). Nevertheless, knowledge of the individuals’ criteria for changing behaviour might open doors for new company policies and other components consistent with the long-term target.

Paper 2. *Policies and incentives toward car-sharing and ride-matching: A field study based on employees' preferences in Stockholm*

Paper 2 is based on empirical data obtained primarily from employees at the IT company Ericsson in a business district outside Stockholm. The study was conducted during the IT boom, when one of the key questions was to identify the role of IT in more efficient car travel. In the specific case of technology-driven companies, sustainability initiatives could be incorporated with development and promotion of attractive IT solutions in order to demonstrate effective examples of the use of their own technology. In the end, this could lead to an additional market advantage, where IT applications might facilitate the introduction of more efficient mobility alternatives.

The results point at a reasonable acceptance among the employees to use: *a) car-sharing* instead of taxi for local business trips and *b) ride-matching* for local business trips and for work commutes. Thus, the findings indicate that the company has a potential to influence its employees' travel behaviour towards these more economically and environmentally efficient alternatives – if the right instruments and incentives are used. For instance, in spite of the fact that only 3% of the respondents claimed they used car-sharing on their latest local business trip, the majority (62%) stated that they would choose car-sharing in favour of taxi, on condition of the attributes presented in the survey.

As discussed in Paper 1, some travel-related alternatives might give negligible economic or environmental benefits under current conditions, but might work as platforms for future development of more environmentally friendly technologies. However, for this to be realised in practice, the new alternatives must first reach an acceptable user uptake rate in order to make them economically feasible. Determining the employees' conditions for choosing alternative travel modes is therefore an essential first step in the discussion of practical paths towards a long-term sustainable target. Paper 2 is also relevant from a traffic planning perspective, focusing on the potential of supporting and integrating company policy with respect to employees travel plans, as an effective traffic control measure.

Paper 3. *Company incentives and tools for promoting telecommuting*

Paper 3 addresses telecommuting from a somewhat different angle: What would a company gain from promoting telecommuting to its employees? As for the services analysed in Paper 2, telecommuting, too, has a potential role in the discussion of more sustainable travel patterns at work, since it might reduce the number of physical commute trips. However, if telecommuting is to become more widespread and thus serve as a traffic-mitigating measure in the future, companies must have clear motives for promoting this work form to their employees. In Paper 3 we tested the employees' acceptance of 'flexible office rooms', where several employees shared the same workplace but on different occasions (since part of the workforce was always telecommuting). This implies possible reductions in office area for the company, and consequently potential savings on rental costs.

To empirically test the employees' acceptance of giving up their present workplaces for flexible office rooms, we again used econometric modelling. The models were specified so that we could predict the probability of accepting the flexible office as dependent on monetary compensation from the company. If telecommuting implies reductions in office space in which employees donate the use of their homes – rent-free – to the employer, it is quite fair for the employer to consider returning some of those savings to the telecommuters in compensation for the use of their homes. The results point to a significant willingness to accept the flexible office room if monetary compensation is provided for the inconvenience. To extend the analysis, a more flexible discrete choice model was developed (a mixed logit model) and compared with a multinomial logit model.

The findings reported in Paper 3 also have the potential to provide information on efficient backcasting paths to economically efficient strategies towards emission targets (Papers 1 and 4). Using econometric modelling, we predicted the company's and the employees' most profitable level of compensation for accepting the flexible office. With this information, the company can strategically plan for other criteria essential to meet the long-term target.

Paper 4. *A model for climate target-oriented planning and monitoring of corporate travel*

In Paper 4, the backcasting framework supplemented with econometric modelling presented in Paper 1 was further developed and concretised to handle the complexity of reaching a predetermined emission target at a company. Here, the backcasting planning involved the following four parts: (1) definition of a relative emission reduction target at the company, in consistency with economic payoff and employee acceptance; (2) mapping of the present situation at the company, in relation to target description, involving staff travel patterns and preferences, individual and collective emissions and costs, benchmarking to compare companies internally; (3) a policy-oriented transformation of the backcasting target, transforming the emission reduction to potential numbers of employees switching to alternative travel modes or virtual communication means; and (4) alternative sets of company policies and strategies that would arrive at target achievement. Detailed cost-benefit analysis of current business travel in relation to more efficient communication and travel alternatives supplemented the ranking procedure of policy sets derived in the statistical and econometrical models. Furthermore, the stated preference approach conducted in Paper 2 and 3 provided a valuable complement to the creation and selection between alternative policy packages, involving employee willingness to switch from present to new hypothetical travel modes or communication alternatives.

The framework developed in this study might well also be an applicable tool for policy-makers in the public sector in order to determine consequences and feasibilities of alternative strategies, or for finding ways of incorporating company travel activities into emissions trading programmes.

Paper 5. *Assessment of transport policies toward future emission targets – a backcasting approach for Stockholm 2030*

In Paper 5 we carried out a backcasting study at regional level, analysing the potential of mobility management services and IT communications discussed in previous papers (1-4) as strategic tools in reaching drastic emission targets for greenhouse gases in Stockholm by 2030. The targets were based on the United Nation's (IPCC) recommendations for an acceptable CO_2 level in the atmosphere, corresponding to a 70% reduction from the present level. We analysed a range of specific transport policies, vehicle technologies and renewable fuel shares that would comply with target achievement. To analyse the effects of various traffic policies and mobility management services at a macro scale in the Stockholm region, we applied the transport modelling system SAMPERS and EMME2, with which we experimented on three alternative types of policy measures contributing to achieving the emission target: (1) Reduced transport volumes from potential future adoption of alternative, less car-dependent 'mobility management services', presented in Papers 1-4, *e.g.* car-sharing, ride-matching, telecommuting, videoconferencing, cycling and public transport; (2) Specific travel demand measures such as traffic tolls, car-free streets, increased fuel taxes and free public transport; and (3) Increased share of renewable fuel vehicles and fuel efficiency regulations on private vehicles in the transport system.

In spite of the most drastic travel demand scenarios experimented with in Paper 5, a renewable fuel mix of at least 50% was required in order to reach the emission target. However, increasing the individual travel choice set (by attractive mobility management alternatives and virtual communication) will most likely be of increased importance in facilitating a market-orientated transition to more energy-efficient travel behaviour, if fossil fuel prices continue to rise as a consequence of national emission targets and the imminent peak oil dilemma. Furthermore, quite modest emission impacts from *e.g.* 10% reduced car commuting in Stockholm might involve large savings in traffic-related costs from emissions, accidents and in vehicle times – savings that should be kept in mind when discussing the investment costs of infrastructure and renewable energy systems for the future.

Paper 6. *Biofuels in the energy transition beyond peak oil – A macroscopic study of energy demand in the Stockholm transport system 2030*

As discovered in Paper 5, future emission targets are strongly dependent on renewable fuel assets. In Paper 6 we focused on the biofuel potential of Swedish biomass, in relation to the energy efficiencies from personal travel at a regional level. The backcasting target consisted of a full transition to domestically produced biofuels in the transport system of Stockholm County by 2030, without exceeding the proportional share of national bio-energy assets. In particular, we demonstrated the energy efficiency potential of a *compound scenario*, synthesising energy-efficient vehicles, various travel demand measures and mobility management services under the influence of tightened conditions on the energy market after the global peak of fossil oil and gas extraction. We discovered that due to potential synergy effects, it is likely that the largest energy efficiencies and emission reductions would be achieved from a variety of measures rather than focusing single-mindedly on one at a time. In this compound scenario the negative rebound effects were kept to a minimum and the backcasting target was met when 65% of the regional proportion of biofuels was set aside for the transport sector.

We concluded that: a) biofuels (*e.g.* methanol, ethanol, DME and Fisher-Tropsch diesel) are efficient hydrogen carriers and will thus play a vital role in the transition from fossil to renewable fuel systems in the post-carbon era, when other renewable energy sources (wind, hydro, solar, wave energy) will successively enter the market; b) Swedish bioenergy assets in combination with a well-developed vehicle industry could be used strategically. Peak oil is a global dilemma, and countries taking the lead in adapting to this will have the opportunity to export technology and know-how to other countries as oil prices continue to rise and the need for alternative energy systems becomes acute; c) transport modelling is needed in order to derive energy quantities at a macro scale of the transport system, incorporating negative rebound effects and fuel price effects; and d) it is necessary to conduct rigorous studies of energy efficiency potentials in *all* energy sectors before making comprehensive assessments of reasonable distributions of bioenergy assets. A question for further research is the extent to which is it profitable to produce biofuels in Sweden in relation to production in low cost regions in the developing world.

4. Summary and conclusions

The thesis develops a generic approach for efficiency assessments and monitoring of compound urban travel strategies meeting future demands on resource efficiency, with particular emphasis on climate and energy targets. Methods of dealing with these problems involve higher energy efficiency of traffic systems per utility. Such methods also exert positive effects on sustainability aspects other than climate, e.g. on land use for traffic infrastructure and energy production and on consumption of materials. We focused on how the regional and organisational levels of society could meet the challenge of diverting the transport system into sustainable directions, without compromising individual mobility. To a large extent, the study is characterised by a bottom-up travel demand approach, providing decision-makers with a quantitative basis for prioritising between travel strategies consistent with individual preferences.

Adaptation to future conditions regarding tougher emission restrictions and increased fuel prices beyond peak oil is a multi-stakeholder process that should be flexible over the course of time and incorporate many viewpoints and complex factors consistent with the conceptual target. In this respect, backcasting is applicable in the creation of strategic travel policies at company, regional or global level. Furthermore, long-term targets should preferably be supplemented by a chain of intermediate targets where short-term payoffs could be identified early in order to fuel the process and maintain the motivation to achieve more long-term targets. In identifying such short-term payoffs while avoiding harm to individual preferences and mobility, we found econometric modelling and traffic modelling a rewarding instrument in the search for feasible strategies in the planning process. Without a comprehensive transport modelling approach, it is impossible to quantify potential rebound effects adherent to efficiencies in the transport system and to explore how these could be counteracted by various travel demand measures. Furthermore, this work highlights the importance of implementing and synthesizing both demand and supply-side policies in order to reduce energy use and greenhouse gas emissions from the transport sector.

Two complementary driving forces could be identified, potentially inducing a paradigmatic shift toward development of sustainable transport. On is a successive transition to renewable fuels, induced by hardened travel demand strategies to counteract the greenhouse effect and tougher conditions on the energy market after the approaching peak of fossil oil. Another is creation of more attractive and resource-efficient mobility management and communication alternatives that would increase the individual's set of travel choices and help renewable fuel assets to suffice.

There is reason to believe that all actors and energy sectors of society will be influenced by harsher future energy conditions. From this perspective, companies fill a vital role as a link between individuals and society at large in the coming energy transition of the transport system. The main incentives for companies to launch travel plans, emerging from the analysis in the thesis would be to: a) Reduce costs from inefficient business travel and employee commuting to work since emissions and costs often go hand in hand; b) be foresighted and prevent risks with unstable energy prices and stricter demands on travel in order to counteract the greenhouse effect and local traffic problems in the future; c) improve public relations and raise the standard for environmental audits by developing profound climate strategies; d) provide employees with good communication and transport alternatives in order to attract efficient, competent and healthy staff; and e) show best practice through their own products or services related to sustainable communications in relevant lines of business.

Employees spend considerable amounts of money and time on each commute. Thus, employers helping their workforce to achieve more resource-efficient travel would play an active role in improving the employees’ working conditions. Empirical studies of employees’ conditions for changing travel behaviour could be of significant value to market-orientated traffic planning based on a dialogue between employees and actors potentially realising employee requirements for choosing more resource-efficient alternatives (real-estate managers, public transport providers, local governments).

The all-embracing conclusion from the studies in the thesis is that target oriented traffic planning at a regional macro scale, in combination with travel plan initiatives at companies and organisations at a micro scale, will play an increasing role in the future with stricter energy and emission conditions imposed on society. From a strategic planning perspective, the transport system of Sweden in general, and the Stockholm region in particular, has favourable prospects for the transition to a renewable fuel economy: A well-developed public transport system; relatively large national biofuel assets; a strong tradition in the engineering and vehicle industries; and relatively high public and political awareness of climate change. Peak oil and climate change are global dilemmas, and countries taking the lead in adapting to these are likely to have the opportunity to export technology and know-how to other countries as oil prices continue to rise and the need for alternative energy systems becomes acute.

To that end, the thesis highlights the research field of sustainable planning and modelling as yet another vital dimension of technological development in the approaching energy transition.

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