Sustainability. Exploring the road ahead for car mobility

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Preface

The concept of sustainable development, achieving improvement on social, environmental and economical aspects always interested me. After previous researches on free public transport and on cycling in Tanzania and in the Netherlands, it was time to discover the possibilities for the car to be sustainable. It all started with the project ‘A car in the future’, to which I contributed on behalf of the University of Twente and what was supposed to be my graduation project. It was an interesting project about designing an environmental sustainable car for the future with the AutoRAI exhibition as a climax. I was supposed to write a scenario for the car in the future. However, I found some difficulties concretising my master thesis. Normally you first write some scenarios and than you use the scenarios to see if you your ideas or products fit in it. I had to do it the other way around, because when I entered the project there were already far developed plans. Because I did not want to loose my own graduation out of sight, I made the decision to help the project where I could, but also to start my own research after sustainable car mobility in the future.

At the Netherlands Environmental Assessment Agency (MNP) in Bilthoven, I found a place to do my research in a professional organisation. I felt very welcome and enjoyed my stay. Besides performing the research there, I found it very interesting to hear and see what important issues on the political agenda were, how political games were played via media and above all if found it interesting to learn from and work with colleagues.

From all the people working at MNP, I especially would like to thank Karst Geurs for his advice as a traffic expert and for being such a pleasant roommate, Hans Nijland and Gerben Geilenkirchen for being great colleagues, and last but not least my coach Anco Hoen for his time, supervision and useful comments.

From the University of Twente I would like to thank Kasper Van Zuilekom for the pleasant collaboration in the ‘car in the future project’, for his interesting views and for reading my report. Of course, I also would like to thank my professor Martin van Maarseveen for his supervision, comments and flexibility.

Finally, I would like to thank my dad, Ton Terlouw, for reading my report and giving suggestions on improving my English.

Jeroen Terlouw

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Samenvatting

Een verkenning van de route naar duurzame automobiliteit.

Mobiliteit heeft een belangrijke maatschappelijke functie en kan gezien worden als een van de drijfveren van onze samenleving. Echter, mobiliteit heeft ook negatieve effecten voor de maatschappij zoals uitputting van natuurlijke bronnen, luchtvervuiling, geluid en stank overlast, verkeersonveiligheid en files. De auto speelt hierin een belangrijke rol, zowel bij de positieve als de negatieve effecten van mobiliteit. Deze studie probeert inzicht te geven in de mogelijkheden om de negatieve effecten van automobiliteit te verminderen en de positieve effecten te versterken. Om hierbij enig houvast te hebben, wordt het concept van ‘duurzame ontwikkeling’ toegepast op mobiliteit.

‘Duurzaamheid’ bestaat uit drie hoofdelementen: economische, sociale en ecologische. Een vertaling van dit concept naar mobiliteit heeft geresulteerd in vijf pilaren waarop duurzame mobiliteit rust: i) bereikbaarheid representeert de economische voorwaarden, ii) toegankelijkheid, iii) verkeersveiligheid en iv) leefbaarheid vertegenwoordigen de sociale aspecten en v) natuur en milieu vertegenwoordigt de ecologische condities. Aan deze pilaren voor duurzame mobiliteit zijn vervolgens streefwaarden gekoppeld. Deze zijn achtereenvolgens ‘geen voertuigverliesuren’, ‘geen procentuele stijging van de huishouduitgaven aan mobiliteit’, ‘geen verkeersdoden’, ‘geen geluidsoverlast van auto’s’ en ‘geen uitstoot van auto’s’.

‘Ontwikkeling’ is de andere poot onder het concept. De doelstelling van deze studie is het achterhalen van realistische combinaties van maatregelen en technische mogelijkheden die voor 2050 kunnen leiden tot de hierboven genoemde duurzame streefwaarden van auto mobiliteit. Verbeteringen op weg naar deze streefwaarden wordt gezien als ontwikkeling tot duurzame auto mobiliteit daar zowel benaderbaarheid als haalbaarheid van doelen in maatschappelijke besluitvorming belangrijk geacht worden..

In plaats van voorspellen, het extrapoleren van huidige trends, wordt de backcasting aanpak gebruikt. Deze werkwijze schetst wenselijke toekomsten die nadruk leggen op het oplossen van maatschappelijke problemen. Daarnaast analyseert het de gevolgen en voorwaarden om deze toekomsten werkelijkheid te laten worden.

In deze studie is het WLO scenario ‘Global Econmy (GE)’, een scenario met een sterk groeiende economie, gebruikt als referentie om de maximale inspanningen vast te stellen die nodig zijn om de streefwaarden voor duurzame mobiliteit te behalen. Als het GE scenario in 2050 vergeleken wordt met de streefwaarden voor duurzame mobiliteit is een duidelijke beleidsmatige discrepantie zichtbaar. Ten opzichte van de huidige situatie verdubbelt volgens dit scenario het aantal voertuigverliesuren, het aantal verkeersdoden blijft ongeveer gelijk, het gebied met geluidsoverlast neemt iets in omvang toe en de hoeveelheid CO2 uitstoot verdubbelt bijna.

Als het beleidstekort voor duurzame automobiliteit in maatschappelijke kosten wordt uitgedrukt resulteert dit in 1,7 miljard euro voor bereikbaarheid, 6,4 – 8,0 miljard euro voor verkeersveiligheid, 3,3 – 4,4 miljard euro voor leefbaarheid (geluidsoverlast) en 2,6 – 5,7 miljard euro voor natuur en milieu.

Voor het jaar 2050 zijn drie scenario's (of combinaties van maatregelen en technische ontwikkeling) geconstrueerd, waarvan verwacht wordt dat deze de mate waarin mobiliteit duurzaam is verhogen. Van deze scenario's wordt verwacht dat ze de maatschappelijke kosten verlagen. De drie scenario's zijn geschetst binnen het Global Economy scenario. 'Technology Take-over' is het eerste scenario en wordt gedreven door opkomende technologieën. Van volledig geautomatiseerd rijden op de snelweg wordt verondersteld dat het zowel de voertuigverliesuren en het aantal serieuze verkeersslachtoffers vermindert en van batterij elektrische voertuigen (BEV) wordt verwacht dat het op basis van duurzame energie de uitstoot van schadelijke emissies minimaliseert. Een tweede scenario 'Conscious Consumer', verondersteld dat mensen bewust worden van duurzaamheid en hier naar streven. Het minimaliseren van maatschappelijke kosten wordt in dit scenario gerealiseerd door drie aandachtsvelden: i) een verandering van de perceptie van voertuigverliesuren, ii) een infrastructuur die uitnodigt tot wenselijk gedrag dat het aantal serieuze verkeersslachtoffers moet reduceren en iii) keuze van een duurzame brandstofcel auto (FCEV) als vervoermiddel die de schadelijke emissies tot een minimum moet terugbrengen. In het derde scenario 'Exploiting Conventional Technologies', worden conventionele technologieën gebruikt en geoptimaliseerd. Een kilometerheffing gedifferentieerd naar tijd, plaats en emissie moet de voertuigverliesuren verminderen. Van een systeem dat het autogebruik registreert wordt verwacht dat het de verkeersveiligheid verbeterd. Ten derde wordt in dit scenario gebruik gemaakt van een op efficiency geoptimaliseerde auto met verbrandingsmotor (ICEV) in combinatie met biobrandstoffen om de schadelijke emissies terug te dringen. In alle drie de scenario's zijn de maatregelen die geluidsoverlast bestrijden gelijk. Stille banden en stil asfalt zullen de overlast tot een minimum moeten beperken.

Een analyse van de kosten en baten is uitgevoerd om te onderzoeken of de maatregelen succesvol kunnen zijn. Succesvol in de zin van het bereiken of benaderen van de streefwaarden voor duurzame mobiliteit én een gunstige maatschappelijke kosten-batenverhouding. Gebaseerd op deze analyse is tot de volgende bevindingen en aanbevelingen gekomen:

1. *Brede kijk maakt duurzame ontwikkeling voor mobiliteit haalbaar;*
    - Alle drie de scenario's tonen een positieve netto balans. Duurzame ontwikkeling nastreven leek van te voren een ambitieus doel. Dit werd echter vooral ingegeven door het ecologische aspect van duurzaamheid. Wanneer echter ook de andere aspecten van duurzaamheid (sociale ontwikkeling en bereikbaarheid) in ogenschouw worden genomen, blijkt duurzame ontwikkeling op het gebied van automobiliteit op basis van maatschappelijke kosten en baten goed realiseerbaar.

- Op basis van deze bevindingen is het aan te bevelen om duurzaamheid integraal te bekijken. Dat wil zeggen, rekening houdend met zowel de economische, sociale als ook de ecologische aspecten.
- Wanneer de scenario's vergeleken worden, komt 'Conscious Consumer' er het beste uit. Dit komt vooral door de positieve effecten van de verkeersveiligheidsmaatregelen als gevolg van duurzaam veilige aanpassingen aan de infrastructuur in dit scenario. Wordt dit aspect buiten beschouwing gelaten dan blijkt dat het niet veel uitmaakt welke route naar duurzame mobiliteit genomen wordt, alle scenario's tonen dan een vergelijkbare kosten-batenverhouding en vergelijkbare effecten.

2. *Duurzaamveilige infrastructuur en geluidsmitigerende maatregelen hebben prioriteit;*

   - Verkeersveiligheid maakt met de geselecteerde maatregelen een duurzame ontwikkeling door, al blijken de streefwaarden (geen serieuze verkeersslachtoffers) niet haalbaar. De geselecteerde maatregelen hebben wel een positief netto rendement. In het bijzonder de infrastructuur die uitnodigt tot wenselijk gedrag in combinatie met de introductie van specifieke intelligente transport systemen laat goede resultaten zien.
   - Geluidsoverlast van auto's kan geminimaliseerd worden door het gebruik van stille banden en stil asfalt. Deze maatregelen blijken bovendien een zeer positieve netto kosten-batenbalans te hebben.
   - In het streven naar duurzame ontwikkeling van de automobiliteit onder een gunstige maatschappelijke kosten-batenverhouding wordt dan ook aanbevolen prioriteit te geven aan de inrichting van een duurzaamveilige infrastructuur in combinatie met de implementatie van specifieke intelligente transportsystemen en geluidswerende maatregelen.

3. *Voor een duurzame ontwikkeling van natuur en milieu lijkt het niet op voorhand noodzakelijk om onze huidige infrastructuur om te gooien voor bijvoorbeeld een batterij- of waterstofauto, optimalisatie van de conventionele auto kan namelijk ook toereikend zijn. Wel zijn maatregelen onder deze pijler voor een eventuele netto positieve balans erg afhankelijk van ontwikkelingen van de olieprijs, de waardering van een ton vermeden CO_2, en de ontwikkelingen van specifieke motortechnologieën;*

   - Beschadiging van natuur en milieu door emissies kan sterk gereduceerd worden. In alle drie de scenario's kan de uitstoot schadelijke uitlaatgassen tot bijna nul worden terug gedrongen. Netto kost dit de maatschappij echter geld. De bandbreedte van de kosten kan in de toekomst zelfs leiden tot een netto baat. Om dit te bereiken moet echter wel een negatief netto saldo op maatschappelijke kosten en baten worden geaccepteerd. Alle maatregelen laten namelijk een negatief netto saldo zien. De toekomstige olieprijs heeft een grote invloed op de haalbaarheid en is bovendien erg onzeker. Daarnaast heeft de waardering van een vermeden ton CO_2 grote invloed op de baten, hierbij komt dat de in literatuur genoemde bandbreedte zeer groot is. Ook de onzekerheid over en de ontwikkeling van specifieke motortechnologieën en de hiermee samenhangende kosten zijn erg groot. Deze onzekerheden betekenen dat een mogelijke positieve omslag met betrekking tot de kosten-batenverhouding bereikt kan worden door een verdere stijging van de olieprijs, scherpere doelstellingen voor CO_2 emissie reductie of een gunstige prijsontwikkeling van de gerelateerde motortechnologieën.

- Verder onderzoek is nodig om de onzekerheden te reduceren en de bandbreedte van de drie hierboven genoemde aspecten, olieprijs, emissiewaarde en additionele auto technologie kosten, te verkleinen.
- Geen van de verschillende voertuigtechnologieën, BEV, FCEV en de geoptimaliseerde ICEV zijn onderscheidend in kosten en baten., welke emissie waarde of olie prijs dan ook. Derhalve kan op basis van de resultaten van dit onderzoek in dit opzicht geen beleidsmatige conclusies worden getrokken.
- Omdat een keuze voor een specifieke voertuigtechnologie niet kan worden gemaakt op basis van de kosten en baten, betekent dit dat andere factoren die een rol spelen bij beslissingen belangrijker worden. De weg naar de geschetste scenario’s of het transitiepad wordt hierdoor essentieel. Ook al bieden de BEV en FCEV iets hogere energie efficiency en een hogere flexibiliteit in brandstof keuze, er moeten nog wel enkele technologische barrières overwonnen worden en bovendien is een ingrijpende infrastructurele verandering vereist. Voor de optimalisatie van de ICEV, geldt dit niet en deze lijkt daarom een makkelijker transitiepad te hebben. Dus waarom zou Nederland een hele infrastructuur omgooien als met optimalisatie van huidige technieken hetzelfde kan worden bereikt? Om deze reden wordt geadviseerd dat beleid zich niet alleen richt op nieuwe voertuigtechnologieën maar dat ook het optimaliseren van de ICEV en het verbeteren van de energie-efficiency niet uit het oog wordt verloren.
- Tegelijkertijd wordt aanbevolen de mogelijke negatieve effecten van de benodigde biobrandstoffen zoals suikerrietethanol op concurrentie met de voedselproductie te onderzoeken. Als de negatieve effecten hanteerbaar zijn, betekent dit een relatief gemakkelijke weg naar duurzame auto mobiliteit. Zijn de effecten niet hanteerbaar, dan kunnen de efficiëntieverbeteringen ook nuttig zijn voor een transitie naar een BEV of een FCEV. In het bijzonder het verminderen van gewicht, rolweerstand en luchtweerstand zijn voor alle wegen naar duurzame automobiliteit nuttig.

4. *En bereikbaarheid dan?;*

- Bereikbaarheid geeft veel stof tot discussie omdat het mensen direct en persoonlijk raakt als reistijden toenemen. Natuur en milieu, verkeersveiligheid en geluidsoverlast hebben daarentegen veel hogere maatschappelijke kosten en dus hogere potentiële baten. Deze leiden tot minder discussie omdat ze mensen meestal minder persoonlijk raken. Het is daarom aanbevelingswaardig om mensen meer bewust te maken van deze tegenstrijdigheid door internalisering van deze externaliteiten.

- De bereikbaarheidsmaatregelen hebben een positieve netto balans, al is deze geringer dan die van verkeersveiligheid en leefbaarheid. Bereikbaarheid kan niet verbeterd worden in het hoogste groei scenario (GE), maar zonder de geselecteerde maatregelen en technologieën verslechterd de bereikbaarheid. Bovendien, wordt de positieve balans voornamelijk veroorzaakt door het minimaliseren van externe effecten. De kilometerheffing en de geautomatiseerde snelweg laten het hoogste netto rendement zien in termen van maatschappelijke kosten en baten. De verwachting is overigens dat de maatregelen in de andere drie WLO scenario's (met minder hoge economische en inwonersgroei) wel tot een verbetering van de bereikbaarheid leiden.
- Bereikbaarheid is het enige duurzaamheidaspect dat in de drie geschetste scenario's verslechtert ten opzichte van de huidige situatie, tenminste als het aantal voertuigverliesuren als indicator wordt gehanteerd. Dit zou betekenen dat er meer en andere maatregelen noodzakelijk zijn. Overigens dient hierbij de kanttekening te worden gemaakt dat dit aspect relatief lage maatschappelijke kosten met zich meebrengt. Met de komst van intelligente transport systemen is het aannemelijk dat de perceptie van voertuigverlies uren verandert en dat andere indicatoren zoals bijvoorbeeld de betrouwbaarheid van reistijd belangrijker worden. Het hanteren van andere indicatoren voor bereikbaarheid lijkt dan ook wenselijk.

5. Voor zover onderzocht, lijken alleen de additionele autokosten een gelijke toegang voor alle personen tot automobiliteit in de weg te staan.
   - Gelijke toegang tot personenautomobiliteit kan een probleem worden door de hoge additionele kosten voor de in de scenario's veronderstelde voertuigen. Dit zou ondermeer gecompenseerd kunnen worden door subsidies.
   - Bovendien kunnen lagere gebruikskosten worden verwacht voor brandstof omdat in alle scenario's sprake is van een verbeterde energie-efficiency van de voertuigen.

Trefwoorden:

Duurzame mobiliteit, Duurzaam transport, Bereikbaarheid, Toegankelijkheid, Verkeersveiligheid, Leefbaarheid, Natuur en milieu, Backcasting, Kosten Baten Analyse

Summary

Sustainability. Exploring the road ahead for car mobility.

Mobility has an important societal function. It can be seen as the motor of our society. However, mobility and its growth have external effects on welfare as well, such as, depletion of natural resources, air pollution, noise and smell nuisance, traffic un-safety, and congestion. The car has both positive and negative effects on mobility and therefore an important influence on welfare. This study strives to gain an insight into the possibilities to improve positive effects and at the same time minimise negative effects of car mobility. In order to have a reference, the concept of 'sustainable development' is applied to mobility.

'Sustainability' includes economic, social, and environmental aspects. A translation of this concept to mobility resulted in five pillars on which sustainable mobility rests: i) accessibility representing the economical conditions, ii) transport equity, iii) traffic safety, and iv) liveability representing the social conditions and v) nature and environment representing the environmental conditions. In addition, targets were linked to these sustainable mobility pillars. These targets are 'zero lost vehicle hours', 'no rise of pro rata household expenditures on mobility, 'zero traffic casualties', 'no road traffic noise nuisance' and 'zero emissions from cars'.

'Development' is the other angle of the concept. The objective of this study is to find realistic combinations of measures and technical possibilities for 2050 that might lead to the sustainable target values of car mobility referred to above. Improvements that approach these target figures are considered an important contribution to developing sustainable car mobility, since both approachability and achievability are considered important for decision-making.

Instead of forecasting, the extrapolation of current trends, the backcasting approach is used. This method describes desirable futures that focus on solving societal problems. In addition, it analyses consequences and conditions to arrive at these futures.

In this study the WLO scenario 'Global Economy (GE)', a scenario with strong growing economy, was used as a reference to address the maximum required effort for achieving the sustainable mobility targets. Comparing the GE scenario in 2050 with the sustainable mobility targets, illustrates a policy discrepancy. According to the GE scenario and in comparison with the current situation, the lost vehicle hours will double, the number of fatalities in traffic remains equal, the area with noise nuisance shows a little increase and CO2 emissions almost double.

Expressing these gaps in costs for society resulted in 1.7 billion euro for accessibility, 6.4 – 8.0 billion euro for traffic safety, 3.3 – 4.4 billion euro for liveability, and 2.6 – 5.7 billion euro for nature and environment.

Three scenarios (or combinations of measures and technical possibilities) for the year 2050, were constructed of which it is expected to increase the degree to which the sustainable

mobility targets are achieved. These scenarios were intended to decrease the social costs. The three scenarios were constructed within the ‘Global Economy’ scenario. ‘Technology Take-over (TT)’ is the first scenario and is driven by emerging technologies. Autonomous driving on a highway is supposed to reduce lost vehicle hours and traffic casualties and battery electric vehicles (BEV) are expected to minimise emissions to a minimum. A second scenario, ‘Conscious Consumer (CC)’, presumes people becoming aware of sustainability striving to it. Minimising social costs should be realised by changing the perception of lost vehicle hours. Infrastructure that invites for desired usage that should reduce traffic casualties. People adopting the fuel cell electric vehicle as their transport means is expected to minimise the emissions. In the third scenario ‘Exploiting Conventional Technologies (ECT)’, conventional technologies and measures are used, and optimised. A kilometre and emission based charge for vehicles should minimise lost vehicle hours, an event recording system is expected to improve traffic safety and an optimised conventional combustion vehicle in combination with the usage of biofuels are used in this scenario to minimise social costs related to the environment. Equal in all three scenarios are the usage of silent tires and silent asphalt to tackle the noise nuisance problem.

An analysis of the costs and benefits is carried out to examine if the measures are successful, in the sense of achieving or approaching the targets for sustainable mobility coupled to a favourable social cost benefit ratio. This analysis resulted in the following findings and recommendations:

1. A broad look makes sustainable development for mobility achievable;
    - All three scenarios show a positive net balance. Before this study, striving for sustainable mobility seemed ambitious. This was mainly inspired by the ecological aspect of sustainability. However, when the other aspects of sustainability (social development and accessibility) are taken into account as well, sustainable development for car mobility seems to be feasible based on costs and benefits.
    - Based on these findings, it is recommended to use sustainability integrally. This means, considering economical, social and environmental aspects.
    - When comparing the scenarios, ‘Conscious Consumer’ shows the best results. This is mainly due to the positive effects of the traffic safety measures because of sustainable safe adaptations on infrastructure. Not considering this aspect shows that it does not matter which road to sustainable mobility will be taken, since they have equal cost benefit ratios and equal effects.
2. Sustainable safe infrastructure and noise abatement measures have priority;
    - Traffic safety can make a sustainable development; however, the targets (no serious traffic casualties) are not achieved. Selected measures do have a positive net benefit. Especially the sustainable safe infrastructure in combination with some intelligent transport systems showed good results.

- Noise nuisance of car mobility can be reduced to a minimum by implementing silent tires and silent asphalt; in addition, these measures have a very positive net benefit.
- In striving for sustainable development for car mobility under a favourable societal cost benefit ratio, it is recommended to give priority to the design of sustainable safe infrastructure in combination with specific intelligent transport systems and noise abatement measures.

3. For sustainable development of nature and environment there is no need to change our current infrastructure to battery or hydrogen vehicles, since optimising the conventional car can be sufficient as well. However, the measures belonging to this pillar depend on development of the oil price, the value of an avoided tonne of CO_2, and the development of specific engine technologies in order to realise a positive net balance;

- Damage to nature and environment by emissions can be reduced heavily. In all three scenarios, emissions can be minimised to almost zero. However, this can only be done at net costs to the society. The extend to which these cost may vary in future can even result in a benefit to society. Future oil price is uncertain and has a direct impact on feasibility. The value of one tonne avoided CO_2 emission has great impact on the benefits and has wide range in literature. Uncertainty about the development of specific engine technologies and related costs are high. These uncertainties indicate that an even further increasing oil price, higher CO_2 emission reduction targets, or improvements in one of the related engine technologies could give positive net benefits.
- Further research is required to reduce the uncertainties and narrow the bandwidth of the three above aspects: oil price, CO_2 emission value and additional car technology costs.
- From the various vehicle technologies, BEV, FCEV, and the optimised biofuel ICEV none stand out on costs and benefits, whatever emission value or oil price, consequently no policy conclusions can be drawn on this aspect. Difference in development of on the vehicle technologies might lead to a distinguishing cost benefit ratio.
- Because a decision in relation to nature and environment cannot be made based on costs and benefits, other factors that play a role in decision-making become increasingly important. The road towards the sketched scenarios becomes vital. Although the BEV and the FCEV show higher efficiency rates and higher flexibility in fuel choice, they still need to overcome some technical barriers and require considerable changes in infrastructure. For exploiting conventional car technologies this is not required, and thus seems to have an easier transition path. So why should the Netherlands (and other countries) shift towards to other infrastructures, while optimising current technologies lead to the same results? Therefore it is recommended that policies emphasise on optimising ICEVs and on increasing there efficiency, not ignoring other new vehicle technologies.

- At the same time, the possible negative effects of using biofuels like sugarcane ethanol on food competition should be studied in more detail. If the negative effects of sugar cane ethanol are manageable, this is an easy sustainable road ahead. If they are not manageable, the achieved efficiency improvements can also be beneficial for a transition towards BEVs or FCEVs. Especially weight, rolling resistance, and drag reduction are favourable for all roads to sustainability.

4. And what about accessibility?

- Accessibility is much debated because it affects people directly and personally by increasing travel times. However, nature and environment, traffic safety and noise nuisance have much higher social costs and thus higher potential benefits. These are less debated since they do not affect people so much on a personal level. It is therefore recommended to make people more aware of this discrepancy by internalising externalities.
- The accessibility measures have a positive net balance although smaller then safety and liveability measures. Accessibility cannot be improved in the highest economic growth scenario (GE), but without the selected measures and technologies, the accessibility would aggravate. Moreover, the positive net benefit is mainly achieved by minimising external effects. The ‘kilometre and emission based charge’, and the ‘automated highway system’ reveal the highest net benefits. It is expected that in the other three WLO scenario’s (with lower economic and population growth), the selected measures would result in improved accessibility.
- Accessibility is the only sustainable mobility aspect that aggravates in the three sketched scenarios compared to the current situation, at least when lost vehicle hours is used as an indicator. This would mean more and other measures are required to improve this pillar. On the other hand, it has to be noted that accessibility has relative low costs to society. With the arrival of ‘intelligent transport systems’ it is plausible that the perception of lost hours changes and other indicators like reliability of travel time become more important. Using other indicators for accessibility seems advisable.

5. Only additional car costs prevent indiscriminate access to car mobility.

- Transport equity, equal access to mobility, could be a problem due to high additional car costs. This can be compensated by subsidies.
- In addition, lower usage costs can be expected for fuel because in all scenarios the energy efficiency of the vehicles is improved.

Keywords:

Sustainable mobility, Sustainable transport, Accessibility, Transport equity, Traffic Safety, Liveability, Nature and environment, Backcasting, Cost Benefit Analysis

Contents

1 Introduction

1.1 Mobility

Mobility has an important societal function. An increase in passenger transport contributes to more welfare. After all, by moving themselves over longer distances, individual persons are able to accept jobs that better fit there capacities and specialities, move into accommodations and visit shops and other facilities that better fit to their personal preferences. In addition, transportation of goods enables agriculture, industry and specialized production to grow, especially on an international scale. On their turn, those developments also lead to an increase of material welfare.

In the last 20 years, the mobility in our country has grown. This growth is associated with an increase of travel distances, one of the reasons being the increasing availability of faster transport modes and transport systems itself (for instance better road connections). This trend is the result of strong increases in income, real decrease in transport costs, individualisation, smaller households, emancipation and an increase in double-income couples. In addition, a larger group reached the ‘active’ age group, between 20 and 65 years old. The growth of this group caused an increase in car possession and use. Over the last 30 years, the car fleet has increased from three until seven million cars.

Next to positive internal effects on welfare, mobility and its growth has external effects on welfare as well, mainly negative.

1.2 External effects of traffic and transport

In general, external effects are side effects that can be positive or negative. However, the external effects are mainly negative. This applies for external effects in traffic and transport listed here (Van Wee & Dijst, 2002):

- Exhaustion of natural resources
- Enhanced greenhouse effect
- Acidification
- Local air pollution
- Noise and smell nuisance
- Traffic un-safety
- Accessibility and congestion

All the listed external effects have a negative effect on economy, sociology and ecology. In short, these items will be clarified in the next paragraphs.

1.2.1 Exhaustion of natural resources and enhanced greenhouse effect

The total global emission of CO_2 (the main global warming gas) has increased by about 60% (1971-2001) to nearly 24 billion tonnes (IEA, 2000 and 2001). The share of transport of this total has increased from 19.3% (1971) to 28.9% (2001), so both the absolute and relative share attributable to transport consumption is increasing (EC, 2003). In addition, transport depends almost totally on oil for energy and there seems to be little prospect for a major change even if prices were to rise substantially (Banister, 2005).

1.2.2 Acidification and local air pollution

Traffic and transport are (together with agriculture and horticulture) the main source of the acidifying substances sulphur dioxide (SO2), nitrogen oxides (NOx) and ammonia (NH3) (figure 1.1) for acidifying substances by target sector. For the nitrogen oxides, traffic is even the only main source, accounting for over 65% of the emissions in the Netherlands in 2002 (MNP, 2007).

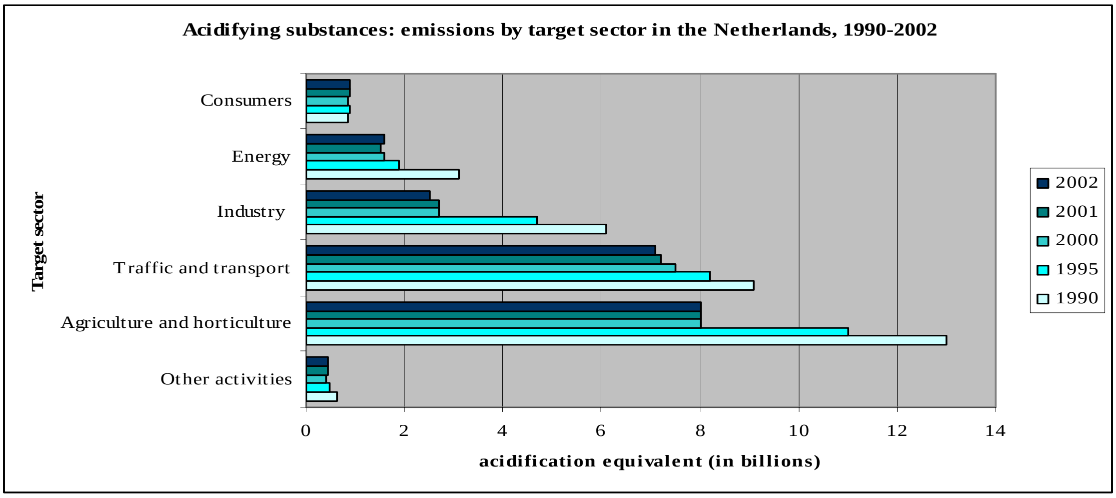

Figure 1.1 Acidifying substances: emissions by target sector in the Netherlands, 1990-2002 (based on MNP(2007))

The effects of acidifying substances is summarised by MNP (2007) as follows: 'The acidifying substances enter plants and trees through leaves and roots, making them more susceptible to disease. Acid deposition leads to higher concentrations of acid and aluminium in rivers and lakes, and ultimately affects the animals that live in them or drink from them. Acidification also affects groundwater. Two-thirds of Dutch drinking water comes from the soil, so this constitutes a threat to public health. Excessive nitrate concentrations in drinking water are particularly harmful for babies. Excessive concentrations of aluminium can cause Alzheimer's disease.'

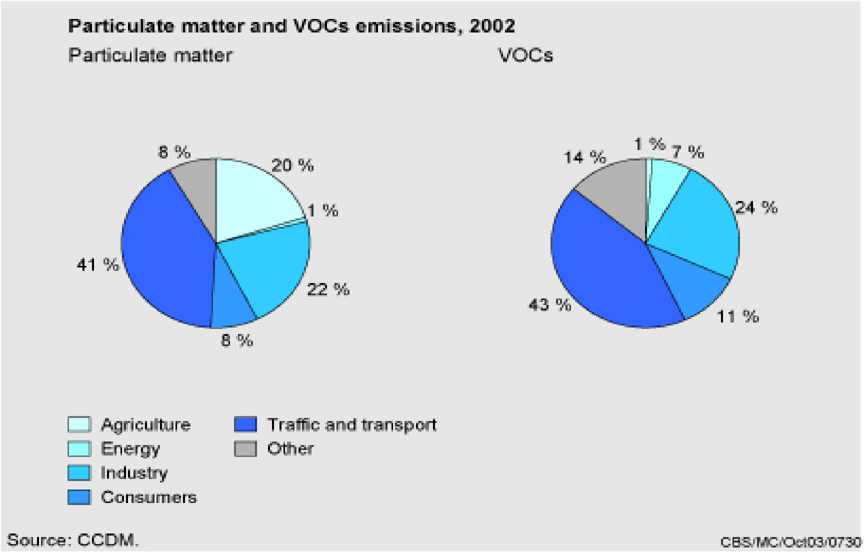

Figure 1.2 Particular matter and VOCs emissions in 2002 per source in the Netherlands (source: MNP (2007))

Transboundary air pollution also includes emissions of volatile organic compounds (VOCs) and particulate matter (MNP, 2007). As can bee seen in figure 1.2, VOCs and particulate matter are both mainly emitted by traffic and industry. The pollution of the environment with these substances has harmful effects on ecosystems, materials and public health (MNP, 2007).

1.2.3 Noise and smell nuisance

Exposure to noise can cause hindrance and disruption of sleep and to a capacity reduction. Via physical stress reactions, this can lead to an increased blood pressure and heart and vascular disease.

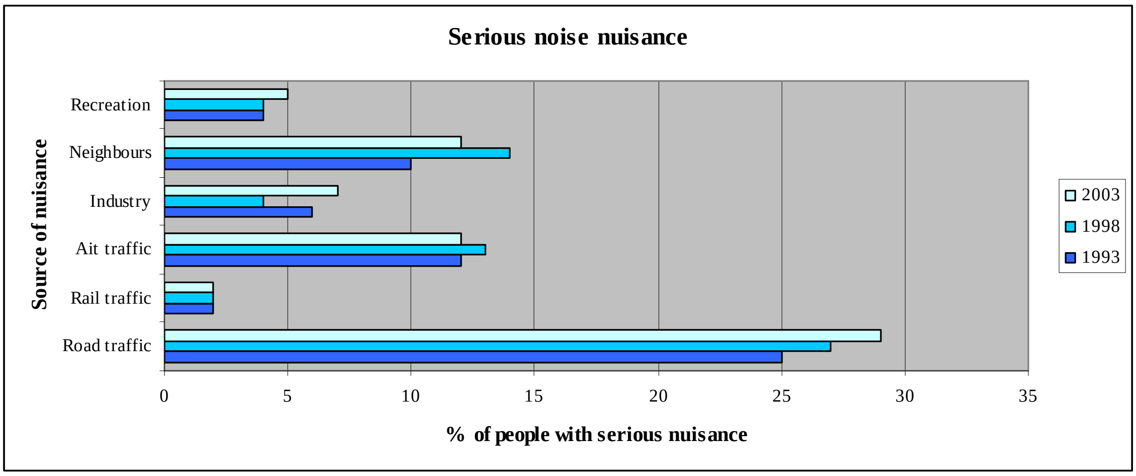

Figure 1.3 Development of serious noise nuisance per source of nuisance in the Netherlands (based on MNP, 2007)

As can be seen in figure 1.3, road traffic is the most important cause of serious noise nuisance. In 2003 29% of the Dutch population (16 years and older) was exposed to serious noise nuisance caused by road traffic. In 1993, this percentage was 25%. This emerged from the national hindrance inventory (Franssen et al., 2004). Because of growing traffic, population density and urbanization the noise nuisance is expected to continue to increase.

In addition, road traffic causes smells. Smell nuisance can lead to physical effects like headache and breathing problems.

1.2.4 Traffic safety

Over the last 30 years, road safety in the Netherlands has improved considerably (figure 1.4). In 2006, 811 people died because of a traffic accident (SWOV, 2007).

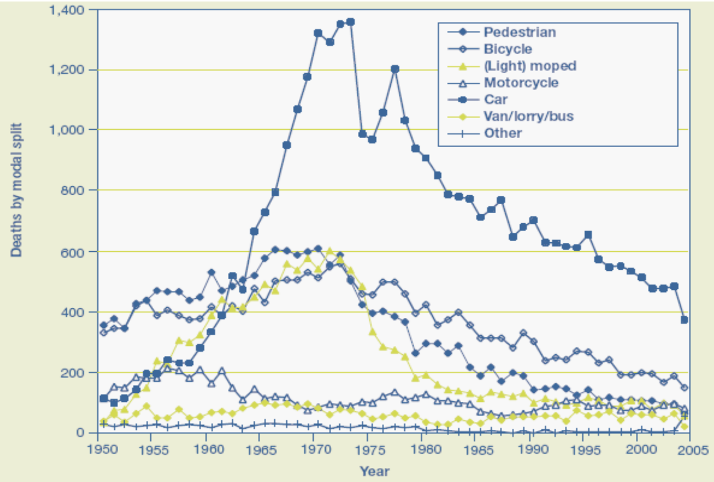

Figure 1.4 Annual registered number of road deaths in the Netherlands by modal split 1950-2004. (Source: Wegman and Aarts (2006))

Although this number is much lower than before, the number of deathly casualties needs to be further reduced. In addition, future social developments such as increased mobility and an aging population put an extra weight on the continued need to focus on achievement of sustainable safe road traffic (Wegman & Aarts, 2006).

1.2.5 Accessibility and congestion

Because of congestion, nodes are less accessible as preferred. This results in economic loss. This loss can be expressed in the number of lost vehicle hours on the road. The total numbers of lost vehicle hours on Dutch motorways on working days are presented in Table 1.1.

Table 1.1 Lost vehicle hours in 1999-2002

Year	Lost vehicle hours (x 1 million)
1999	43,9
2000	45,0
2001	51,6
2002	47,2

(Source: AVV (2004))

1.2.6 Positive effects

Of course, traffic and transport are the driving forces of our society and have many positive effects as well; however, these effects are mainly internal effects. Positive external effects of traffic and transport are negligible and are limited to plane or train spotting (ECOPLAN, 1993; Wit & Gent, 1996).

1.3 The role of the car

There is an important role for the car in respect of the above-mentioned external effects. Modal choices are often made on an individual level; consequently, many choose the car as their means of transport. Commuter and recreational traffic is often done by car. In other words, it provides access to work and recreation. Driving a car is often considered much more attractive than other modes of transport are. The car is especially attractive because of its (Steg & Gifford, 2005):

- Convenience
- Independence
- Flexibility
- Comfort
- Speed
- Pleasure
- Status

In more detail, this means that a car can transport a person and his entire luggage. (convenience). The car can bring someone from door to door, something, which is not possible using the public transport (speed, independence). It is ready whenever it is needed and it goes wherever required (independence and flexibility). There is no physical effort associated with driving a car. In addition, does it provide shelter from weather influences (comfort). Driving can be fun and drivers have their privacy, they can listen to their own music, scratch their nose; actually they can do whatever they want in their own car. Cars are like a ‘second home’ (pleasure). People also feel they can show who they are by showing their car (status).

In comparison to the negative external effects mentioned in the previous paragraph, all these aspects are individual advantages of car use. Collective effects, like most external effects, are only visible on the long term and most advantages of car use are experienced immediately. This causes many to act in their own interest. Steg en Gifford (2005) argue that individuals themselves cannot control the external effects caused by car use; these will be solved only if many individuals cooperate. They also argue that it does not seem sensible to ignore the individual advantages of car use because of the uncertainty about whether others also will act the same.

This report does not judge people that are driven by self-interest, however consequently the number of vehicle kilometres increases annually. Nowadays, passenger cars drive more than 100 billion kilometres, see figure 1.5. Furthermore, at present the increase of vehicle kilometres is coupled to an increase in the external effects.

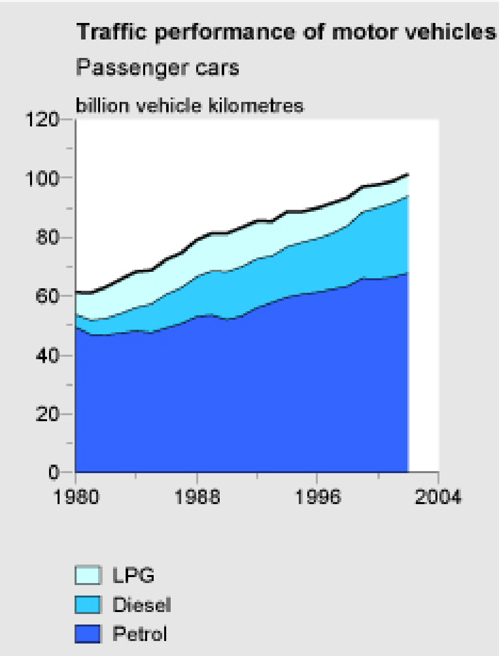

Figure 1.5 Growth of traffic performance of passenger cars in the last decades in the Netherlands (Source: MNP (2007))

1.4 Sustainable development

1.4.1 The limits to growth

'If the present growth trends in world population, industrialisation, pollution, food production, and resource depletion continues unchanged, the limits to growth on this planet will be reached sometime within the next 100 years. The most probable result will be a sudden and uncontrollable decline in both population and industrial capacity.' This is one of the main conclusions of the influential book named 'The Limits to Growth' by Meadows et al. (1972). Another main conclusion in that book sketches another outcome: 'It is possible to alter these growth trends and to establish a condition of ecological and economical stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realise his or her individual human potential.' As third main conclusion Meadows et al. (1972) state that if the world's people decide to strife for this second outcome rather than the first, the sooner they begin working to attain it, the greater will be their chances of success. Understandable, this document created some uproar. This uproar resulted in the establishment of the World Commission on Environment and Development (WCED) in 1984, with the task of formulating 'a global agenda for change'.

1.4.2 Definition of sustainable development

In 1987, the United Nations introduced the concept of sustainable development in a survey known as the Brundtland report. It described sustainable development as: 'Development which meets the needs of the present without compromising the ability of the future generations to meet their own needs'(WCED, 1987). Next to this widely quoted definition, there are many other definitions. Analysis by Akinyemi and Zuidgeest (2000) of those definitions and their underlying philosophy indicates that sustainable development involves two main aspects – sustainability and development. They found that, the basic idea is to harmonise those two aspects of human activities. Their analysis also shows that the focus of most people and organisations is on sustainability related only to the preservation of hypothetically good environment.

1.4.3 Main elements of sustainable development

In contradiction of those who only focus on environmental conditions, other organisations, including the World Bank, define sustainability in terms of three main elements: economic, social and environmental conditions. They are also referred to as triple-P (PPP), standing for people, planet and profit. Since the most recent sustainability conference in Johannesburg (2002), the meaning of the last 'p' is replaced (figure 1.6). Profit became prosperity, indicating that next to economical profit also societal profit should be taken into account. In the present research, sustainability in the broader sense of the definition will be used, emphasising on all the three main elements. In addition, focus will be on development of triple-P.

Figure 1.6 The three main elements of sustainability: people, planet and prosperity

1.4.4 Sustainable mobility/transport

In this study, an attempt is made to translate sustainable development into sustainable mobility. With sustainable development in mind, sustainable mobility can be referred to as a system of mobility for people and goods that cater for the needs of the current generation, without compromising the needs of future generations. Sustainable mobility contributes to economical development, social development (where access plays an important role) and does not (irreversibly) harm the environment, nature and health (Nijland and Ritsema van Eck, 2004). Another definition of sustainable mobility is given by the WBCSD (2004); the ability to meet society's desires and needs to move freely, gain access, communicate, trade and establish relationships, without sacrificing other essential human or ecological values, today or in the future.

The most widely accepted definition of sustainable transportation was agreed on during a council meeting of The Ministers of Transport of the 15 European Union countries in 2001.

This EU definition was taken almost word for word from the definition developed in 1997 by the Centre for Sustainable Transportation in Canada (Gilbert et al., 2002) and defines a sustainable transportation system as follows (Bickel et al., 2003):

- Allows the *basic access* needs of individuals and societies to be met *safely* and in a manner consistent with *human and ecosystem health*, and with *equity* within and between generations.
- Is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy.
- Limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise.

Just like Akinyemi and Zuidgeest (2000) concluded for other definitions, this definition emphasises on the elements of sustainability in transportation, rather than how to develop one. In this study, there will be a focus on developing sustainable mobility.

1.4.5 Five pillars for sustainable mobility

In order to have a reference, this research formulated five pillars for sustainable mobility (figure 1.7). Immers and Stada (2003) used the three main elements of sustainable development to formulate five policy targets for sustainable mobility. These policy targets agree with the EU definition and form the basis for formulating pillars for sustainable mobility.

Economical development stands for economic wellbeing, employment and productivity. For mobility this is summarised by Immers and Stada (2003) with one term, accessibility. No delays or congestions, or in other words shorter travel times would have a great impact on the economical development. Equity, health, safety, and the quality of living environment representing social development, cannot be summarised with one term. Immers and Stada (2003) used three terms. Equity in transport can best be referred to as access to transport for everyone, also for the less wealthy and the disabled in the society. Health and safety can easily be translated to traffic safety, so less fatalities and injuries in traffic. The living environment can be translated to liveability, which includes some forms of nuisance, local air quality and space occupancy. The last element of sustainable development is ecological development, including exhaustion of natural sources, pollution of air, water and soil and biodiversity. These items all reflect the nature and environment (Immers & Stada, 2003) and will be represented by this pillar. Off course, there is some overlap between the five pillars of sustainable mobility. For example, most ecological aspects have influence on the health aspect of social development as well. Here it is important to know that the ecological aspects are divided in global and local influence. Global influence, like global warming, fit in the nature and environment pillar and local influence, for example local air quality, are associated with health and thus liveability. There is also an interface between equity and some parts of economic development, just like traffic safety also implies material damage and thus has economical influence. In spite of this overlap, these five pillars represent the main elements of sustainable development in mobility.

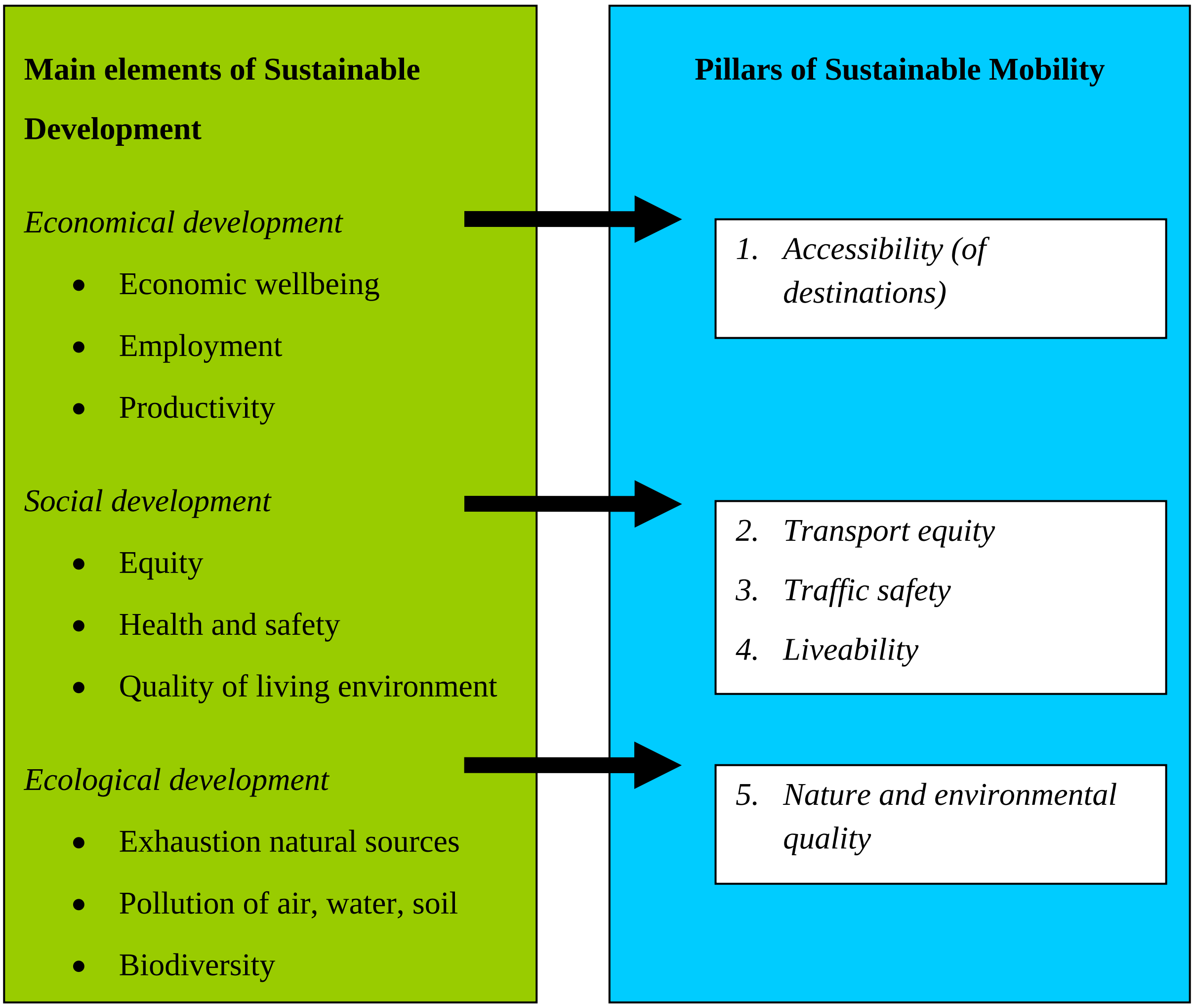

Figure 1.7 From sustainable development to sustainable mobility (Adapted from Immers and Stada, 2003)

1.5 This research

1.5.1 Reason for this research

Europe has announced that by 2020, exhaust of greenhouse gasses are to be reduced with 20% compared to 1990. The Dutch government has even declared in their coalition agreement of 2007 that it wants to go a step further: 30 % reduction of greenhouse gasses in combination with 20% climate neutral fuels and 2% energy reduction. On the long term (2050) even further reductions should be strived for in order to minimise warming up of the earth to a maximum of 2 degrees Celsius. To be able to reach these ambitious goals, the European and Dutch government declared that also the traffic and transport sector should contribute to reduction of CO_2 emissions. In the introduction, these external effects of traffic and transport were also emphasised. In addition, other external effects such as accessibility, liveability and traffic safety are mentioned, as these external effects are important as well. In accordance with the EU definition of sustainable transportation that was derived from the concept of sustainable development, deals with more than only environmental issues: Translation of the main elements of sustainable development to five pillars of sustainable mobility, end goals for sustainable transportation are in sight.

Sustainable development consists of three elements, ecological, social and economical development. As mentioned before, the car is used predominantly for commuting and recreational traffic. In other words, car use contributes to social and economic development. Moreover, despite of policies, people resist getting out of their cars. Instead, car use even continues to increase. People are willing to get into long queues as long as they can take their ‘second homes’ with them. The motives for car use are clear and discussed earlier. Combining the facts that the car is already playing a role in social and economical development and the fact that many people are resisting to take other transport modes than the car, makes it interesting to search for a way in which the car becomes more sustainable.

It is expected that by 2050, significant steps towards sustainable mobility could be made. However, there are different routes towards 2050 that would be a sustainable development. In this study, three of those roads will be examined for passenger car mobility, in order to feed the debate on external effects of traffic and transport and to advice policy makers on possible routes to sustainable mobility. Effects of these routes, on overall welfare and minimised external effects of traffic and transport are considered important outcomes of this study.

1.5.2 Objective

The objective of this study is to find realistic sets of measures and technical possibilities for 2050 that increase the sustainability of passenger car mobility in the Netherlands, by comparing costs and benefits of three different routes. In which sustainable passenger car mobility means zero lost vehicle hours, no pro rata rise of household expenditures on mobility, zero traffic casualties, no road traffic noise nuisance and zero emissions from cars.

Improvements that approach these target figures are considered an important contribution to developing sustainable car mobility, since both approachability and achievability are important. This vision is shared by many goals on different levels in the hierarchy of social and political goals.

1.5.3 Research questions

This report will deal with the following questions:

1. What actions are required to increase the degree to which the targets for sustainable passenger car mobility mentioned in the objective are fulfilled;
2. Which costs and benefits are associated with increasing the degree of fulfilment of these conditions?

1.5.4 Scope of this research

This research has the following boundaries:

- Although other modalities can play a role in sustainable mobility and measures can imply differences and impacts for the whole transport system, this study will only discuss passenger car mobility.
- Aspects like emissions, noise nuisance, space occupancy and congestion are emphasising the need of a sustainable use of the car. According to Orsato and Wells (2006) sustainable mobility cannot be delivered by any industry or production-consumption system that is itself unsustainable. With this in mind a car can be (un)sustainable in two ways. The first is in the way it is used, and the second is in the way it is produced. Looking after production, Lifecycle analysis (LCA) play an important role. In a LCA, the whole life of a product is analysed and assessed, including the raw material production, manufacture, distribution, use and disposal including all intervening transportation steps. For full sustainability, the production needs to be sustainable too. The production method however is not subject of this study. For sustainable production methods one can read the production method according to the philosophy of McDonough and Braungart (2002).
- Although the global aspect is not to be ignored, this research will focus on the Netherlands.
- For this research the WLO (CPB/MNP/RPB, 2006) scenario ‘Global Economy’ will be used. This outlook is used as a reference, in which current trends continue after 2020. This scenario is chosen because the external effects of mobility tend to be the largest because of the relative high economic growth. This gives a good idea of the maximum required efforts when aiming at sustainable mobility. The high economic growth in the Global Economy scenario makes it more difficult to reach sustainable mobility, yet more funds can be made available to finance the attainability of the chosen targets.

1.5.5 Reading guide

Chapter 1 introduced the mobility related external effects and the role the car plays in this. In addition, the concept of sustainable development is applied to mobility and resulted in five pillars for sustainable mobility. The introducing chapter also included the objective of this study. In chapter 2, the used methodologies are described, being backcasting for writing scenarios and analysis of costs and benefits for comparing the scenarios. In the third chapter, the targets required for the backcasting study are described and made measurable. In addition, influencing possibilities of the different targets are explained. Chapter 4 concerns about the scenarios. First the used reference scenario is discussed. The gap between this reference scenario and the backcasting targets is identified. In this same chapter, three scenarios are sketched with measures that aim at increasing the degree to which the targets are fulfilled. In addition, the costs and benefits of all these measures are described. The results, conclusions, discussion and recommendations can be found in the last chapter, chapter 5.

2 Methodology

2.1 Scenario writing

2.1.1 Different methods

There are different scenario writing methods. To find the most suitable method for this study a literature research is performed. The results of this research can be found in appendix I. A review of existing scenario-writing methods, including some helpful tips on writing scenarios is presented. In this appendix, forecasting is found to be unsuitable for sustainability problems. Since it is based on dominant trends, it is unlikely to generate solutions that would presuppose the breaking of trends (Dreborg, 1996). Also in the appendix, it is found that backcasting can deal with long-term complex issues, involving many aspects of society as well as technological innovation (Dreborg, 1996) and thus seems to be suitable for this study. Based on these findings, this research will use a backcasting approach to answer the research questions mentioned above.

2.1.2 Backcasting approach

To describe backcasting a comparison will be made with the well-known method of forecasting. In fact forecasting is the construction of projective scenarios. And a projective scenario's starting point is the current situation; extrapolation of current trends results in future images (Geurs and Van Wee, 2004). Most recent scenario studies are projective scenarios and those are very common in transport studies.

Backcasting however, is the construction of prospective scenarios. According to Geurs and Van Wee (2004) a prospective scenario's starting-point is a possible or desirable future situation, usually described by a set of goals or targets established by assumed events between the current and future situations. They also say that backcasting is therefore capable of highlighting discrepancies between the current and desirable future, and incorporating large and even disruptive changes.

Figure 2.1 by Banister and Hickman (2005) shows the main features of the backcasting process. Instead of starting with the present situation and prevailing trends, the backcasting approach designs images of the future representing desirable solutions to societal problems. Possible paths back to the present are then developed - 'casting back' from the future - in 25, 20, 15, 10 and 5 years time. The term 'scenario' covers both the images of the future and the trajectory leading back to the present.

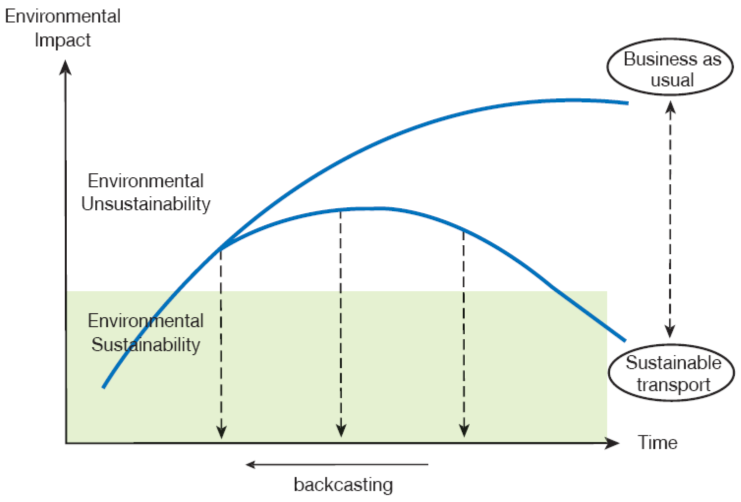

Figure 2.1 Backcasting process (source: Banister and Hickman (2005))

To see a complete overview of the differences between forecasting and backcasting one can look at table 2.1.

Table 2.1 Differences between forecasting and backcasting

Measure	Forecasting	Backcasting
Philosophy	Justification as the context Causality determinism	Discovery as the context Causality and intentions
Perspective	Dominant trends Likely future Possible marginal adjustments Focus on adapting to trends	Societal problem in need of a solution Desirable future Scope of human choice Strategic decisions Retain freedom of action
Approach	Extrapolate trends into future Sensitivity analysis	Define interesting futures Analyse consequences and conditions for these futures to materialise
Method and technique	Various econometric models Mathematical algorithms	Partial and conditional extrapolations Normative models, system dynamic models, Delphi methods, expert judgement

(Source: based on Geurs and Van Wee (2004) and Bannister and Hickman (2005), adapted from Dreborg (1996))

Robinson (1990) and Geurs and Van Wee (2004) gave an outline and description of this method. The outline of the approach will be used to explain how the objective will be obtained (figure 2.2).

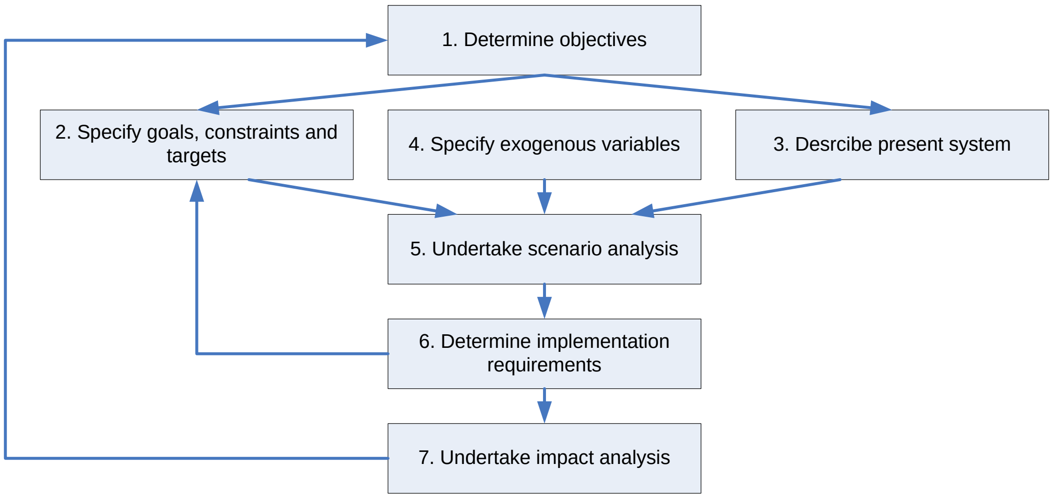

Figure 2.2 Backcasting approach (based on Geurs and Van Wee (2004), adapted from Robinson (1990)).

The backcasting approach consists of several steps, the description of the approach is taken from Geurs and Van Wee (2004) and completed for this study:

- Step 1 is meant to determine the objectives, i.e. to describe the purpose of analysis, determine temporal, spatial and substantive scope of analysis, this is carried out in the previous chapter.
- Step 2 will specify concrete goals and targets for the scenario analysis based on the objectives outlined in the first step. Where possible, qualitative goals will be expressed in terms of quantitative targets to provide a measurable point of reference for the scenario analysis. For this purpose, the sustainable mobility pillars from the previous chapter need to become measurable and quantifiable. This is realised in the next chapter.
- Step 3 is meant to describe the present system, in this case the transportation system. It will describe how the system can be influenced, including an analysis of the main driving forces behind measures and main developments. The external effects of the current transportation system are already presented in the previous chapter. In addition, for every sustainable mobility pillar the driving forces will be explained in the next chapter.
- Step 4 is to specify exogenous variables, e.g. assumptions on economic growth, demography, the stability of the supply of fossil fuels, prices of fossil fuels, incomes and international relationships. These are derived from the WLO scenario 'Global Economy' (CPB/MNP/RPB, 2006) which will be used as a reference scenario. This scenario is described in chapter 4.
- Step 5 will present the scenario analysis carried out, i.e. a scenario generation approach will be chosen, and future processes at the endpoints in 2050 will be analysed to develop the scenario(s) and to iterate the analysis as required to achieve internal consistency.

Within the Global Economy scenario, three different routes to the sustainability targets in 2050 will be set out. This step is also integrated in chapter 4.

- Step 6 is to determine the implementation requirements, i.e. ascertain the behavioural and institutional responses required for implementation of the scenarios and the policy measures necessary at different spatial levels to influence the driving forces behind measures and main developments, e.g. pricing policy, regulations, and infrastructure policies. For this study, this step is not carried out, however in chapter 4 some uncertainties concerning implementation are pointed out.
- Finally, in Step 7 an impact analysis will be undertaken to: (a) consolidate scenario results, (b) analyse social, economic and environmental impacts, (c) compare results of step 6(a) and (b) with the goals and targets, as set down in step 2 and (d) iterate analysis (Steps 2, 4 and 5), required to ensure consistency between goals and targets, and results. For the analysis of social, economic, and environmental impacts an analysis of costs and benefits will be performed. The used method is described in the next paragraph and the results can be found in chapter 4.

2.2 Cost benefit analysis

2.2.1 The classic method

Boardman et al. (2001) define cost-benefit analysis as a policy assessment method that quantifies in monetary terms the value of all policy consequences to all members of society. The net social benefits measure the value of the policy.

In general, the steps of a cost-benefit analysis can be summarised as follows. After defining a project in relation to the baseline situation all effects need to be identified. Some effects will seem to be less economically relevant. Only the economically relevant effects are physically quantified. The next step is monetising these effects. Sometimes effects are expected to be relevant; however when they are controversial or due to difficulty they are not monetised. These effects are called ‘imponderabilia’ and are referred to on the balance as a PM-item (Hellendoorn, 2001). To get a solid comparison of costs and benefits, effects that are monetised should be discounted. This means finding the present value of the costs and benefits at a future date. The sum of the discounted costs and benefits can be compared and should be followed by a sensitivity analysis. Last step is making a recommendation based on the net present value and the sensitivity analysis.

The outcomes of cost-benefit analyses should be treated with some caution. Studies by Flyvbjerg et al. (2002; 2005) show that the outcomes of cost-benefit analyses may be highly inaccurate. Despite some scepticism, cost-benefit analysis is a much used decision making tool and can help to select the best project or make ‘go’ or ‘no-go’ decisions (Boardman et al., 2001).

2.2.2 Analysis of costs and benefits

In this study an analysis of cost and benefits will be performed. It will differ to a certain extent from a standard cost-benefit analysis. The effects are identified and monetised from a national and societal standpoint. If monetising is found to be extensive or controversial, relevant effects are mentioned as a PM-item. The next steps however will be a comparison of the costs and benefits. Due to the exploring character of this study, the costs and benefits are compared on main features and the discounting of the values is not applied. This causes some inaccuracy, however it is expected that this will not significantly affect the conclusions. In addition, due to long-term uncertainties using global costs and benefits seems to be a reasonable approach. A sensitivity analysis is not performed either. On the other hand, by using bandwidths an idea of sensitivity can be found in the results. The sensitivity analysis however could be broader, and might suggest that the scenario with the highest net benefits is not necessarily the best under all circumstances. The costs and benefits will be based on literature as much as possible. If relevant literature lacks, assumptions will be made. The final analysis of costs and benefits is used to asses whether the sketched routes are worthwhile.

3 Backcasting targets

To be able to determine what actions are required to ensure sustainable passenger car transport in 2050 the sustainable mobility pillars (see section 1.4.5) need to be measurable and quantifiable. In this chapter, the targets that are needed for this backcasting study are described and made quantifiable. In addition, measures that can influence the degree to which the targets are achieved are derived from appendix II.

3.1 Accessibility

Accessibility is the first out of five pillars and emphasises on economic development. Accessibility improvements result in an increase in the employment potentials for different job types (Ozbay et al., 2006). To realise this, the accessibility of economic nodes and portals has to be guaranteed. Capacity problems on different traffic networks cause high and unreliable travel times.

To asses the flows on highways, different accessibility indicators are used. Commonly used indicators are; traffic-jams, route speed, vehicle kilometres, I/C -ratio (intensity/capacity) and lost vehicle hours. They all indicate a different dimension of accessibility. The lost vehicle hours indicate how many delay vehicles get because of congestion. It gives an idea of the travel time loss of road users. It is an important base for quantifying the economical effects of congestion (AVV, 2004). Reducing the number of lost vehicle hours means an important economical benefit. In addition, travel time reliability plays an important role. Hilbers et al (2004) use the buffer time as an indicator for reliability; how many extra travel time must the traveller take into account in order to arrive on time with a certainty of 95%.

Reducing the number of lost vehicle hours can also have a negative influence since saving of travel time will probably be used for other trips. According to the ‘Law of Constant Travel Time and Trips’ (‘BREVER-wet’), formulated by Hupkes (1977), notwithstanding changes in modal split, the individual’s total time spent on transport remains (and will remain) unchanged. Hupkes based his ‘law’ on some arguments, which, however, need much more elaboration (Dijst, 2004). Dijst argues that giving empirical evidence, Hupkes only used highly aggregated data from various years and countries, without a necessary statistical elaboration. Recently, his hypothesis on a constant travel time budget of 70 minutes per person a day in all societies is supported by research of Schafer and Victor (1997). Although the saved travel time will probably be used for other trips, these trips can still represent an economic improvement. That is why lost vehicle hours, representing economic development in the form of accessibility is chosen in this study. Using ‘lost vehicle hours’ as an indicator, might pretend that no accessibility improvements can be reached when new roads are built. In reality however, this could have an economical impact.

Improving the travel time reliability will not be used as a target, it will however be taken into account in the analysis of costs and benefits when measures influence the reliability.

3.1.1 Accessibility target

The accessibility target for 2050 will be to reduce the ‘number of lost vehicle hours’ to zero. In this research, reduction to zero is chosen, since this gives the most profitable results. The calculation of the lost vehicle hours can be done by using the method proposed by Dutch transport research centre AVV (2004). However in this study the number of lost vehicle hours have been adopted from the WLO (CPB/MNP/RPB, 2006) scenario.

3.1.2 Influencing accessibility

One way of influencing accessibility is limiting the traffic volume. When the traffic demand is reduced, the remaining traffic will have better accessibility. It is also possible to stimulate other modalities or increase efficiency of the current infrastructure by increasing occupancy rates of vehicles, optimising route choice, or spreading the traffic over the day. One could also build new infrastructure, however this is often a temporary solution. In the past, technology has not proved to be a factor of major influence on accessibility. This could partly be because accessibility is a relatively ‘young’ problem and technology still has to be developed and partly because technology can cause resistance in society (Van den Brink, 2002). However, changes can be expected in the coming decades, as more and more intelligent transportation systems enter the market. These systems will play a role in providing information, optimising route choice and increase the use of potential capacity.

Instead of increasing the actual driving speed, an alternative approach to reduce lost vehicle hours, is to make the lost hours useful. The lost vehicle hours are not lost but useful when they can be used for business or pleasure meanings. In other words, this means a change in perception of lost hours. Redmond and Mokhtarian (2001) show that many commuters do not perceive congestion as necessarily an evil of their daily commute. Based on their study, Nasser (2002) notes that, in these modern times, many people can find complete privacy in only two places, the car or the toilet. Jain & Lyons (2007) even go a step further by calling travel time a gift.

3.2 Transport equity

Transport equity is one of the three social pillars. According to Litman (2005) three types of equity with transportation impacts can be formulated. The first is horizontal equity, where equal individuals and groups should receive equal shares of resources, bear equal costs and in other ways be treated the same. The second is vertical equity with regard to income and social class, which is used to support affordable modes, discounts and special services for lower-income people, minorities and other disadvantaged groups. The third and last is vertical equity with regard to mobility need and ability, which supports increased transportation diversity and land use accessibility, accessible design (a set of design principles which provides access to people of all ages and abilities), to support transportation services that provide basic mobility. In the context of sustainability, equity deals with fairness, whereby all people have similar rights and opportunities and basic needs to maintain an acceptable quality of life. One could call this “equity of opportunity", meaning that disadvantaged people have adequate access to essential services, education, employment opportunities, and service and freight transport. Translated to mobility this means that people from all different strata in society and people with different kinds of ability should have access to transport in order to get social (and economical) development. Litman (2005) refers to this as basic access, which means that people are able to reach activities considered important to society.

To assess basic access, different measures can be thought of. Nicolas et al. (2003) use the following measures which apply to access very well: proportion of households owning 0,1 or more car(s), distances travelled and the expenditures for mobility as a share of the average income of households. The latter being most suitable for this report. However, to make it even more appropriate, a time aspect needs to be added. In developing countries for example, people walk a lot, at virtually no cost. In using an assessment based on expenditure for mobility as a share of the average income of households, people are better of walking compared to people using a car. People who walk need much more time to travel the same distances. To make the comparison fairer, a time aspect needs to be added. The ‘Law of Constant Travel Time and Trips’ can be used as constraint. This ‘Law’ mentions an average travel time-budget of 70 minutes per day (Hupkes, 1977). The share of the average income of households on expenditures for mobility and average travel time-budget will be used as measures for transport equity. An example of the amount and share of average income dedicated to urban transport by households, according to income and place of residence for the Lyon (France) conurbation is given in figure 3.1.

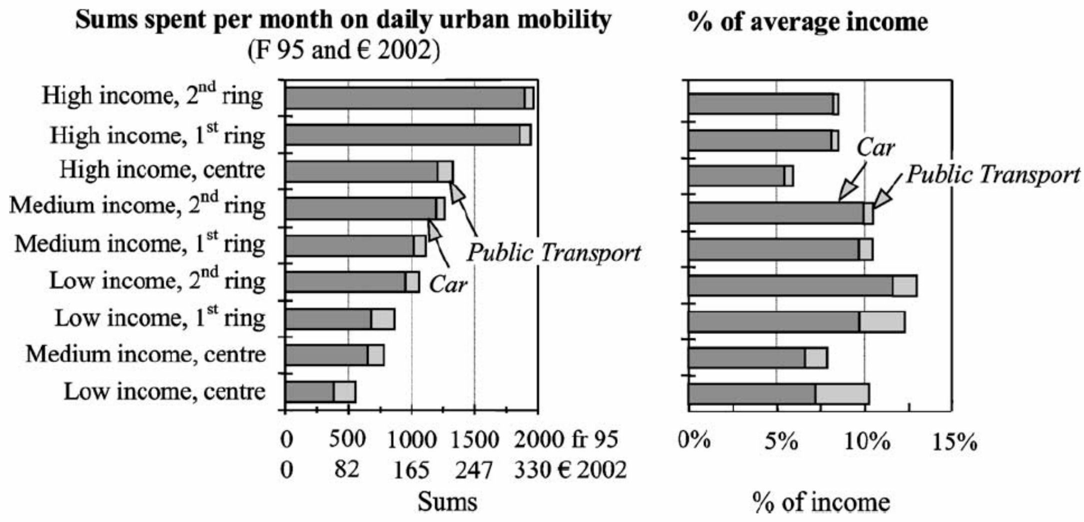

Figure 3.1 Share of average income spent on mobility (Nicolas et al., 2003)

The information required to value the transport equity can also be found in Nicolas et al. (2003). In order to keep the travel time and travel expenditures equal to its current state the following factors need to be identified:

- Average income
- Expenditures for mobility
- Average travel times

3.2.1 Transport equity target

Keeping the share of the average household income for mobility expenditures equal to its current share and the average travel time-budget of 70 minutes per day is chosen as target for transport equity. It is assumed that the current equity level in transport in the Netherlands is fair, and thus does not need changing in whatever direction. This target will not be worked out quantitatively.

3.2.2 Influencing transport equity

Transport equity can be influenced by pricing measures. A subsidy for the financially weak, could give people more equal chances to mobility. This could be a subsidy for car rental, ownership and usage but also other modalities can play an important role in access to mobility for everyone.

3.3 Traffic safety

Safety is the second social pillar that emphasises on traffic safety. Traffic accidents cause personal sorrow, but also cause important societal consequences and costs. Two kinds of traffic safety can be distinguished, objective and subjective. Subjective safety describes the safety feeling of traffic participants. Objective safety shows the number of casualties. In this case, the objective safety will be used as a reference and measure.

3.3.1 Traffic safety target

Every road death is, in fact, one too many. What is sufficiently ambitious in respect of deathly casualties? For this, SWOV proposes maintaining the criteria of ‘avoidable accidents’. Avoidable means that we know what to do to prevent accidents, and that it is socially profitable to do so (Wegman, 2001). In other words, the benefits exceed the costs. In this study, the target is to reduce the serious traffic casualties to zero. Traffic casualties include fatalities, heavily injured and lightly injured. In this case, the fatalities and heavily injured should be reduced to zero.

3.3.2 Influencing traffic safety

To reduce casualties, the chances of an accident can be reduced as well as the impact of an accident. Respectively this is referred to as passive and active safety. Three policy areas can be formulated by which these targets can be reached:

1. Infrastructure; design and safety measures (crash barriers).
2. Vehicle; in-car safety measures (like the safety belt and the airbag), safety construction, intelligent transport systems (like intelligent speed assistance (ISA) and other advanced driver assistance systems (ADAS)).
3. People; education, rules, enforcement or stimulation.

3.4 Liveability

Liveability is the last social pillar, which emphasises on social development. This includes nuisance of noise, vibrations, smells and light. Next to that, space occupancy, barriers and visual adverse structures protecting city and or landscape are important.

3.4.1 Liveability target

As a target, only noise nuisance will be studied. To protect most people (80%) from annoyance and other adverse effects, sound levels from road traffic should not exceed 60 dB at the most-exposed side (Ohrstrom et al., 2006). The WHO (2001) there uses a guidance level of noise exposure of 55 dB. If traffic noise does not exceed this level, there is no serious damage to health. According to the WHO, still 20% of the people are annoyed by noise at this level. In this study, the WHO guideline is followed and the target for road traffic noise levels is set to 55 dB. Health effects are than minimised. Target in this study will be to reduce the number of (health) effected people to zero and therefore the noise levels at one’s dwelling are to be diminished to 55 dB.

3.4.2 Influencing liveability

Noise hindrance can be reduced when the traffic intensity is reduced, when the traffic produces less dB(A) or when the number of bothered or affected people is reduced. Decrease of the intensity can be obtained by a reduction of demand for movement. The source can produce less dB(A) when better technologies are applied. Finally, the number of bothered or affected people can be reduced by protecting them with noise barrier or for example by rerouting the traffic. Of course, the number of bothered or affected people can also be lessened by reducing the traffic intensity or the dB(A) level. According to Ohrstrom et al. (2006) , having access to a quiet side of one’s dwelling also reduces disturbances by an average of 30-50% for the various critical effects, and corresponds to a reduction in sound levels of 5 dB at the most-exposed side.

3.5 Nature and environmental quality

The fifth pillar, nature and environmental quality, emphasises on ecological development. To get ecological development the damage to the nature and environment should be diminished. The traffic emissions exceed the limits, the use of exhaustible resources is too high and the biodiversity of the ecosystem is seriously threatened (Banister, 2005).

3.5.1 Nature and environmental quality target

The target is set to reduce all emissions of passenger cars (CO_2, NO_x and PM10) to zero by 2050.

3.5.2 Influencing nature and environmental quality

The total passenger car emissions depend on the traffic volume and the emissions per car. The traffic volume can be influenced by volume measures. The emissions per car depend on the way the car is used, the energy efficiency of the car and the fuel type. These can be influenced by introducing cleaner/ clean technologies and fuels, more energy efficient driving and for example speed reductions. Zero emissions cannot be reached by volume measures only, since this would require banishment of all traffic. It can however reduce costs when lower emissions need to be dealt with.

3.6 Résumé

To be able to determine what actions are required to ensure sustainable passenger car transport in 2050 the pillars need to be measurable and quantifiable. These measurable and quantifiable determinants including their targets are presented in table 3.1 and explained below. It is important to note that the mentioned targets are strived for; however, a sense of reality is not to be neglected. Improvements that approach these target figures are considered an important contribution to developing sustainable car mobility, since both approachability and achievability are important.

Table 3.1 Sustainable mobility pillars including their determinants and targets for 2050

Pillar	Determinant	Target 2050
Accessibility	Number of ‘lost vehicle hours’	Reduce to zero
Transport equity	Household expenditures on mobility	No pro rata raise
Traffic Safety	Serious traffic casualties	Reduce to zero
Liveability	Number of (health) affected people by noise nuisance	Reduce to zero
Nature and environment	Emissions of passenger cars	Reduce to zero

Sustainable mobility pillars including their determinants and targets for 2050 are:

- Accessibility will be represented by the, less congestion will lead to less ‘lost vehicle hours’ and will contribute to this sustainability aspect. Measures must lead to zero ‘lost vehicle hours’ by 2050
- For transport equity, mobility to everyone, the determinant is the share of the average income of households on expenditures for mobility in combination with the average travel time-budget per household per day. Targets are maintaining an equal percentage of the average income of households on expenditures for mobility in 2050 compared to the current status and keeping the average travel time-budget of 70 minutes per day. However, this determinant will only be looked after qualitatively.
- Concerning safety, traffic casualties will be used as a measure. Fewer casualties will add to more sustainable passenger car transport. The target is zero serious traffic casualties in 2050.
- Liveability concerns more than one determinant: (1) Number of (health) affected people by road traffic noise, (2) Air pollution affecting public health. The target for noise nuisance is set to zero affected people by road traffic noise. The air pollution will be reduced to zero and will be dealt with under the name of the last pillar.
- The last pillar is nature and environment, which is being measured by emissions of passenger cars (CO_2, NO_x and PM_{10}). The target is set to zero emissions from cars by 2050.

Note that the second determinant of liveability and the determinant of nature and environment will both be met with the last target.

4 Scenarios

4.1 Reference scenario

4.1.1 Global Economy (GE)

In all backcasting studies, a reference scenario is required. The WLO contains four scenarios for the future of the Netherlands. The scenario Global Economy (GE) will be used for this study. This scenario is not a business as usual scenario; instead, it is a scenario with the highest economic growth. This scenario emphasises on international cooperation and private responsibilities. Achieving sustainable mobility targets in this scenario is expected to reveal the maximum required effort. In this paragraph some relevant topics are adopted from the WLO (CPB/MNP/RPB, 2006) and summarised.

4.1.2 In general

In Global Economy, the EU expands further eastwards. In addition to Turkey, countries like the Ukraine also join. The WTO negotiations are successful, and international trade flourishes. Political integration does not get off the ground, however. International cooperation in areas other than trade fails. The government in this scenario emphasises the individual responsibility of citizens. The strong worldwide economic integration in Global Economy gives an additional boost to labour productivity. The growth of prosperity is therefore highest in this scenario. No agreement is made regarding the tackling of cross-border environmental problems. Together with the worldwide high economic growth, this leads to substantial environmental pollution. However, high prosperity does lead to local environmental initiatives.

4.1.3 Mobility

Expansion road network

In the WLO scenario, an expansion of the road network is presumed. Until 2020, it concerns investments in intended expanding of infrastructure and measures for a more efficient use of road capacity. This means that 3000 lane kilometres will be added to the highway network (HWN). For the period that follows, 2020-2040 the WLO presumes equal investments existing out of circa 2000 extra lane kilometres for the HWN and a further expansion of the underlying road network (OWN).

Passenger mobility

In the current and future situation the speed of the existing traffic, systems (car and train) hardly increase. This means that with preservation of the same travel times, the moving distances per modality cannot increase much. Still, there will be a slight increase in mobility per person because the shift towards faster modes will continue; however, this will happen slower than in the past. The development of mobility per person will grow less fast because the share of working people in society will not rise in contrast to the share of elderly in society. Although the elderly will be more mobile than they are now, their mobility stays behind compared to the active part of society. To a lesser degree passenger mobility is determined by an increase in income and eventual special trends like individualisation, intensifying (more activities on a day) and working on a distance. The result of all this is an increase of 15% in mobility per person until 2040. The 'car park' now counts seven million cars. Development in the number of households will lead a growth of twelve million cars by the year 2040. Furthermore the number of passenger kilometres by car increases from 70% to 78%.

Road transport

Due to the developments of passenger car transport, goods transportation by road and the presumed expansion of infrastructure, vehicle kilometres increase with 80%. The building programs of the "Mobility Paper" and the tendency of expanding infrastructure after 2020 are taken into account. Still, there will be an increase in congestion in the Global Economy scenario. However, per driven kilometre the individual driver will not encounter more congestion than today. The reason being that there will be more congestion, but at also more vehicle kilometres.

Fuel prices

The fuel price is one of the influencing factors on mobility. This price is co-determined by the crude oil price. In this study, the oil price per barrel increases from 22 dollar in 2000 to 28 dollar in 2040.

Traffic safety

First of all the traffic safety will be influenced negatively due to higher traffic intensities. Later on the ageing of people resulting in a larger share of elderly in society and traffic, in combination with an increasing share of lorries in road transport leads to higher risks. In spite of these negative influences, the society will make progress in association with unsafe traffic situations. This progress is in line with the trend of the past decades and is supported by intended policy, formulated in the Dutch Mobility Paper. All together, the increase in unsafety as result of growth will be minimised.

Environmental pollution

In the last decennia (until 2000), the air quality has strongly improved. In GE, this improvement will continue the coming decades. In the future, traffic will emit less particulate matter (PM10) and nitrogen oxides (NOx). This will be mainly because of the effects of policy of the European Union that looks after cleaner cars. However, the traffic emission of carbon dioxide (CO_2) in 2040 will increase with 70% compared to level in 2000.

Spatial division

The mobility increases most in and around the big cities, especially the Randstad. Circa 75% of the lost hours can be contributed to congestion in the Randstad. Congestion outside of the Randstad can in particular is concentrated around the bigger cities.

4.1.4 Extrapolation to 2050

In this report, the target year is 2050. Based on the global economy scenario, extrapolations to this target year are made and summarised in table 4.1.

Table 4.1 Characteristics of the GE scenario extrapolated to 2050

Global Economy in 2050 compared to 2000			
	2000	GE 2050	Unit
Inhabitants	1.590.000	20.550.000	-
Length of HWN	18400	24200	lane km
Required energy for passenger transport	243,64	451,41	peta joule
Oil price per barrel	22,00	32,00	dollar
Alternative oil price per barrel*	-	80,00	dollar
Electricity price per MJ	1,1	1,5	eurocent
Vehicle fleet	6,54	11,38	million
Percentage diesel driven kilometres	26,00	58,00	%
Percentage gasoline driven kilometres	67,00	42,00	%
Passenger vehicle kilometres	91,55	162,16	billion vkm
Percentage vehicle kilometres on HWN**	48	48	%
Lost vehicle hours	47,20	93,93	million
Variance in travel time***	14 - 20	40	%
Fatalities	1.166	1.178	-
Injuries	18.300	17.904	-
Number of bothered people by noise nuisance	1,95	2,34	million
Emitted CO_2	17,58	33,13	million tonne
Emitted NO_x	62,02	33,72	million kg
Emitted PM_{10}	3,03	0,82	million kg

*close to 2007 oil price ** based on AVV *** based on Hilbers et al. (2004)

4.2 Potential savings

4.2.1 Gap between GE and sustainable mobility targets

The following figure (figure 4.1) shows how the determinants of the sustainable mobility pillars will grow according to the GE scenario. These figures show the maximum gap between the GE scenario and the sustainable mobility targets. In the following sub-paragraphs, these gaps will be monetised.

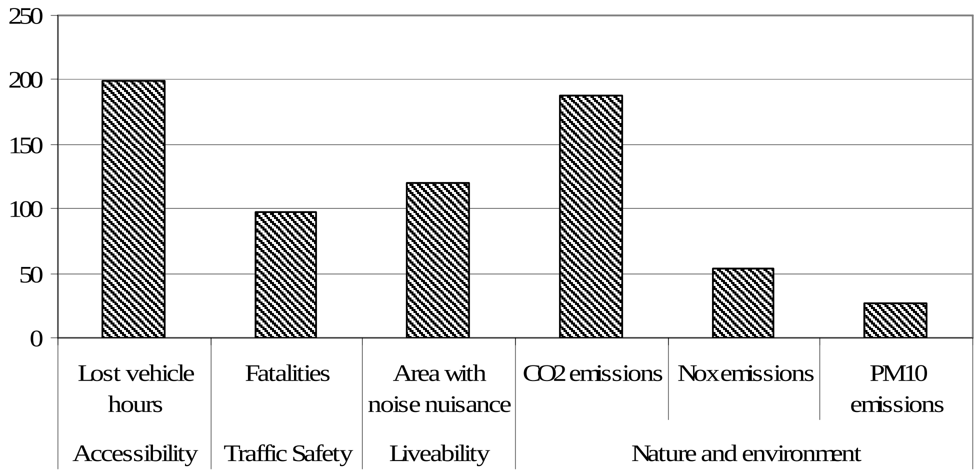

Figure 4.1 The sustainability targets under the GE scenario in 2050 (index 2000 =100)

4.2.2 Accessibility: no lost vehicle hours

GE extrapolation for 2050 resulted in: 94 million lost vehicle hours. With an average value of time of 17,58 euro per hour in 2050 (extrapolation based on 2040 value of time for GE in AVV (2006a)) this results in ***1.7 billion*** euro loss and represents potential benefits when the right measures are implemented.

4.2.3 Safety: no serious casualties

GE extrapolation for 2050 results in: 1.178 fatalities and 17.904 injuries. The larger margin of a value of a statistical life according to SWOV (Wesemann et al., 2005) ranges from 1.600.000 and 3.000.000 and the value of an injury is around 250.000 euro. This leads to possible savings of ***1.9 – 3.5 billion*** euro for reducing fatalities to zero and ***4.5 billion*** for reducing the injuries to zero.

4.2.4 Liveability: no noise nuisance

It is assumed that there are no (health) affected people when passenger cars do not exceed noise levels of 55 dB (A) in residential areas. In 2050, the area with noise above the 50 dB(A) is about 85% (extrapolation based on 2030 value in Nijland et al. (2003)). By reducing the area where noise nuisance of road traffic exists to around zero, possible savings lie between ***3.4 - 4.4 billion*** euro and higher (Nijland et al., 2003). They also argue that because methods and input data for nature and quiet zones are not available, the savings only include effects on human health and well-being; this clearly leads to an underestimation of the benefits.

4.2.5 Nature and environment: no emissions

GE extrapolation for 2050 resulted in the following emissions: 33 million tonne CO_2, 34 million kg NO_x and 0.82 million kg PM_{10}. The valuations of reductions of these emissions are respectively: 56 euro per reduced tonne CO_2, 13 and 336 euro per reduced kg NO_x and PM_{10} (Vermeulen et al., 2004). In other literature, a bandwidth of 14 - 280 euro for the valuation of a tonne CO_2 is found (Downing et al., 2005; Infras/FiFo, 2007; Krewitt & Schlomann, 2006;

Stern et al., 2006; UBA, 2007). In this study, a mean bandwidth of 56 – 150 euro per reduced tonne CO_2 will be used. This results in potential savings of ***1.9 – 5.0 billion*** for CO_2, ***0.4 billion*** for NO_x and ***0.3 billion*** for PM_{10}.

4.3 Technology Take-over (TT)

In this paragraph, a description of the scenario will be given. Benefits and costs will be clarified and uncertainties will be pointed out.

4.3.1 Scenario description

In 2050, the acceptance of and trust in technology is high since most people have grown up in a society driven by emerging technologies. This trust results in the belief that technology can be the solution to almost every problem, including traffic related problems.

The lost time due to road congestion is often subject to discussion. At this moment the first intelligent transport systems enter the market. On the long term, these systems are expected to take over all driving tasks of the driver through so-called automated highway systems (AHS). A traffic control centre manages speed and routes of all users; it also divides space and monitors traffic safety. Road navigation is already used widely, but is much more improved by then. Travel times are easier to predict. Keeping the system optimum in mind, cars are guided as fast as possible to their destination. On the highway, the hands can be taken off and the time in the car can be spent as one wishes. Because of the vehicle-to-vehicle communication, close following becomes possible. This increases the capacity and decreases the fuel consumption due to drag reduction. Another advantage of the communicating vehicles is a considerable reduction of traffic accidents since they are largely related to driver mistakes such as inattentiveness, inability to respond quickly enough, or bad driving decisions. On urban roads, driver aid is also available, although the awareness of the driver is still required.

Another much-debated subject is the global and local air pollution through combustion of fossil fuels. In the coming decennia, the conventional cars are more and more replaced by hybrids that use assistance from batteries. Battery assisted or driven vehicles have an improved driving comfort. Moreover, with oil prices still increasing, battery powered vehicles become more cost effective as well, due to their high energy-efficiency. The government at the same time tries to stimulate the use of zero-emission vehicles and initiates an international agreement. This agreement restricts car designers to design for a maximum speed of 100 km/h. This means that vehicles will not be over-dimensioned, with a weight reduction as result. This weight reduction and even more the actual speed reduction, result in a much lower energy usage of vehicles. With this lower energy usage, the action radius of battery vehicles becomes comparable to current driving ranges of conventional vehicles (internal combustion engine vehicles). For the vehicles to be ‘zero emission’, the electricity has to be produced in a sustainable manner. This is realised by large-scale wind and solar power.

The wide usage of battery electric vehicles creates a money saving opportunity, since the onboard electricity of a parked vehicle has significant co-benefits. Electricity companies will reward electric vehicles who give a part of their stored energy back to the grid at peak moments. At this moment, energy companies need to keep immense energy buffers available for unexpected energy requests. Most of the times these buffers are not used and become wasted energy. Since batteries have the ability to respond in milliseconds, battery vehicles that are parked and plugged on to the electricity grid, can form the buffer capacity for the energy companies. A large number of people who buy an additional plug-in for there vehicle are able to make money by just being plugged onto the grid and on top sell electricity.

By the year 2050, the noise nuisance from vehicles is greatly reduced due to the application of silent tires and silent asphalt. In addition, the shift from combustion engines to electric vehicles results in a reduction of urban noise nuisance.

4.3.2 Degree to which targets are fulfilled

The degree to which the sustainable mobility targets are fulfilled in the TT scenario is presented in figure 4.1.

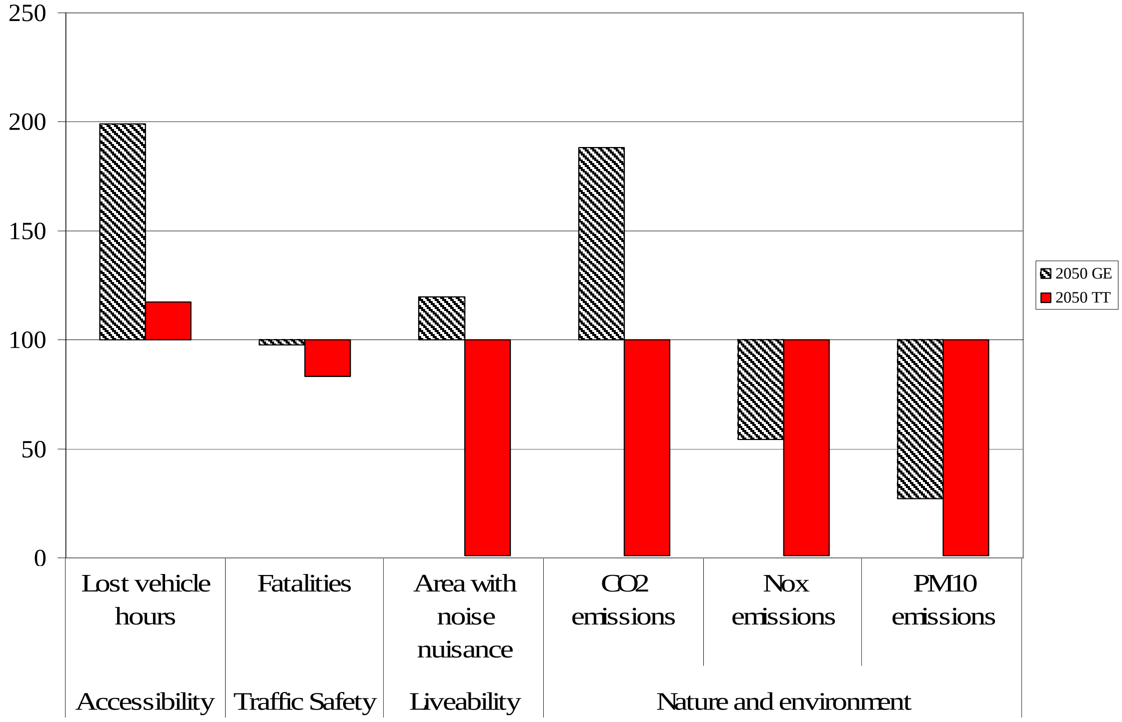

Figure 4.1 The sustainable mobility targets in the TT scenario in 2050 (index 2000 = 100)

In the TT scenario, the lost vehicle hours are reduced by 41% in comparison with the GE scenario. This means, in relation to the current situation there is a slight increase of the lost vehicle hours. Fatalities are minimised by 15% in comparison to the GE scenario. Noise nuisance and emissions are reduced to zero.

4.3.3 Benefits and costs

The measures described in the scenario above have costs and benefits. An overview is presented in table 4.2 on the next page. A brief explanation of the costs and benefits will be presented here, for a full explanation including a description of the measures and a discussion, see appendix IV.

Automated highway system

An automated highway system (AHS) is a lane or set of lanes where specially equipped cars, can travel together under computer control. Because the vehicles being under computer control, they can form a platoon or convoy and drive much closer to each other than they would normally. AHS is expected to improve the safety and efficiency of the transport system significantly.

Benefits

- Lost vehicle reduction

On an Automated Highway System, vehicle hours of delay can be reduced by 75% per vehicle mile of travel (Miller et al., 1997). According to AVV (2006b) the percentage of vehicle kilometres driven on the highways is currently 48. In this report, it is assumed to be equal in 2050. The introduction of AHS causes a shift in usage towards highways of circa 15% (Miller et al., 1997). Multiplying 48% with 1.15 results in 55% vehicle highway kilometres. Multiplying this with the share in hours of delay, results in a 41% reduction of lost vehicle hours overall. GE extrapolation for 2050 results in: 9.4 billion lost vehicle hours. A reduction of 41% means a benefit of 3.9 billion hours. With an average value of time of 17,58 euro per hour in 2050 this comes down to ***0.7 billion*** euro.

- Reliability improvement

According to Rand Europe and AVV (2005) the value of reliability is 0.8 times the value of time and comes down to 14.06 euro per hour. A disputable assumption is made that the introduction of AHS increases the predictability or travel time variance with 80% on highways. Hilbers et al (2004) give numbers for the travel time variance per road type until 2020. Extrapolation to 2050 of those figures in combination with the 80% decrease in travel time variance on highways gives an overall increase in predictability of 52% (see Appendix IV for a more detailed description of this extrapolation). Multiplying this with the value of reliability and the number of lost vehicle hours gives us a benefit of ***0.7 billion*** euro.

- Reduction of fatalities and injuries

Extrapolation based on GE gives 1.178 fatalities and 17.904 injuries in 2050. There are about 5 times fewer fatal accidents on highways as on the other roads (VenW, 2006). This ratio seems to be stable and is assumed to be same in 2050. For injuries this ratio has changed over the last 20 years from 6.4 to 5.4 (VenW, 2006). For this research, the assumption is made that in 2050 this ratio will be equal to the fatalities ratio. Two safety effects can be contrbuted to AHS. First, the introduction of AHS causes a shift in usage of safer highways upto 15%. Secondly, according to Postema (1998) at least 50% of the fatalities and 31-85% of the

Technology take-over

Benefits in billion euros	min	max	Effects in %	**Costs in billion euros**	min	max
Total*	**23,1**	**31,1**		Total*	**23,5**	**29,1**
Automated Highway System	**4,7**	**6,2**		**Automated Highway System**	**3,3**	**5,2**
Lost vehicle hours reduction	0,7	0,7	41	Traffic management systems	0,1	0,1
Reliability improvement	0,7	0,7	52	Roadway infrastructure	0,1	0,1
Reduction of fatalities and injuries	1,0	1,7	resp. 41; 26-71	User costs/ in-vehicle equipment	1,9	3,8
Fuel savings (end user)**	1,9	2,3	14	Missing out on gasoline taxes (government)**	1,2	1,2
Emission reductions**	0,4	0,8	14	Rebound effects	pm	pm
Noise abatement measures	**3,3**	**4,4**		**Noise abatement measures**	**0,8**	**1,4**
Noise nuisance reduction	3,3	4,4	n/a	Silent tires	<0,1	<0,1
				Silent asphalt	0,8	1,4
Battery electric vehicles	**18,0**	**24,2**		**Battery electric vehicles****	**21,7**	**24,8**
Emission reduction	2,6	5,7	100	Wind electricity cost incl. taxes and distribution (end user)	8,6	9,5
Noise nuisance reduction***	0,2	0,2	pm	Additional car costs (battery)	4,2	6,3
Cost savings on fossil fuels (end user)	10,7	13,6	67	Charging points	0,2	0,3
Vehicle 2 Grid	0,4	0,6	n/a	Missing out on fossil fuel taxes (government)	8,7	8,7
Taxes on extra electricity usage (government)	4,1	4,1	n/a	Welfare losses due to speed reduction*****	pm	pm
Making wind power reliable	pm	pm	n/a	Rebound effects	pm	pm
Secondary effects of speed reduction (safety, reliability travel time)*****	pm	pm	n/a			
				Range of net benefits in billion euros	**-0,4**	**2,0**
					-6,0	7,6

*To avoid double counting, the total is reduced by the (**)-items, the fuel saving caused by AHS is replaced by electricity cost reduction of 1100 million euro, in addition taxes on electrity reduce by 600 million euro **These effects will be eliminated by the battery electric vehicles ***Noise nuisance reductions below 55 dB (A) don't have health effects, but still have some value ****An electrified highway was also calculated with, see appendix III *****These costs are hard to define, but could have a significant influence

Table 4.2 Overview of costs and benefits of the TT scenario injuries on highways can be reduced by AHS. This means in total 216 fatalities and between 2669 and 4402 injuries can be spared. Resulting in benefits of respectively ***0.3 – 0.6 billion*** euro and ***0.7 – 1.1 billion euro***.

- Fuel savings end-user

According to Browland et al. (1997) AHS can realise a 50% drag reduction, this leads to a 25% reduction in fuel usage, which can only be allocated to highways. 55% of the kilometres are driven on highways. The assumption is made that the fuel usage is split the same way as the driven kilometres. This results in a 14% fuel economy. Using the fossil fuel bandwidths of 0.81 – 1.03 euro per litre (see appendix III), and 34,2 MJ per litre (Gilbert & Perl, 2007), gives an end user advantage of 0.0237 – 0.0302 euro per reduced MJ of energy. With a total fuel usage in 2050 of 4.5 PJ/year, this comes down to ***1.5 – 1.9 billion*** euro.

- Emission reductions

A 14% reduction in fuel usage results in an equal reduction in emissions. Potential benefits were already calculated in the previous chapter. These numbers can be multiplied with 14% and result in the following benefits, ***0.3 – 0.7 billion*** for CO_2, ***<0.1 billion*** for NO_x and ***<0.1 billion*** for PM_{10}.

Costs

- Traffic management systems

In Ran et al. (1997) a cost benefit analyses on the deployment of automated highway systems is carried out. According to this analysis traffic, management systems will cost 5.866 euro per year per km road. (after conversion from dollars to euro, miles to kilometres and peak hours to all hours per year). Applying these costs over 24200 km (the number of lane kilometres of the HWN), this results in ***0.1 billion*** euro.

- Cost of roadway infrastructure

The costs of roadway infrastructure consist out of expenditures on the operating packages and the maintenance. The roadway infrastructure will cost 5.489 euro per km (Ran et al, 1997). Due to learning curves, a reduction in price of 20% is assumed for the lower costs in the bandwidth. Multiplying with the number of lane kilometres of HWN this results in ***0.1 billion*** euro.

- User costs/ in-vehicle equipment

The in-vehicle equipment includes vehicle lateral control (keep your lane), vehicle longitudinal control (keep distance), vehicle route guidance and a vehicle system for AHS. Costs for these systems are estimated to be between 2000 and 4000 euro per vehicle (own assumption based on cost estimates for several intelligent systems in Abele et al. (2005). In the same study, a depreciation period of 12 years is used. Multiplying the vehicle costs with all vehicles and divide by the depreciation period gives costs estimates of ***1.9 – 3.8 billion*** euro.

- Missing out on taxes

Currently taxes are 0,87 cent per litre gasoline and 0,45 cent per litre diesel (Brink & Annema, 2007). These taxes are assumed the same in 2050. However, the usage of gasoline and diesel will change. With 58% usage of diesel and 42% usage of gasoline, the shares will be reversed. Due to a reduction in fuel usage of 1.8 billion litres, the government will miss ***1.6 billion*** euro on taxes.

- Rebound effects

The lower price that end-users pay for their trips also has secondary effects. It often leads to more vehicle kilometres. Although the effect of a decrease in price is not as big as a price, increase there is still an effect. This effect however, is not monetised.

Noise abatement measures

This package of measures is adopted from Nijland et al. (2003). The package includes silent tires and silent asphalt. These measures can reduce noise nuisance by absorbing sound.

Benefits

- Area without noise nuisance

Applying silent tires gives a noise reduction of 4 dB (A), in addition applying silent pavement results in a noise reduction of 6-8 dB (A) (Nijland et al., 2003). In 2050, the area with noise above the 50 dB (A) is about 85% (extrapolation based on Nijland et al.). With the mentioned noise measures, the area where noise nuisance of road traffic exists will be reduced to around zero. Based on the willingness to pay for noise reduction (questionnaires and house prices) Nijland et al. come to a benefit of ***3.4 - 4.4 billion*** euro for 2030, these values are assumed the same in 2050.

Costs

- Silent tires

According to Nijland et al. (2003), applying silent tires would cost next to nothing since it merely consists of banning the noisiest tires on the market today by introducing emission limits. Since the silent tires already exist, no new technology is needed. In this study, no costs will be brought into account for silent tires.

- Silent asphalt

According to Nijland et al. (2003) 6500 km of silent pavement on all highways, main provincial and urban roads have to be applied. They come to total costs of ***0.9 – 1.4 billion*** euro in 2030, and these are assumed the same in 2050.

Battery electric vehicles

Battery electric vehicles (BEV) are vehicles driven by electric power and can realise zero emission vehicles when the electricity used is generated in a sustainable way.

<u>*Benefits*</u>

- Emission reduction

Due to the introduction of battery electric vehicles the emissions are reduced to zero and the possible benefits sketched in § 4.2 will be realised. These benefits are ***1.9 – 5.0 billion*** for CO_2, ***0.4 billion*** for NO_x and ***0.3 billion*** for PM_{10}.

- Noise nuisance

Next to the reduction of the emissions, a noise nuisance reduction is incorporated with battery electric vehicles. Compared to conventional vehicles the motor of a BEV does not make any noise. Especially in urban areas, this effect can be noticed. This leads to a small benefit of ***0.2 billion*** euro.

- Cost savings on fossil fuels (end user)

Because electricity is used, no fossil fuels are needed. Avoiding the usage of 5.5 billion litres gasoline and 7.7 billion litres diesel, will spare the end user ***10.7 to 13.6 billion*** euro. This is based on a raw oil and diesel price of 0.15 to 0.37 euro per litre (price per barrel respectively 32 and 80 dollar) and taxes of respectively 0.87 and 0.51 euro per litre.

- Vehicle to grid (V2G)

Vehicle to grid gives car users the ability to make profit by sharing their vehicles energy while it is parked. For more details on this system, see appendix IV. Letendre and Kempton (2002) made an overview of the owner's annual net profit from V2G. For a battery electric vehicle, these are 3162 dollar for regulation services, 720 dollar for spinning services and 267 dollar for peak services (see appendix IV for an explanation of these services). These calculations are inclusive of capital costs for any additional equipment required, and shortening of battery pack lifetime due to additional use. As the V2G-capable BEV fleet grows, it will begin to saturate existing ancillary service markets. Letendre and Kempton made saturation number estimates for the California market, these are translated to the Dutch market based on a comparison of number of inhabitants, power usage and vehicle fleet. For regulation services, the highest value market could be met with 70.532 to 112.592 vehicles and spinning reserves with an additional 49.178 to 176.653 vehicles and for peak services 323.540 vehicles. After a conversion to euro this comes down to a total benefit of ***0.4 – 0.6 billion*** euro.

- Other benefits of speed reduction

Speed reduction also has a positive influence on traffic safety and means a cost reduction for car users since they use less energy. These benefits are not taken into account for this study.

- Making wind power reliable

If wind becomes more important for electricity generation, grid integration must be resolved, particularly to smooth fluctuations in wind power output. Adding energy storage or back-up has been proposed as a solution, but dedicated storage or back-up adds capital costs to wind power. Kempton and Dhanju (2006) propose vehicle-to-grid power (V2G) as a storage resource for large scale wind power. According to them, V2G enables multiple types of electric vehicles to play valuable roles as back-up/or storage for wind power, eventually making large-scale wind integration more stable and more economical.

<u>*Costs*</u>

- Electricity generation

In literature current cost price ranges of 4-8 eurocents/kWh can be found for wind energy (PDE, 2002 in Van den Brink (2003), (Ampere, 2000) and (Morthorst & Chandler, 2004)). Costs have declined by 30%, or around 3% per year from 1989-2001 (EWEA, 2004)). Using those learning curves make EWEA arrive at 3.1-4.4 eurocents/kWh produced in 2010. The UNDP (2000) expects that the cost price of wind energy will decrease with 35-45% between 1997 and 2020. This comes down to 2.0 - 2.5% reduction in price per year. For this study the assumption is made that the cost price in 2050 will be between the lowest price in literature for 2020 (3.1 eurocents with a reduction of 2,5% until 2020) and a price when the 4.4 eurocents keeps reducing with 2% per year until 2050. This gives a range of 2.0 – 2.4 eurocents/kWh. Because BEVs are more energy efficient than ICEVs, only one third of the energy demand for passenger vehicle traffic, will be needed, being 150 PJ. This equals 42 billion kWh. Multiplying the prices for 1 kWh in 2050 with the total energy demand for battery electric vehicles in 2050, results in ***0.8 – 1.1 billion*** euro.

One could also realise clean energy by using solar thermal electricity. When the electricity is imported from the Sahara a range of 3.0 – 4.0 eurocents/kWh seems to be reasonable for the Netherlands in 2050 (based on Visser et al. (2006) and Nagelhout and Ros (2006), including transportation costs by Trieb (2006)). For a more comprehensive calculation of the costs, see appendix IV.

- Additional car costs

Additional car costs exist mainly of battery costs. The whole vehicle park of 11.4 million cars needs to be equipped with a battery. The US advanced battery consortium (USABC) use long-term goals for cost of two-third of the actual price and for 12 year lifetime. The lifetime almost equals that of a vehicle (assumed 14 years). At this moment batteries cost approximately of $9000 (Delucchi & Lipman, 2001). In the bandwidth, the learning factor is used get the lower value. This gives a range for additional battery costs of ***4.2 – 6.3 billion*** euro.

- Charging points

Delluchi and Lipman (2001) mention charging points are expected to have a cost range of 296 – 591 euro (or 400 – 800 dollar for medium and high volume cases). It is assumed that, as many charging points are required as there are vehicles. There are 11.4 million vehicles in 2050, assuming a depreciation period of 20 years this gives costs of ***0.2 – 0.3 billion*** euro.

- Missing out on taxes

No fossil fuels will be used for passenger vehicles anymore. This means a reduction in fossil fuel usage of 5.5 billion litres gasoline and 7.7 billion litres diesel. With taxes of respectively 0.87 and 0.51 euro per litre, this means the government misses out ***8.7 billion*** euro on taxes.

- Rebound effects

The lower price that end-users pay for their trips has the same secondary effects as for the AHS, however larger this time.

4.3.4 Uncertainties

- Undervaluation of safety effects on urban roads

The intelligent safety systems required for the automated highway also have an effect on the safety on urban roads. This however is not quantified and not included in this study and leads to an undervaluation of the benefits.

- Underestimation of noise abatement measures

Because methods and input data for nature and quiet zones are not available, the savings only include effects on human health and well-being; this clearly leads to an underestimation of the benefits (Nijland et al., 2003).

- Battery price and life-time uncertain

The battery price is identified as an important uncertainty. Pro et al. (2005) assume for an optimistic scenario (‘high’) there would be only one battery required for the vehicle lifetime and for the ‘low’ scenario the battery needs to be replaced once. Using the same assumption would mean a doubling of the battery costs.

- *Social inclusion and second-hand cars*

Lucas (2006) highlights two UK studies in which there is a high expectation that technology will solve most of the environmental risk associated with car-based travel. She notes that this appears to avoid consideration that new cars cost much more money and so are usually out of the price range of most low-income households. According to Lucas (2006) this means that fleet replacement will be slower than it ideally could be and that some of the environmental benefits that could be realised will be undermined by the growth of second-hand car ownership from this sector. By implementing strict rules or banning those second-hand cars, this problem could be solved. The higher price however can cause social inclusion. On the other hand, travel expenses for mobility will be lower due to the higher efficiency of BEVs and this could compensate for the higher car costs.

- Restriction of freedom not valued

Implementing an international design speed reduction, could lead to resistance. Less drastic speed reductions are already proposed by the European Parliament (Davies, 2007) at this moment, with resistance of big car manufacturers as a result[1]. Also for car users, a speed reduction means a restriction of freedom and a loss of welfare. This is hard to monetise, but could play a significant role in decision-making. On the other hand, a speed reduction does not only realise wider action radius for the battery electric vehicle. It also has positive effects on for example energy usage and traffic safety.

- Lithium dependency

The possibility of using batteries depends much on the availability of lithium (Li). Recently there were some questions about the future availability of lithium. Using the data available, the Li reserves/resources could supply fusion needs in the range of 250–600 years (Fasel & Tran, 2005). They also give encouraging results of both recent studies and experimental tests regarding extraction of Li from the seawater have been obtained. They say the latter becomes an attractive method and Li could, thus be considered as an “unlimited” source of energy.

- Uncertainty about the valuation of CO_2

The wide cost range for emission reductions is caused by the uncertainty of the valuation of CO_2. The bandwidth could even be wider when the total bandwidth found in the literature was used. The valuation (56 euro per tonne) used in the CE study (Vermeulen et al., 2004), are based on prevention costs method and are correlated with the 1997 Kyoto protocol targets. With higher European (IPCC, 2007) greenhouse gas emission reduction targets, higher avoiding costs can be expected. Another method is based on risk assessment and valuation of impacts. Due to uncertainties on the impacts, the valuation of a reduced tonne CO_2 in studies using this method varies from 14 to 280 euro per tonne, where 70 euro is used as a mean value (UBA, 2007; Infras/FiFo, 2007; Krewitt et al., 2006; Downing et al., 2005). Stern et al (2006) use 63 euro (85 dollar) as social costs for a tonne carbon today. For 2050, these costs are only expected to rise. With this in mind, a bandwidth of 56 – 150 euro per tonne is used for this study. The bandwidth in literature however, is even wider.

- Fuel price

Based on the WLO an oil price of 32 dollar per barrel is used for the year 2050. Currently, this oil price is around 80 dollar per barrel. In this study both values are used, however this does mean an important uncertainty.

4.3.5 Résumé

In the TT-scenario, the lost vehicle hours are reduced by 41%, noise nuisance is reduced to zero, fatalities are minimised with 15%, and emissions are reduced to zero. The automated highway system and the noise abatement measure are cost effective measures. The battery electric vehicle showed a negative cost benefit ratio.

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[1] Acea rejected Mr Davies's controversial proposals to limit the top speed of cars to 160 kilometres per hour and to ban vehicles that emit more than 240g/km of CO2 by 2015. These "come close to political symbolism", it said. The top speed of a car made little difference to its greenhouse emissions, Acea said. http://www.eceee.org/news/news_2007/2007-06-26/

Cost savings on fuel are huge benefits for the end user, and compensates well for the high costs on electricity. The remaining benefit is mainly because the government misses out more tax from fossil fuels than it receives taxes on electricity, due to the higher efficiency of the battery electric vehicle. Other striking characteristics are the high benefits for emission reduction and the high additional car costs. On top, fuel price, CO_2 valuation and not valuing restriction of freedom are considered important uncertainties.

4.4 Conscious Consumer (CC)

4.4.1 Scenario description

In 2050, consumers are more and more aware of the impacts of their behaviour. Documentaries like Al Gore's 'An Inconvenient Truth' (2006) and the wide availability of information can be seen as a turning point. People think about their actions and the consequences on a wider scale. This awareness results in an easier adoption and acceptance of measures by the public. This also has its impacts in the traffic and transport domain, and not only at environmental level.

Congestion is no longer the much debated traffic problem, due to a change in perception. This change in perception can already be perceived. By listening to music and making phone calls, drivers bring some moments of joy into their commute. By 2050, this trend has been developed much further. With the introduction of low speed automation (LSA) or automated congestion driving, it becomes safely possible to let the attention slip away form the driving task at low speeds, thus during congestions. Campaigns emphasise that congestion driving could be fun. With LSA activated, one could play a game, browse the internet, check email or watch television during their congestion drive. Drivers in 2050 increasingly accept congestion driving as part of their commute. Additionally, drivers will start to realise that their daily commute, is one of the scarce moments of complete privacy, and value this moment accordingly.

Traffic safety will be significantly improved by 2050. In the coming decades a sustainable safe infrastructure[2] will be realised. A sustainable safe road network has a functional layout, based on three main road types. This infrastructure aims at homogeneity in mass, speed, and direction. This means that vehicles with large differences in mass, speed, and direction are physically separated from each other (e.g. lorries, cars and cyclists). When physical separation is not possible, the speed is significantly reduced. Furthermore, people can recognise the road type and will drive accordingly. Training and education programs focus on known high-risk road groups (like children in traffic, young moped riders, novice drivers and elderly road drivers) and on unsafe behaviour (alcohol and drug usage, fatigue, speeding, aggression, etc.). Since speed has an enormous impact on traffic safety, the government also

[2] Based on sustainable safety vision of SWOV, http://www.swov.nl/UK/Research/Kennisbank/Inhoud/05_duurzaam/sustainablesafety.htm

implemented intelligent speed adaptation. This restricts people to drive faster than the maximum allowed speed at a certain road. These measures together will result in a considerable more safe traffic system than we know now.

By 2050, the emission problems of passenger vehicles are history. By then, all cars are fuel cell electric vehicles (FCEV) which use hydrogen as a fuel. Hydrogen is a carrier of energy, will be centrally produced via electrolysis of renewable electricity, and is distributed via a network of pipelines. Biomass, wind and solar power form the basis of this zero-emission fuel for vehicles. The only thing the car emits is water, which can be used to make an espresso on-board of the vehicle.

By the year 2050, the noise nuisance from vehicles is greatly reduced due to the application of silent tires and silent asphalt. In addition, the shift from combustion engines to fuel cell electric vehicles results in a reduction of urban noise nuisance.

4.4.2 Degree to which targets are fulfilled

The degree to which the sustainable mobility targets are fulfilled in the CC scenario is presented in figure 4.2.

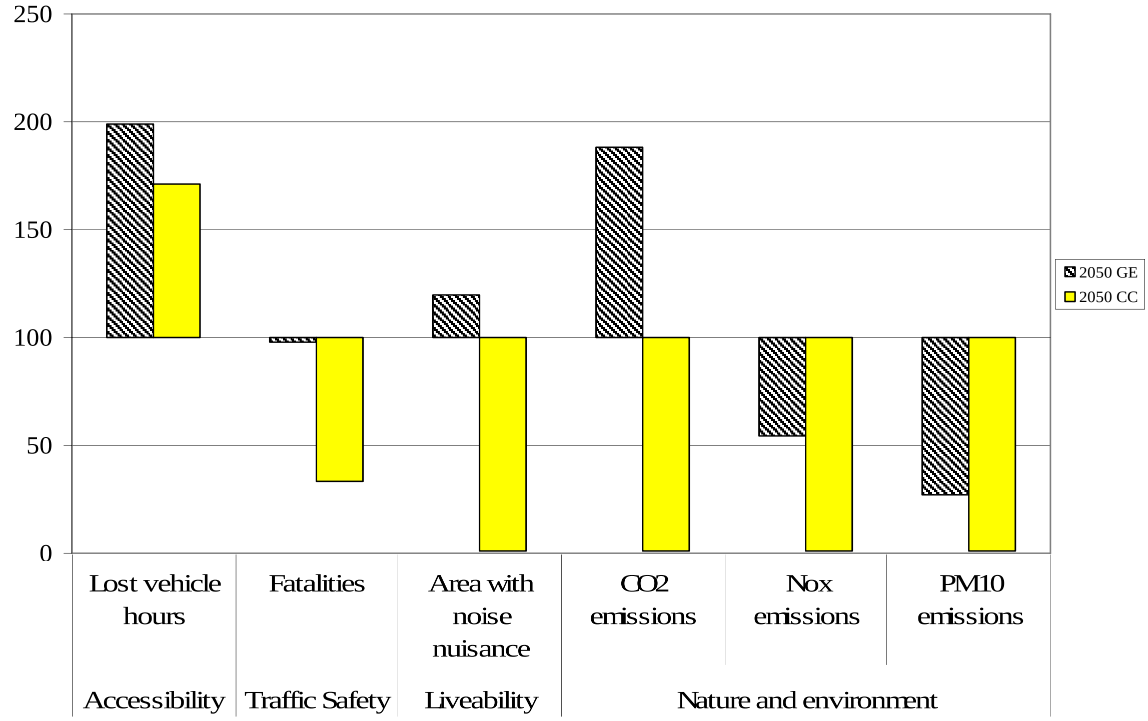

Figure 4.2 The sustainable mobility targets in the CC scenario in 2050 (index 2000 = 100)

In the CC scenario, the lost vehicle hours are reduced by 14% compared to the GE scenario. This means, in relation to the current situation there is an increase of the lost vehicle hours. Fatalities are minimised by 66% in comparison with the GE scenario. Noise nuisance and emissions are reduced to zero.

4.4.3 Benefits and costs

An overview of the costs and benefits is presented in table 4.3 on the next page. A brief explanation of the costs and benefits will be presented here, for a full explanation including discussion, see appendix V.

Low speed automation (LSA)

LSA systems can be used in slow-speed congested traffic conditions. When in use, the driver can relax instead of controlling the vehicle under these tedious circumstances. When the congestion clears and speeds increase, the driver will resume control. By using this measure, the perception of lost vehicle hours can change.

<u>*Benefits*</u>

- Reduction of lost vehicle hours

According to Rand Europe and AVV (2005) the value of reliability is 0,8 times the value of time. When the travel time and its reliability together represent the total travel time costs, the calculation can be made that 44% of total travel time costs originate from the deviation in travel time and 56% from the average travel time or non-productive time. The assumption is made that, non-productive time is reduced with 25% due to the introduction of LSA. Overall, this would result in a 14% reduction of the total loss of lost vehicle hours. With an average value of time of 17,58 euro per hour and 94 million lost vehicle hours this comes down to ***0.2 billion*** euro.

- Comfort and convenience

By smoothening the congestion drive this system is expected to give more comfort and convenience for the driver. The benefits are not taken into account in this study; however could be significant.

- Secondary effects

By making the traffic flow less dynamic, there are also positive effects on required energy and traffic safety. These effects are not taken into account in this study; however, they are expected to have a considerable contribution to the benefits.

<u>*Costs*</u>

- Stop-and-go system

The costs of a stop-and-go system are derived from Abele et al.(2005). In their study, the costs for this system are labelled as high. For another system, with the same label, the costs are estimated to be 400 and 750 euro, respectively in 2020 and 2010 with a penetration of respectively 8 and 3%. Based on this, the assumption is made that for the stop-and-go system in 2050 with a penetration of near 100% the costs per system will be between 250 and 400 euro. With 11 million cars and an amortisation period of 12 years this comes down to ***0.2 – 0.4 billion*** euro.

Conscious Consumer

Benefits in million euros	min	max	Effects in %	**Costs in million euros**	min	max
Total	**23,4**	**32,0**		Total	**20,9**	**26,4**
Low speed automation	**0,2**	**0,2**		**Low speed automation**	**0,2**	**0,4**
Lost vehicle hours	0,2	0,2	14	In-vehicle equipment	0,2	0,4
Comfort and convenience	pm	pm		Campaign	<0,1	<0,1
Secondary effects/ rebound	pm	pm				
Sustainable safe infrastructure	**4,2**	**5,3**		**Sustainable safe infrastructure**	**1,7**	**2,2**
Reduction of fatalities and injuries	4,2	5,3	66	Upgrade infrastructure	0,4	0,4
Congestion reduction	pm	pm	pm	Influence behaviour	0,2	0,2
Emission reduction	pm	pm	pm	Vehicle modifications	0,2	0,2
				Intelligent transport systems	0,9	1,4
Noise abatement measures	**3,3**	**4,4**		**Noise abatement measures**	**0,8**	**1,4**
Nois nuisance reduction	3,3	4,4	n/a	Silent tires	<0,1	<0,1
				Silent asphalt	0,8	1,4
Fuel cell Electric Vehicles	**15,7**	**22,1**		**Fuel cell Electric Vehicles**	**18,2**	**22,4**
Emission reduction	2,6	5,7	100	Additional car costs	<0,1	4,1
Noise nuisance	0,2	0,2	pm	External safety	<0,1	<0,1
Cost savings on fossil fuels (end user)	10,7	13,6	41	Charging points	0,2	0,3
Vehicle 2 Grid	0,3	0,7	n/a	Missing out on fossil fuel taxes (government)	8,7	8,7
Taxes on hydrogen (government)	1,9	1,9	n/a	Hydrogen costs (end user)	9,3	9,3
Making wind power reliable	pm	pm	n/a	Rebound effects	pm	pm
				Range of net benefits in million euros	**2,5**	**5,6**
					-3,0	11,1

Table 4.3 Overview of costs and benefits of the CC scenario

Sustainable safe infrastructure

This package of measures is adopted from the SWOV, which they presented in Wegman (2001). A sustainable safe infrastructure is an infrastructure, which is functional, homogeneous, recognisable, forgiving and realises state awareness by the road users. In addition to the infrastructure, education and intelligent transport systems will help achieving these principles. These measures are expected to improve traffic safety considerably. More about this measure can be found in appendix V.

Benefits

- Reduction of fatalities and injuries

According to SWOV (Wegman, 2001), the selected measures give a reduction of 700 fatalities compared to the current situation. This is a reduction of 66%. When the assumption is made that, this percentage is the same in 2050 and counts for the reduction of injuries as well, this means 778 reduced fatalities and 11822 reduced injuries. With the value of a statistical life ranging from 1.600.000 and 3.000.000 euro and the value of an injury around 250.000 euro, this results in benefits amounting to ***4.2 to 5.3 billion*** euro. Since a study by Wesemann (2000a) this includes the costs of congestion caused by traffic accidents.

Costs

- Infrastructure upgrade

The costs of a sustainable safe infrastructure are estimated to be 11 billion euro (Schoon, 2000) or 8 billion euro (Wesemann & Devillers, 2003). The differences in costs are caused by the fact that in the period 1998 - 2002 extra investments are made (1/2 billion) and the fact that rural through-roads under supervision of the State are not taken into account (2 billion)[3]. To compare the measure type with other measures the complete costs of this project will be taken into account. A depreciation period of 30 years gives costs per year of ***0.4 billion euro***.

- Influence behaviour

This includes enforcement and education, a special driver's licence for beginning drivers, a safety culture for freight traffic, special exams for moped drivers and lights on during the winter months. Summing the costs for these measures given in Wesemann (2000b) gives ***0.2 billion*** euro.

- Vehicle modifications

These modifications do not only include passenger cars but also especially refer to reflectors for bicycles, modifications to improve view in delivery vans and lorries. Again, based on costs for these measures given in Wesemann (2000b) sum to ***0.2 billion*** euro.

[3] The differences in cost were explained in an email by Wim Wijnen (2007), employee of the SWOV.

- Intelligent transport systems

This includes a tachometer in lorries and delivery vans. Furthermore, all passenger cars will be equipped with intelligent speed adaptation (ISA). Costs for tachometer are derived from Wesemann (2000b) and are 0.6 billion euro. For ISA the costs are derived from Wedlock et al. (2006) and they vary from 300 – 1000 euro per system. With 11.4 million vehicles this comes down to 0.2 – 0.8 billion euro. Together this means ***0.9 – 1.4 billion*** euro.

Noise abatement measures

This measure is equal in all scenarios, a description of the benefits and costs of these measurements can be found under the TT scenario (§ 4.3.3).

Fuel cell electric vehicles

A fuel cell combines hydrogen fuel and oxygen to produce electricity used to power an electric motor that moves the vehicle. If hydrogen is produced on a sustainable manner, this would measure will reduce the emissions to zero, since the only exhaust is water.

Benefits

- Emissions

Due to the introduction of fuel cell electric vehicles the emissions are reduced to zero and the possible benefits sketched in § 4.2 will be realised. These benefits are ***1.9 – 5.0 billion*** for CO_2, ***0.4 billion*** for NO_x and ***0.3 billion*** for PM_{10}.

- Noise nuisance

Comparable to the BEV, a noise nuisance reduction is incorporated with fuel cell electric vehicles. Compared to conventional vehicles the motor of a FCEV does not make any noise. Especially in urban areas, this effect can be noted. This results in a small benefit of ***0.2 billion*** euro.

- Cost savings fossil fuels (end user)

Because hydrogen is used, no fossil fuels are needed. Just like in the TT scenario, the end user will spare ***10.7 to 13.6 billion*** euro.

- Vehicle to grid (V2G)

Moreover, FCEV owners have the opportunity to make profit with V2G. In the overview of Letendre and Kempton (2002) the owner's annual net profit from V2G for a FCEV are 2430 to 2685 dollar for spinning services, and -50 to 1266 dollar for peak services. The market is saturated at 49.178 to 176.653 vehicles for spinning reserves and for peak services at 323.540 vehicles. Multiplying these numbers with the average net profit per vehicle and converting it to euro, gives a benefit of ***0.3 – 0.7 billion*** euro.

- Taxes on hydrogen

A tax of 25% is presumed to be added to the future price of hydrogen. This tax is a benefit for the government, however on the other side of the balance this price is added on the hydrogen costs for the end user. The purpose of this is a fairer comparison with the measures in other scenarios. The tax comes down to ***1.9 billion euro***.

- Making wind power reliable

The suggested value of battery electric vehicles for making wind power reliable applies on fuel cell electric vehicles as well. These benefits are however not taken into account for this study.

<u>*Costs*</u>

- Additional car costs

The additional car costs are somewhere between 0 – 5000 euro (Wietschel et al., 2006). With 11.3 million vehicles and depreciation period of 14 years, this comes down to ***0.0 – 4.0 billion*** euro.

- Safety

Another small debit item incorporates the external safety. It is assumed that the same external safety accounts for hydrogen as it accounts for LPG. The total costs are based on the external safety costs per LPG vehicle given by Ecorys (Beumer et al., 2004) and sum to ***<0.1 billion*** euro.

- Hydrogen costs (end user)

The well-to-wheel production costs of hydrogen are estimated to be between 0.093 euro and 0.113 euro/kWh and include electricity costs, hydrogen production by electrolysis, transport by a pipeline network, compression, storage and refuelling at a fuelling station. The first figure comes from a calculation for 2030 by Wietschel et al. (2006) and the second for 2050 by the American department of energy (DOE, 2003). Differences in calculation can be found by the fact that Wietschel et al. only look at wind power, while DOE first uses cheaper renewable sources. This means that in DOE (2003) about 70 percent of the hydrogen is produced from wind energy. In this study, the 2050 figures of DOE (2003) will be used. Adding a 25% tax resulting in 0.14 euro/kWh or 0.0392 euro per/MJ. Due to an improved energy efficiency of a fuel cell electric vehicle, 47% of the energy in GE is required. This is 2.4 PJ and results in ***9.3 billion*** euro.

- Missing out on fossil fuel taxes (government)

Just like in the TT scenario, no fossil fuels will be used for passenger vehicles anymore. This means the government will miss ***8.7 billion*** euro out on taxes.

- Rebound effects

Just like in the TT scenario, the lower price that end-users pay for their trips has rebound effects, these are not quantified.

4.4.4 Uncertainties

- Chicken-and-egg problem

A known difficulty of hydrogen-powered vehicles is the chicken-and-egg problem. There is no incentive to develop hydrogen delivery infrastructure until there is substantial demand from hydrogen users. On the other hand there is no incentive to produce hydrogen technology (e.g., cars) until there is adequate hydrogen delivery infrastructure.

A transition towards hydrogen (H_2) can commence only when economic value of this transition is realised[4]. In the first decades of the 21st century, stationary fuel cells are applied in buildings for efficient cogeneration. In the beginning, natural gas reformers fuel hydrogen and energy will be extracted by using coal carbon capture and storage. This step is closely followed by the introduction of H_2-ready vehicles. Customers who work near buildings that have fuel cells use the buildings' hydrogen appliances for refuelling and sell kWh and ancillary services to the grid when parked, by doing that they earn back part of the cost of car ownership. Hydrogen vehicles get cheaper and former 'gas' stations will be used to improve the availability of H_2. As both hydrogen and fuel cells become widespread, bulk production and central distribution by pipelines becomes feasible. By 2050, the hydrogen is produced via electrolysis of renewable electricity, like biomass, wind and solar power forms the basis of a zero-emission fuel for vehicles.

- Wide range additional car costs

The additional costs are somewhere between 0 – 5000 euro (Wietschel et al., 2006). Wietschel et al. found that many experts assume that the prices of fuel cell cars could be in the same range or lower than conventional cars, they also found some more pessimistic views, explaining the wide range used here. Reasons for these assumptions are the intrinsic simpler construction of the drive system and the huge learning potential associated with fuel cell technology. Learning curves however do not represent a physical law. This forms the basis of the more pessimistic view.

- Price of hydrogen of renewable resources

The price of hydrogen is based on the future price of renewable recourses. Since their future costs are uncertain, the price of hydrogen is uncertain as well.

- Platinum availability

For the production of fuel cells platinum is required in big numbers. Except for the most aggressive market penetration cases (those with the fastest and largest mounting FCEV scales to 2020), estimated platinum demand does not appear to be a limiting factor for long term-sales of FCEV (Spiegel, 2004).

[4] Based on a transition according to http://gcep.stanford.edu/pdfs/hydrogen_workshop/Swisher.pdf

- Perception of hydrogen safety

A major issue facing hydrogen as a fuel is public perception about its safety. Looking at figure 4.3, one can see the differences in burning of a hydrogen tank and a gasoline tank. Due to the high pressure, hydrogen goes straight up. In addition, the fire is over in a much shorter period compared to the gasoline car. Safety of hydrogen is not such a big issue, as it is perceived by the public.

Figure 4.3 Hydrogen car left, gasoline car right

- CO_2 price and fuel price

Again, the price of CO_2 and the fuel price are uncertain factors.

4.4.5 Résumé

In the CC scenario, the lost vehicle hours are reduced by 14%, fatalities and injuries are minimised by 66% and emissions are reduced to zero. Just like in the TT scenario, noise nuisance is reduced to zero. The sustainable safe infrastructure and the noise abatement measures are cost effective. A fuel cell electric vehicle has a negative costs and benefits balance.

Just like in the previous scenario, there are huge benefits for the emission reduction and high additional car costs. Also, sustainable safe infrastructure shows high benefits reducing serious casualties. Moreover, fuel price, CO_2 valuation and the chicken-and-egg problem are considered important uncertainties.

4.5 Exploiting Conventional Technologies (ECT)

4.5.1 Scenario description

In 2050, sustainability targets are patly full-filled, by using and optimising technologies that already exist today. This is driven by strict international policy targets, which the Dutch government tries to meet by internalisation of external costs. Kilometre based charging is already on the agenda now and is a good example of this.

In 2050, congestion has become much less relevant. Due to a kilometre charge that will be implemented somewhere in the next few years, there will be a slight reduction in car usage, especially for recreational travel. In combination with congestion charge, which will replace the MRB (road tax) and a part of the BPM (tax on passenger cars), the traffic will be spread over the day. To charge all the driven kilometres, a GPS-module will be placed in every car. This charge means that drivers pay a constant fee per kilometre to internalise the usage in terms of environmental costs. On top of this fee, there will be a variable fee depending on time and place. This fee means to internalise the congestion costs. At this moment many companies reimburse the travel expenses of their employees, it is expected that a part of the future road users still get all expenses reimbursed, and thus be indifferent to the charge. However, a bigger group is expected to get incentives from their company to move closer to work. By the year 2050, internalisation will even go further. The kilometre-based fee will then depend on the type of car and the way the car is used. Not only congestion and emission related, but also traffic safety and noise nuisance related problems will then be internalised. Lower car use and a spread of traffic over the day results in a considerable reduction in congestion.

With the GPS-module already onboard in 2050, it will be easy to register the use of the car. With this registration, federal agencies can see if someone is violating traffic rules, e.g. speeding. A so-called black box will be implemented and makes the chance of being caught after a violation nearly 100%. Due to this guarantee of being caught and having to pay for it, drivers will not easily violate traffic rules anymore. This results in a significant safer traffic system.

Stricter European emission limits, including CO_2, will result in demand for more fuel-efficient vehicles. The car manufacturers will take notice of this and start making more fuel-efficient cars by improving the combustion engine, hybridisation, using different materials with weight and drag reduction as a result. Drivers will be stimulated to take extra driving lessons in order to learn how to drive efficiently and people choose to drive slower on highways just to avoid the high costs. These actions together can result in halving fuel usage. However, with a further increase of the oil price, and even stricter European targets people will ask for a fuel alternative. The market will meet this demand with biofuels. Biofuels are already used in small proportions in a mix with fossil fuels. According to European norms, this share is to increase and this has positive effects on the price of biofuels. The increasing oil prices, the internalisation of environmental costs and the reduction in cost price of biofuels will make biofuels replace the fossil fuels. By the year 2050, this leads to near-zero emission vehicles.

By the year 2050, the noise nuisance from vehicles is greatly reduced due to application of silent tires and silent asphalt. In addition, the cars are equipped with a silent-mode, which further reduced the noise nuisance in urban areas.

4.5.2 Degree to which targets are fulfilled

The degree to which the sustainable mobility targets are fulfilled in the ECT scenario is presented in figure 4.4.

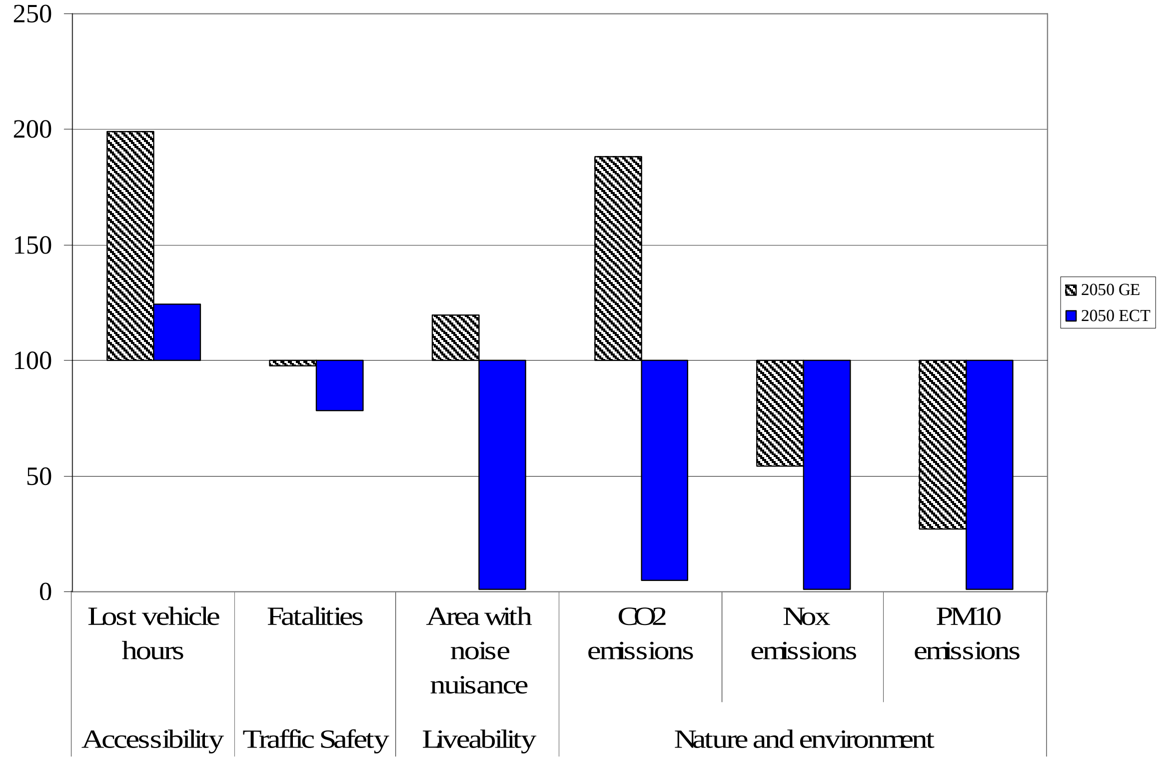

Figure 4.4 The sustainable mobility targets in the ECT scenario in 2050 (index 2000 = 100)

In the ECT scenario, the lost vehicle hours are reduced by 38% (average of 30 and 45%) in reference to the GE scenario. This means, compared to the current situation there is a slight increase of the lost vehicle hours. Fatalities are minimised by 20% in comparison to the GE scenario. Noise nuisance is reduced to zero and emissions are reduced to near zero.

4.5.3 Benefits and costs

An overview of the costs and benefits is presented in table 4.4 on the next page. A brief explanation of the costs and benefits will be presented here, for a full explanation including a discussion, see appendix VI.

Kilometre plus congestion charge

This charge consist of a kilometre based charge and a congestion charge. The first part mitigates the growth of car travel. The second part, paying more on busy roads and busy times, initially leads to traffic diverting onto other roads or a spreading over the day. A combination of both is proved to have the highest impact on congestion.

Benefits

- Lost vehicle hours

Based on Besseling et al. (2005) and Tillema et al. (2007) a reduction of lost hours between 30 and 45 percent is expected (see uncertainties further on for an explanation of this bandwidth). The 30 - 45% reduction of lost vehicle hours can be multiplied with the potential benefits mentioned in § 4.2. This leads to a benefit of ***0.5 – 0.7 billion*** euro.

- Reduction of fatalities and injuries

In addition to the reduction of lost vehicle hours, a reduction of 10 to 14% in vehicle kilometres is expected (also based on Besseling et al. (2005) and Tillema et al. (2007)) . This reduction in vehicle kilometres also results in an equal reduction of fatalities and injuries. This benefit is equal in percentage to the reduction of vehicle kilometres. This means ***0.6 to 1.1 billion*** euro.

- Emission reduction

The same reduction in vehicle kilometres also results in a benefit of emission reduction. Again, this benefit is equal in percentage to the reduction of vehicle kilometres. This means ***0.3 to 0.8 billion*** euro.

- Noise nuisance reduction

It is also assumed that a noise nuisance reduction is realised by travelling less vehicle kilometres. This results in a benefit of ***0.3 to 0.6 billion*** euro.

- Reduction on fossil fuel usage (end user)

Since less vehicle kilometres are driven, the end user saves a spending on fuel of ***1.1 to 1.9 billion*** euro.

- Rebound effects

Just like in the TT scenario, the lower price that end-users pay for their trips has rebound effects (§ 4.3.3).

Costs

- Onboard units investment

Based on LogicaCMG et al. (2005) on board units cost 234 – 436 euro. Multiplying this with 11.4 million passenger vehicles and a depreciation period of 7 year results in total costs of ***0.4 – 0.7 billion*** euro.

- Registration, helpdesk, invoice, monitoring and enforcement

Because these costs aren’t expected to differ much now or in 2050 these costs are adopted from LogicaCMG et al. (2005) and come down to ***0.1 billion*** euro.

Exploiting conventional technologies

Benefits in million euros	min	max	Effects in %	Costs in million euros	min	max
Total*	**11,2**	**19,7**		Total**	**11,6**	**17,3**
Kilometre charging	**2,8**	**5,1**		**Kilometre charging**	**2,5**	**4,3**
Lost vehicle hours	0,5	0,7	30-45	On board units investment	0,4	0,7
Reduction of fatalities and casualties**	0,6	1,1	10-14	Registration, helpdesk, invoice, monitoring and enforcement	0,1	0,1
Emission reductions*	0,3	0,8	10-14	Other system costs	0,1	0,3
Noise nuisance***	0,3	0,6	10-14	Exploitation costs	0,7	1,6
Reduction on fuel usage (end user)*	1,1	1,9	10-14	Missing out on gasoline taxes (government)**	0,9	1,2
Rebound	pm	pm	n/a	Less road usage due to charge (welfare loss end user)	0,3	0,4
Black box	**1,3**	**1,6**		**Black box**	**1,0**	**1,0**
Reduction of fatalities and casualties	1,3	1,6	20	Tachometer and event data recorder	1,0	1,0
Noise abatement measures	**3,3**	**4,4**		**Noise abatement measures**	**0,8**	**1,4**
Noice nuisance redution	3,3	4,4	n/a	Silent tires	<0,1	<0,1
				Silent asphalt	0,8	1,4
Optimisation convential vehicle and bio fuels	**5,2**	**11,3**		**Optimisation convential vehicle and bio fuels**	**7,7**	**11,1**
Emission reductions****	2,6	5,7	100	Optimisation ICEV	2,8	5,5
Cost savings on fossil fuel (ICEV optimisation)	0,8	2,0	40	Driver behaviour	<0,1	0,1
Cost savings on fossil fuel (Driver behaviour)	0,1	0,4	8	Bio fuel costs (Wood FT, methanol and ethanol)*****	0,3	0,9
Fossil fuel replaced wood FT, Methanol and Ethanol*****	0,2	0,5	10	Bio fuel costs (Sugar cane ethanol)*****	0,7	0,7
Fossil fuel replaced by sugar cane ethanol*****	0,8	2,0	40	Missing out on gasoline taxes (less fuel usage) (government)	3,9	3,9
Vehicle to grid	0,6	0,6	n/a			
Noise nuisance	0,1	0,1	pm			
				Range of net benefits in million euros	**-0,4**	**2,4**
					-6,1	8,1

* To avoid double counting, the total is reduced by the emission reduction and fuel usage reduction of the kilometre charge **Again, to avoid double counting from missing taxes due to optimisation of ICEV resp. 0.4 and 0.5 billion euro are substracted from the total ***There might be an interference with the casualty reductions of the black box ****Noise nuisance reductions below 55 dB (A) don't have health effects, but still have some value ***** It is assumed that emissions are reduced to zero, in reality there might be a small percentage left ****** Taxes are not included but are assumed to be the same for bio as for fossil fuels

Table 4.4 Overview of costs and benefits of the ECT scenario

- Other system costs

Also these costs are adopted from LogicaCMG et al. (2005). These costs comprise the costs which are hard to divide among the others and are ***0.1 – 0.3 billion*** euro.

- Exploitation costs

Again adopted from LogicaCMG et al. (2005), these are ***0.7 – 1.6 billion*** euro.

- Missing out on fossil fuel tax (government)

Due to the 10 – 14% less fuel usage, the government will miss out on taxes on fossil fuels. This comes down to ***0.9 – 1.2 billion*** euro.

- Less road usage due to charge levy (welfare loss end user)

These welfare losses are calculated by Besseling et al. (2005) and are ***0.3 – 0.4 billion*** euro.

Black box

It is known that people aware of being observed tend to modify their behaviour. The black box observes and records the behaviours of drivers, and confronts them with their behaviour. This results in drivers adjusting their behaviour ahead of time. They can also react this way because of an actual confrontation. This form of behaviour influence is proved effective and results in fewer road traffic accidents.

Benefits

Wouters and Bos (1997) estimate an accident reduction of some 20% based on a field study. Here it is assumed that 20% of the fatalities and 20% of the injuries are avoided. This results in a benefit of ***1.3 to 1.6 billion*** euro.

Costs

The costs of a tachometer are derived from Wesemann (2000b) and are 909 euro per tachometer. With a depreciation period of 10 years, 11.4 million vehicles this comes down to ***1.0 billion*** euro.

Noise abatement measures

This measure is equal in all scenarios, a description of the benefits and costs of these measurements can be found under the TT scenario (§ 4.3.3).

Optimising internal combustion engine vehicle in combination with biofuels

The internal combustion engine vehicle is the vehicle we all know today. By optimising the vehicle technology, reduce weight by using lighter materials and reduce drag resistance this vehicle could use much less energy. The remaining energy required will than be delivered by the most sustainable biofuels, which should be able to reduce the emissions to near zero. More on this measure can be found in appendix V.

<u>*Benefits*</u>

- Emission reduction

Due to the replacement of fossil fuels by sugar cane ethanol and second generation biofuels based on wood residues, the emissions are reduced to near zero and the possible benefits sketched in § 4.2 will be realised. These benefits are ***1.9 – 5.0 billion*** for CO_2, ***0.4 billion*** for NO_x and ***0.3 billion*** for PM_{10}.

- Fuel usage reduction (ICEV optimisation)

Based on Van de Brink and Annema (2007) and Johansson and Ahman (2002), optimisation of the internal combustion engine vehicle can reduce fuel usage with 30 - 50%. In this study, a 40% fuel reduction will be realised by optimising the ICEV. This result in a fuel saving for the end user of ***0.8 – 2.0 billion*** euro.

- Fuel usage reduction (driver behaviour)

Improved driver behaviour can also contribute to a fuel usage reduction. According to the OECD/IEA (2005a) this can be between 5 and 10%. The German Federal Environmental Agency estimates that measures to promote fuel-efficiency driving habits could provide additional fuel usage reduction potential of between 6 and 17% (SRU, 2005). In this study, a mean percentage of 8% will be used. This fuel usage reduction results in a benefit of between ***0.1 – 0.4 billion*** euro.

- Fossil fuel replacement by biofuels

All fossil fuels will be replaced by biofuels. Due to a more energy efficient ICEVs, only 50% of the energy in GE scenario needs to be replaced by biofuels. Depending on the used oil price, this means a reduction of ***1.0 – 2.5 billion*** euro.

- Vehicle to grid

In addition, hybrid car owners have the opportunity to make profit with V2G. In the overview of Letendre and Kempton (2002) the owner’s annual net profit from V2G for a hybrids are 322 for spinning services, and 1681 dollar for peak services. The market is saturated at 49.178 to 176.653 vehicles for spinning reserves and for peak services at 323.540 vehicles. Multiplying these numbers with the average net profit per vehicle and converting it to euro, gives a benefit of ***0.6 billion*** euro.

- Noise nuisance

Hybrid vehicles could be more silent when they are on electric mode. Most of the time hybrids are on electric mode in the city, where noise nuisance of the engine is dominant over the noise of the tires.

<u>*Costs*</u>

- Optimisation ICEV

Based on a literature review, Brink and Annema (2007) come to additional car costs of 3400-6800 euro per vehicle in order to achieve the maximum fuel usage reduction of 30 – 50%. This includes engine improvements, lightweight material usage, friction and resistance reduction and hybridisation. With 11.4 million vehicles and a depreciation period of 14 years, this comes down to ***2.80 – 5.50 billion*** euro.

- Driver behaviour

According to the OECD/IEA (2005) special driving lessons, aiming at efficient driving behaviour will cost 150-250 euro per vehicle. With 11.4 million vehicles and a depreciation period of 40 years this comes down to ***<0.1 billion*** euro.

- Biofuels

The second generation biofuels with the highest greenhouse gas reduction potential are used to cover 10% of the initial and ca 20% of the fuel usage when a more fuel efficient ICEV and driver behaviour are taken into account. According to Kampan et al. (2005) these are cellulosic ethanol with a greenhouse gas reduction potential of 73-94% and costs of 11-16.5 euro/gj, FT diesel with a greenhouse gas reduction potential of 94-98% and costs of 11-21 euro/gj and HTU diesel with a greenhouse gas reduction potential of 88-107% and costs of 7-16.5 euro/gj. The whole bandwidth of 7 – 21 euro/gj will be used. In addition, a first generation bio-fuel will be used. According to Hamelink and Hoogwijk (2007) sugar cane ethanol has an even better prospective than the second generation biofuels, with a greenhouse gas reduction of 92% and costs of 4 euro/gj. This bio-fuel will be used to replace the remaining fossil fuels. This is 80% of the fuel usage in this scenario and about 40% of the original fuel usage. Costs for these biofuels than come down to ***1.0 -1.7 billion*** euro.

- Missing out on fossil fuel taxes

The taxes on biofuels are expected to be equal to fossil fuels. The government will still miss out on taxes due to the efficiency optimisations; this comes down to ***3.9 billion*** euro.

4.5.4 Uncertainties

- Effects of kilometre charging uncertain

At the moment of writing, the effects of a kilometre-based charge are subject to debate among traffic experts. One of the issues is about reimbursement of travel expenses. It appears that the introduction of a kilometre charge may have an important effect on the way employees are compensated by employers. The results of Tillema et al. (2007) indicate that about 30% of the employees will be fully reimbursed by their employer. Hence, they conclude that, the direct effect of road pricing on employees may be (much) less than if this effect is ignored. In Besseling et al. the reimbursement of travel expenses are seen as a lump sum, a one-time payment by companies. This means no traffic effects are taken into account for this part. This makes the 45% reduction in lost vehicle hours and the 14% reduction of vehicle kilometres arguable. With this in mind, these values will be used as the maximum of the bandwidth. Respectively 30 and 10% will be used as a minimum.

- Effect of pricing on equity of transport

One can argue about the effects of pricing on equity of transport. The share of the average income of households on expenditures for mobility is expected to be equal to its current share. Since the MRB (road tax) and a part of the BPM (tax on passenger cars) are given back to the end user, these can be used to pay the kilometre charge. This off course is not unlimited. However, it is expected that people who drive more now and in the future have a higher income.

- Resistance against black box

It is expected that a tracing system like the black box will cause strong resistance among car drivers as it deprives them from their privacy. To reduce the resistance this black box could first be offered as an additional feature in cars. When people choose for this black box a significant reduction in assurance fee can be offered to them. When more and more people use it, the step to obligation will be easier to make. People who drive safer are expected to make fewer costs for assurance companies.

- CO_2 emissions from biofuels

The greenhouse gas emission reductions of the used biofuels are very high; however, the emissions are not reduced to zero. It is expected that circa 5% of the greenhouse gasses still exist after the suggested measures in this scenario. This is because of the use of fertilisers and the use of fossil fuels in the production and transportation process. The percentage can even be lower if biofuels are also used in the production and transportation process of the biofuel as well.

- Biofuels and competition with food production

The production of sugar cane may lead to competition with local food production (and energy supply, medicines and building material), which can result in higher prices of food which will mainly affect the poor. On the other hand, also positive impacts can be expected because of the economic benefits of sugar cane production. Smeets et al (2006) did a study after the sustainability of sugar cane ethanol in Brazil. Regarding a criterion concerning competition with food production, they conclude that, considering the importance of food security, the lack of criteria and indicators and the complexity of the issue, this criterion can be a significant bottleneck.

4.5.5 Résumé

In the ECT-scenario, the lost vehicle hours are reduced by 30-45%, fatalities and injuries are minimised by 20% and emissions are reduced to near zero. Just like in the TT and CC scenario, the noise nuisance is reduced to zero. The kilometre charge and black box are cost effective measures. Optimising the internal combustion engine vehicle showed a negative cost benefit ratio.

Just like in the other two scenarios, there are huge benefits for emission reduction and high additional car costs. In addition, fuel price, CO_2 valuation and possible competition of sugar cane with food production are considered important uncertainties

5 Results, conclusions and recommendations

Based on the main elements of sustainable development, five pillars for sustainable mobility were formulated and linked with targets. Three scenarios were constructed, aiming at an increase of the degree to which the targets are fulfilled. From these scenarios, the cost and benefits were compared per scenario and per pillar.

5.1 Sustainable development for mobility

Do the constructed scenarios increase the degree to which the sustainability targets are fulfilled? In other words, do they realise a sustainable development for mobility? In figure 5.1, the results are presented.

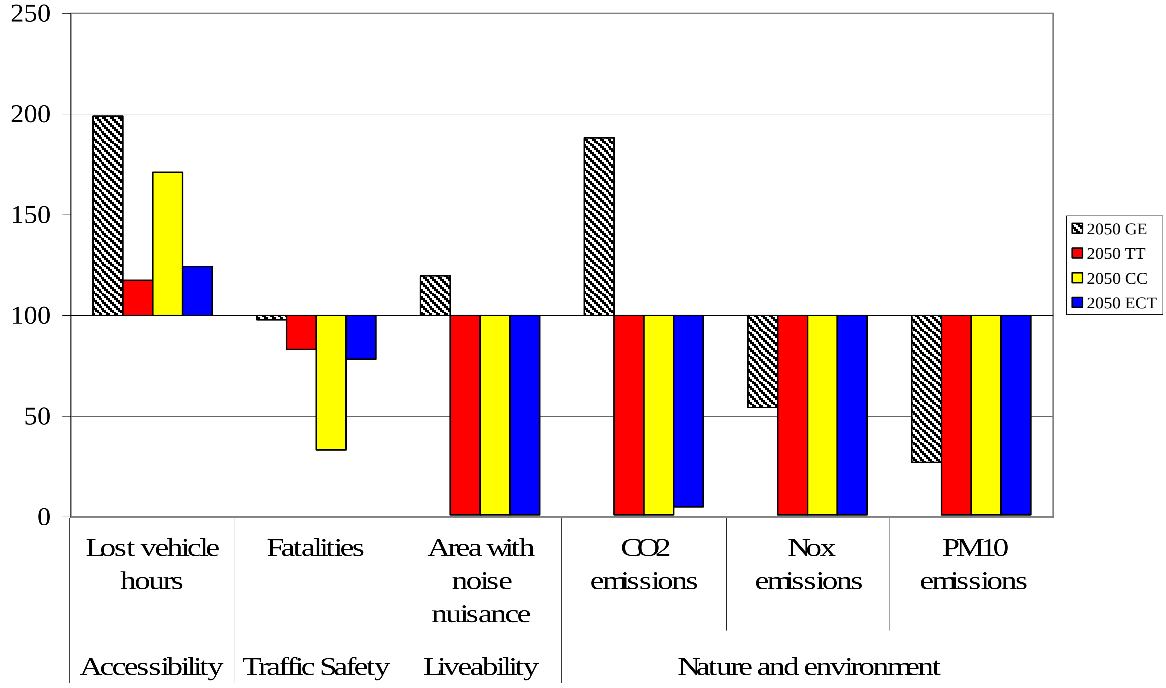

Figure 5.1 The sustainable mobility targets under all the scenarios in 2050 (index 2000 = 100)

Overall, one can conclude that all three scenarios contribute to a sustainable development for mobility. Except for accessibility, all pillars show a decrease compared to the current situation (2000).The lost vehicle hours do decrease compared to the reference scenario, however the measures cannot compete with the traffic growth in the GE scenario. It is also striking that all scenarios reach their targets for liveability and nature and environment, this means no noise nuisance and zero emissions. Furthermore, the scenario with conscious consumers shows some differences in comparison with the other scenarios. In the CC scenario, accessibility decreases most, while traffic safety increases most.

5.2 Benefits and costs

The results of a comparison of benefits and costs on scenario level and per sustainable mobility pillar are presented in figure 5.2.

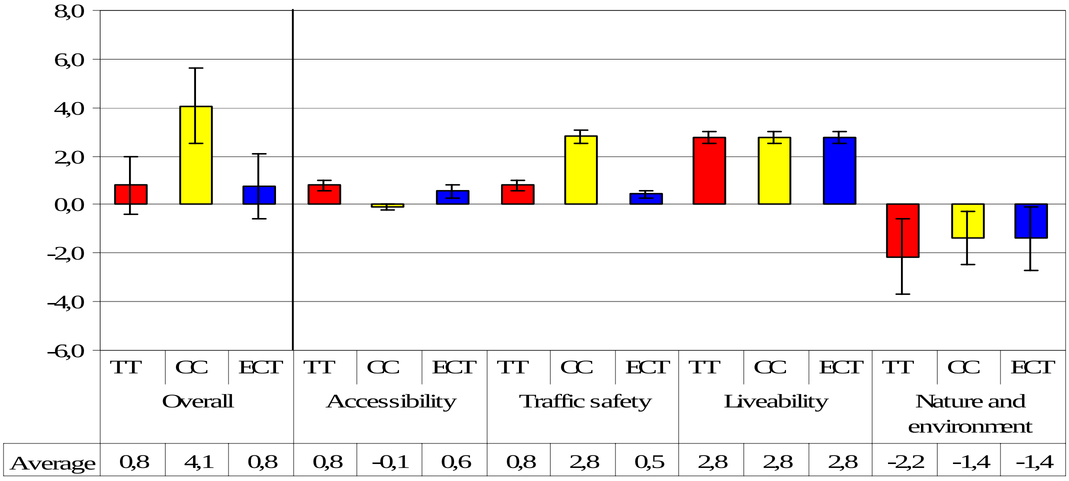

Figure 5.2 Net benefits in billion euros per sustainable mobility pillar per scenario

Overall

On scenario scale, conscious consumers (CC) shows the highest net benefit range, 2.5 to 5.6 billion euro. Emerging new technologies (TT), has a net range of -0.4 to 2.0 billion euro. Exploiting conventional technologies (ECT) shows comparable net benefits of -0.6 to 2.2 billion euro. The higher value for CC is mainly due to the higher net benefit range achieved for the traffic safety measures. Another striking outcome of the figures is the uncertainties in the nature and environment pillar, where ranges are wider than average benefits. The measures under the liveability pillar were equal in all scenarios, and thus have no influence on scenario comparison.

Accessibility

In the TT scenario, the automated highway system (AHS) results in the highest net benefits, 0.6 to 1.0 billion euro. A lower net benefit range is found in the ECT scenario, due to a kilometre charge, net benefits range from 0.3 to 0.8 billion euro. The lowest net benefit range was found in the CC scenario. Due to the lowest reduction in lost vehicle hours by low speed automation, a range of 0.0 to -0.2 billion euros is the result. Nonetheless, the range for CC could be higher if all benefits were monetised. In both the TT and the ECT scenario, the most benefits originate from reducing external effects like safety and environmental costs. The automated highway in the TT scenario however, has higher accessibility effects due to the improvement in reliability of travel time, which according to recent studies plays an important role in valuing travel time.

Traffic safety

The sustainable safe infrastructure in the CC scenario has comparable benefits to the automated highways system in the TT scenario. The costs per year however, are considerable lower in the CC scenario, mainly due to a longer depreciation period of infrastructure compared to in-vehicle technology. This results in a net benefit of 2.5 to 3.1 billion euro in the CC scenario and 1.0 to 1.4 billion euro in the TT scenario. Although the black box in the ECT scenario has the lowest safety effect of the observed measures, the benefits do outweigh the costs.

Liveability

The noise abatement measures are identical in every scenario. By implementing silent asphalt and replacing standard tires by silent tires, costs are low compared to the benefits.

Nature and environment

The optimised conventional vehicles (ICEV) on biofuels in the ECT scenario have a negative cost benefit ratio, however still the lowest net cost range of 2.7 to -0.1 billion euro. The fuel cell electric vehicles (FCEV) in the CC scenario have a slightly lower net cost range of 2.5 to 0.3 billion euro. The Battery electric vehicles (BEV) in the TT scenario also come close, however with a lower net cost range of 3.7 to 0.6 billion euro. These figures suggest that none of the measures is interesting. If choosing a technology measure is required, optimising the ICEV seems to be the best alternative, although the differences are minimal. There are however, some striking findings in respect of the measures under the nature and environment pillar. They all have the same uncertainties. Moreover, these uncertainties all have bandwidths wide enough to make a difference in the outcome of the present analysis. First, there is the valuation of CO_2. Due to uncertainties about this valuation, the bandwidth is 3.1 billion euro. The same applies for the oil price, with a bandwidth width of 3.0 billion euro. Using the current oil price, which is used as a maximum in the oil price bandwidth, would make all measures close to positive on benefits. As a third uncertainty, all the measures deal with additional car costs. The future developments of these costs have a major influence on the future passenger car. This is not only because the costs are high, but also because of their wide bandwidth. For the BEV, FCEV and the optimised ICEV the width of the bandwidths are respectively 2.1, 4.1 and 2.7 billion euro. These uncertainties are mainly caused by technologic barriers that need to be overcome and related learning potentials. For example, when the additional costs for FCEV develop according to the most positive expectations and the additional car costs of BEVs and ICEVs do not; this would make the FCEV technology the most beneficial. On the other hand if the optimised ICEV or BEV overcomes the barriers this could be decisive too. For the battery vehicle, there is even a fourth uncertainty. The design speed reduction, necessary for action radius reasons, can cause considerable welfare losses. These are not brought into account. However, the speed reduction also improves traffic safety, results in energy savings and reliability improvements of travel time, which are not monetised either.

5.3 Comparison with other studies

Many studies comparing mobility scenarios on sustainability only look at effects on nature and environment (e.g.(Åhman et al., 2001; Schade & Wietschel, 2007)). In addition those studies often put emphasis on costs only (e.g. (Contadini, 2000; Lipman, 1999). With those studies in mind, one could expect that achieving ambitious sustainability targets lead to very high costs, which are not outweighed by the benefits. In this study however, all scenarios have a positive balance. This can partly be explained by the fact this study looks after more than one pillar of sustainable mobility. According to the author there are no cost benefit analysis performed on such a wide scale, in other words with several measures aiming at different targets. Especially the inclusion of measures of liveability (noise) and safety has a positive influence on the outcome of the scenarios. The noise abatement measures, which are the same in every scenario make scenarios TT and ECT result positively and covers more than a half of the positive balance of the CC scenario. In the latter scenario, the sustainable safe infrastructure in the CC scenario exists out of cost-effective measures, which strive to achieve the maximum avoidable number of fatalities and injuries, and thus influences the CC scenario positively.

In comparison with other studies, the net costs in the nature and environment pillar could be even larger. The wide range of CO_2 reduction costs and the uncertainty of the oil price are taken into account in this study. Most studies use a lower (mean) value for an avoided tonne CO_2. If this value was used in this study as well, the benefits would be lower for all nature and environment measures, resulting in an even more negative net balance. A similar negative impact on the net balance would exist if only the WLO oil prices were used. However, the bandwidths arrived at in this study indicate up-to-date uncertainties and therefore need to be taken into account

5.4 Conclusions and recommendations

This study resulted in the following findings and recommendations:

1. A broad look makes sustainable development for mobility achievable;

   - All three scenarios show a positive net balance. Before this study, striving for sustainable mobility seemed ambitious. This was mainly inspired by the ecological aspect of sustainability. However, when the other aspects of sustainability (social and economical development) are taken into account as well, sustainable development for car mobility seems to be feasible based on costs and benefits.
   - Based on these findings, it is recommended to use sustainability integrally. This means, considering economical, social and environmental aspects.
   - When comparing the scenarios, ‘Conscious Consumer’ shows the best results. This is mainly due to the positive effects of the traffic safety measures because of sustainable safe adaptations on infrastructure. Not considering this aspect shows that it does not

matter which road to sustainable mobility will be taken, since they have equal cost benefit ratios and equal effects.

2. Sustainable safe infrastructure and noise abatement measures have priority;
   - Traffic safety can make a sustainable development; however, the targets (no serious traffic casualties) are not achieved. Selected measures do have a positive net benefit. Especially the sustainable safe infrastructure in combination with some intelligent transport systems showed good results.
   - Noise nuisance of car mobility can be reduced to a minimum by implementing silent tires and silent asphalt; in addition, these measures have a very positive net benefit.
   - In striving for sustainable development for car mobility under a favourable societal cost benefit ratio, it is recommended to give priority to the design of sustainable safe infrastructure in combination with specific intelligent transport systems and noise abatement measures.
   - In this study, liveability was represented by noise nuisance. However, more items should be included to realise fully sustainable passenger car mobility. One could think of vibrations, smells and light and next to that, space occupancy, barriers, and visual adverse to city and landscape. In addition to the noise abatement measures examined in this study, there are also other noise abatement measures possible. One could think of rerouting traffic or spatial planning in order to minimise noise nuisance. These subjects are recommended for further research.
3. For sustainable development of nature and environment there is no need to change our current infrastructure to battery or hydrogen vehicles, since optimising the conventional car can be sufficient as well. However, the measures belonging to this pillar depend on development of the oil price, the value of an avoided tonne of CO_2, and the development of specific engine technologies in order to realise a positive net balance;
   - Damage to nature and environment by emissions can be reduced heavily. In all three scenarios, emissions can be minimised to almost zero. However, this can only be done at net costs to the society. The extend to which these cost may vary in future can even result in a benefit to society. Future oil price is uncertain and has a direct impact on feasibility. The value of one tonne avoided CO_2 emission has great impact on the benefits and has wide range in literature. Uncertainty about the development of specific engine technologies and related costs are high. These uncertainties indicate that an even further increasing oil price, higher CO_2 emission reduction targets, or improvements in one of the related engine technologies could give positive net benefits.
   - Further research is required to reduce the uncertainties and narrow the bandwidth of the three above aspects: oil price, CO_2 value and additional car technology costs.
   - From the various vehicle technologies, BEV, FCEV, and the optimised biofuel ICEV none stand out on costs and benefits, whatever emission value or oil price,

consequently no policy conclusions can be drawn on this aspect. Difference in development of on the vehicle technologies might lead to a distinguishing cost benefit ratio.

- Because a decision in relation to nature and environment cannot be made based on costs and benefits, other factors that play a role in decision-making become increasingly important. The road towards the sketched scenarios becomes vital. Although the BEV and the FCEV show higher efficiency rates and higher flexibility in fuel choice, they still need to overcome some technical barriers and require considerable changes in infrastructure. For exploiting conventional car technologies this is not required, and thus seems to have an easier transition path. So why should the Netherlands (and other countries) shift towards to other infrastructures, while optimising current technologies lead to the same results? Therefore it is recommended that policies emphasise on optimising ICEVs and on increasing there efficiency, not ignoring other new vehicle technologies.
- At the same time, the possible negative effects of using biofuels like sugarcane ethanol on food competition should be studied in more detail. If the negative effects of sugar cane ethanol are manageable, this is an easy sustainable road ahead. If they are not manageable, the achieved efficiency improvements can also be beneficial for a transition towards BEVs or FCEVs. Especially weight, rolling resistance, and drag reduction are favourable for all roads to sustainability.

4. And what about accessibility?

- Accessibility is much debated because it affects people directly and personally by increasing travel times. However, nature and environment, traffic safety and noise nuisance have much higher social costs and thus higher potential benefits. These are less debated since they do not affect people so much on a personal level. It is therefore recommended to make people more aware of this discrepancy by internalising externalities.
- The accessibility measures have a positive net balance although smaller then safety and liveability measures. Accessibility cannot be improved in the highest economic growth scenario (GE), but without the selected measures and technologies, the accessibility would aggravate. Moreover, the positive net benefit is mainly achieved by minimising external effects. The ‘kilometre and emission based charge’, and the ‘automated highway system’ reveal the highest net benefits. It is expected that in the other three WLO scenario’s (with lower economic and population growth), the selected measures would result in improved accessibility.
- Accessibility is the only sustainable mobility aspect that aggravates in the three sketched scenarios compared to the current situation, at least when lost vehicle hours is used as an indicator. This would mean more and other measures are required to improve this pillar. On the other hand, it has to be noted that accessibility has relative low costs to society. With the arrival of ‘intelligent transport systems’ it is plausible

that the perception of lost hours changes and other indicators like reliability of travel time become more important. Using other indicators for accessibility seems advisable.

- Of the cost effective measures, the kilometre charge can already be implemented, while for the AHS still some technical barriers need to be overcome. For the short-term, emphasis should be on the kilometre charge. Both measures also have significant effects on other external effects. However, AHS also has considerable effects on the reliability of travel time and this could reduce the perception of the lost vehicle hours, which according to the previous analysis might become more important in the future. For the long-term, this measure is expected to be important. Extra research after defining enhanced costs and benefits of an AHS and a broader use of intelligent transport systems to improve accessibility should prove if this is indeed a solution for the long-term.

5. Only additional car costs prevent indiscriminate access to car mobility;

- Transport equity, equal access to mobility, was not studied quantitatively. Still it can be concluded that due to high additional car costs, keeping the share of the average income of households on expenditures for mobility equal to its current share in all three scenarios could be difficult. This can be compensated by subsidies, whether this is politically viable is unclear.
- In addition, lower usage costs can be expected for fuel because in all scenarios the energy efficiency of the vehicles is improved.
- Since little is known about this subject, further research is required to be able to include transport equity in a quantitative manner.

6. Comments on the used methodology;

- In this study, the backcasting approach stopped after comparing endpoints for 2050. Previous analysis, concerning the nature and environment pillar, show that especially for this pillar the transition path becomes more and more important since the costs and benefits are not (yet) distinguishing. Because of that, further research should emphasise on trajectories leading back to the present or in other words on the transition path
- Sensitivity analysis might show that the scenario with the highest net benefits is not necessarily the best under all circumstances. In GE, the required energy for passenger car transport is high compared to the other scenarios in the WLO. In the WLO scenarios 'Strong Europe' and 'Regional Communities', the required energy is almost half of the required energy in Global Economy. In addition, in 'Transatlantic Market' considerably less energy is required as well. Measures like BEV and FCEV have high investment costs. Using GE makes these measures, more positive than they would be in lower mobility scenarios, as the recovery of investments will take much longer in the latter scenarios.

Bibliography

Abele, Johannes, Christiane Kerlen, Sven Krueger (2005) Exploratory Study on the potential socio-economic impact of the introduction of Intelligent Safety Systems in Road Vehicles. VDI/VDE Innovation + Technik GmbH, Institute for Transport Economics, Teltow/ Köln.

Åhman, Max, Lars J.Nilsson, Bengt Johansson (2001) Cars and Fuels of Tomorrow: strategic choices and policy needs. ECEEE 2001 Summer Study, European Council for an Energy-Efficient Economy, Mandelieu, France.

Akinyemi, E., M. Zuidgeest (2000) Sustainable Development & Transportation: Past Experiences and Future Challenges. World Transport Policy & Practice, 6(1), 31-39.

Alcamo, J. (2001) Scenarios as tools for international environmental assessments. EEA, European Environment Agency, Copenhagen.

Asselt, M. B. A. van, C. A. H. M. Storms, et al. (1998) Towards Visions for a Sustainable Europe: An overview and assessment of the last decade of European scenario studies. . ICIS, Maastricht, the Netherlands.

AVV (2004) Voertuigverliesuren op het autosnelwegennet. Voor de periode 1999-2002. Adviesdienst Verkeer en Vervoer, Rotterdam.

AVV (2006a) Personen vervoer: groei reistijdwaardering in de tijd. Adviesdienst Verkeer en Vervoer, Rotterdam.

AVV (2006b) Verrijking MON-data met route-informatie. web: http://www.rws-avv.nl. Adviesdienst Verkeer en Vervoer, Rotterdam/Maastricht.

Banister, D. (2005) Unsustainable Transport. The Bartlett School of Planning University College London, London.

Banister, David, Robin Hickman (2005) Looking over the Horizon; Visioning and Backcasting for UK Transport Policy. UK Department for Transport.

Besseling, P., W. Groot, R. Lebouille (2005) Economische analyse van verschillende vormen van prijsbeleid voor het wegverkeer. CPB Document No. 65, Centraal Planbureau, Den Haag.

Beumer, Leo, Gerbrand van Bork, Ilse van de Velde, Nol Verster (2004) Kosten en baten van vervanging van LPG als autobrandstof. Ecorys, Rotterdam.

Bickel, Peter, Sanna Ahvenharju, Totti Könnölä, Mari Hjelt, Roberto De Tommasi, Michal Arend, Wolfgang Röhling, Robert Burg (2003) SUMMA: Setting the Context for Defining Sustainable Transport and Mobility. Deliverable 2 of Workpackage 1. . European Commission.

Bishop, Richard (2005) Intelligent Vehicle Source, www.ivsource.net.

Boardman, A.E., D.H. Greenberg, A.R. Vining, D.L. Weimer (2001) Cost-Benefit Analysis: Concepts and Practice. 2nd Edition Prentice Hall, Upper Saddle River, New Jersey.

Borjeson, Lena, Mattias Hojer, Karl-Henrik Dreborg, Tomas Ekvall, Goran Finnveden (2006) Scenario types and techniques: Towards a user's guide. Futures, 38(7), 723-739.

Brink, R.M.M van den (2002) Technologie in verkeer en vervoer: de invloed op milieu, veiligheid en bereikbaarheid. Verkeer en vervoer in hoofdlijnen [Traffic and Transport. Basic issues] G.P. Van Wee and M. Dijst, eds., Coutinho, Bussum.

Brink, R.M.M. Van den (2003) Scenario's voor duurzame energie in verkeer en vervoer: Beoordeling op verschillende criteria. 773002025/2003, RIVM, Bilthoven.

Brink, R.M.M. Van den, J.A. Annema (2007) Kosteneffectiviteit CO2-beleid personenauto's: Methodische verkenning. 500076001/2007, MNP, Bilthoven.

Browland, F., M. Zabat, P. Tokumaru (1997) Aerodynmic Benefits from close following. Automated Highway Systems, P. Ioannou, ed., Springer.

Contadini, J.F. (2000) Social cost comparison among fuel cell vehicle alternatives Energy Conversion Engineering Conference and Exhibit, 2000. (IECEC) 35th Intersociety, 2, 1341-1351.

CPB (2006) WLO mobiliteitscenario's met prijsbeleid. Centraal Planbureau, Den Haag.

CPB/MNP/RPB (2006) Welvaart en leefomgeving. Centraal Planbureau/Milieu- en Natuurplanbureau/Ruimtelijk Planbureau, Den Haag/Bilthoven.
Davies, Chris (2007) On the Community Strategy to reduce CO2 emissions from passenger cars and light-commercial vehicles (draft). Europen Parliament, Committee on the Environment, Public Health and Food Safety.
Delucchi, Mark A., T.E. Lipman (2001) An analysis of the retail and lifecycle cost of battery-powered electric vehicles. Transportation research Part D, 6, 371-404.
Dijst, M. (2004) ICTs and accessibility. An action space perspective on the impact of new information and communication technologies. Transport Developments and Innovations in an Evolving World, pp. 27-46. Berlin: Springer.
DOE (2003) Hydrogen from Renewable Energy Sources: Pathway to 10 Quads For Transportation Uses in 2030 to 2050. U.S Department of Energy, Washington, D.C.
Downing, Thomas E, David Anthoff, Ruth Butterfield, Megan Ceronsky, et al. (2005) Social Cost of Carbon: A Closer Look at Uncertainty. SEI, Oxford.
Dreborg, K.H. (1996) Essence of Backcasting. Futures, 28(9), 813-828.
Ducot, Lubben (1980) A typology for scenarios. Futures, 12(1), 51.
DWIA (2003a) Pitfalls in Wind Energy Cost Analysis, http://www.windpower.org/en/tour/econ/pitfalls.htm (accessed May 2007). Danish Wind Industry Association.
DWIA (2003b) Wind Map of Western Europe, http://www.windpower.org/en/tour/wres/euromap.htm (accessed May 2007). Danish Wind Industry Association.
ECOPLAN (1993) External Benefits of Transport? European Federation for Transport and Environment, Brussel.
Elzen, B., F. Geels, P. Hofman (2002) Sociotechnical scenarios, A new Methodology to Explore Technological Transitions,. University of Twente: Centre for Studies of Science, Technology and Society, Enschede, The Netherlands.
Energieraad, Algemene (2006) Briefadvies Concentrating Solar Power (CSP) 3 maart 2006.
European Commission (2003) EU Energy and Transport in Figures – Statistical Pocketbook 2003 DG Energy and Transport in cooperation with Eurostat, Luxembourg.
EWEA (2004) Wind Power Economics: An analysis of wind energy in the EU-25. European Wind Energy Association, Brussels.
Fasel, D., M. Q. Tran (2005) Availability of lithium in the context of future D-T fusion reactors. Fusion Engineering and Design, 75-79, 1163-1168.
Flyvbjerg, Bent, Mette K. Skamris Holm, Søren L. Buhl (2002) Underestimating Costs in Public Works Projects: Error or Lie? . Journal of the American Planning Association 68 (3), 279-295.
Flyvbjerg, Bent, Mette K. Skamris Holm, Søren L. Buhl (2005) How (In)accurate Are Demand Forecasts in Public Works Projects? The Case of Transportation Journal of the American Planning Association 71(2), 131-146.
Franssen, E.A.M. , J.E.F. van Dongen, J.H.M. Ruysbroek, H. Vos, R. Stellato (2004) Hinder door milieufactoren en de beoordeling van de leefomgeving in Nederland. Inventarisatie Verstoringen 2003. RIVM Rapport 815120001.
Geels, F., R. Kemp (2000) Transities vanuit sociotechnisch perspectief (in Dutch). Universiteit Twente/ MERIT, Enschede, Maastricht.
Geels, Frank W., Wim A. Smit (2000) Failed technology futures: pitfalls and lessons from a historical survey. Futures, 32(9-10), 867-885.
Geurs, K.T., B. van Wee (2004) Backcasting as a Tool for Sustainable Transport Policy Making: The Environmentally Sustainable Transport Study in the Netherlands. European Journal of Transport and Infrastructure Research, 4(1), 47-69.
Gilbert, Richard, Neal Irwin, Brian Hollingworth, Pamela Blais (2002) Sustainable Transportation Performance Indicators (STPI) Project, Report on Phase 3. Centre for Sustainable Transportation, Canada.

Gilbert, Richard, Anthony Perl (2007) Grid-connected vehicles as the core of future land-based transport systems. Energy Policy, 35(5), 3053-3060.

Gore, Al (2006) An Inconvenient Truth., D. Guggenheim, ed.

Greeuw, S., M.B.A. Van Asselt, et al. (2000) Cloudy crystal balls, an assessment of recent European and global scenario studies and models. EEA, European Environment Agency, Copenhagen.

Hamelinck, C., M. Hoogwijk (2007) Future scenarios for first and second generation biofuels. Ecofys, Utrecht.

Heijden, K. van der (2000) Scenarios and Forecasting: Two Perspectives. Technological Forecasting and Social Change, 65, 31-36.

Hellendoorn, J.C. (red.) (2001) Evaluatiemethoden ex ante, een introductie. Afdeling Beleidsevaluatie - en instrumentatie Ministerie van Financiën, Den Haag.

Hilbers, H., J. Ritsema van Eck, D. Snellen (2004) Behalve de dagelijkse files. Over betrouwbaarheid van reistijd [Not the usual tailbacks. Journey time reliability]. The Netherlands Institute for Spatial Research, The Hague.

Hupkes, G. (1977) Gasgeven of afremmen: toekomstscenario's voor ons vervoerssysteem. Deventer/Antwerpen.

IEA (2000) The road from Kyoto. Current CO2 and transport policies in the IEA. International Energy Agency, Paris.

IEA (2001) Saving oil and reducing CO2 emissions in transport: Options and strategies. International Energy Agency, Paris.

Immers, L.H., J.E. Stada (2003) Verkeers- en Vervoersystemen. Cursus H111. Katholieke Universiteit Leuven, Faculteit Toegepaste Wetenschappen, Leuven.

Infras/FiFo (2007) Praktische Anwendung der Methodenkonvention: Möglichkeiten der Berücksichtigung externer Umweltkosten bei Wirtschaftlichkeitsrechnungen von öffentlichen Investitionen. Infras/ FiFo Köln, Zürich/Köln.

IPCC (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jain, Juliet, Glenn Lyons (2007) The gift of travel time. Journal of Transport Geography, In Press, Corrected Proof.

Johansson, Bengt, Max Ahman (2002) A comparison of technologies for carbon-neutral passenger transport. Transportation research Part D, 7, 175-196.

Kahn, H. , A. J. Wiener (1967) The year 2000. MacMillan, New York.

Kampman, B.E., L.C. Den Boer, H.J. Croezen (2005) Biofuels under development: An analysis of currently available and future biofuels, and a comparison with biomass application in other sectors. CE, Delft.

Kempton, W., A. Dhanju (2006) Electric Vehicles with V2G: Storage for Large-Scale Wind Power Windtech International, 2(2), pp 18-21.

Kempton, Willett, Steven E. Letendre (1997) Electric vehicles as a new power source for electric utilities. Transportation Research Part D: Transport and Environment, 2(3), 157-175.

Kempton, Willett, Jasna Tomic´, Steven Letendre, Alec Brooks, Timothy Lipman (2001) Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California. Available at www.udel.edu/V2G.

Krewitt, Wolfram, Barbara Schlomann (2006) Externe Kosten der Stromerzeugung aus erneuerbaren Energien im Vergleich zur Stromerzeugung aus fossilen Energieträgern.

Letendre, Steven E., Willet Kempton (2002) The V2G-concept: a new model for power? Connecting utility infrastructure and automobiles. Public Utilities Fortnightly, February 15.

Lipman, T.E. (1999) Zero-emission vehicle scenario cost analysis. University of California, Davis.

Litman, T. (2005) Evaluating Transportation Equity. Methods for incorporating distributional impacts into transport planning. Vicotria Transport Policy Institute, Canada.

LogicaCMG, Capgemini, Get ID (2005) HET KAN! Eindrapportage Techniek, Organisatie, Handhaving en Kosten van varianten van Anders Betalen voor Mobiliteit. Ministerie van Verkeer & Waterstaat.

Lucas, K. (2006) Providing transport for social inclusion within a framework for environmental justice in the UK. Transportation Research Part A: Policy and Practice, 40(10), 801-809.

McDonough, W., M. Braungart (2002) Cradle to Cradle: Remaking the Way We make Things. North point Press, New York.

Meadows, D.H., D.L. Meadows, J. Randers, W.W. Behrens (1972) The limits to growth Universe Books, New York.

Miller, Mark A., Anne Bresnock, Steven E. Shladover, Edward H. Lechner (1997) Regional Mobility Impacts Assesment of Highway Automation. Automated Highway Systems, P. Ioannou, ed., Springer.

MNP (2007) Environmental Data Compendium. Bilthoven, Web: http://www.mnp.nl/mnc/index-en.html.

Morthorst, Poul Erik, Hugo Chandler (2004) The Cost of Windpower: The Facts Within Fiction. Renewable Energy World, July-August.

Nagelhout, D., J.P.M. Ros (2006) Brandstofcelauto op waterstof verkregen uit zonthermische krachtcentrales (CSP): Evaluatie van transities op basis van systeemopties. 500083007/2006, MNP, Bilthoven.

Nasser, H. (2002) Commuting offers coveted refuge for some. http://www.usatoday.com/money/covers/2002-05-30-driving-alone.htm. (accessed 31 May 2007). USA Today

Nicolas, J. P., P. Pochet, H. Poimboeuf (2003) Towards sustainable mobility indicators: application to the Lyons conurbation. Transport Policy, 10(3), 197-208.

Nijland, H., J. Ritsema van Eck (2004) Welvaart en Leefomgeving: Wat betekent de toekomstige mobiliteit voor het klimaat? Colloquium Vervoersplanologisch Speurwerk 2005, Antwerpen, MNP, RPB.

Nijland, H.A., . E.E.M.M. Van Kempen, G.P. Van Wee, J. Jabben (2003) Costs and benefits of noise abatement measures. Transport Policy, 10(2), 131-140.

OECD/IEA (2005a) Making cars more fuel efficient: technology for real improvements on the road,. OECD/ International Energy Agency (IEA), Parijs.

OECD/IEA (2005b) Prospects for hydrogen and fuel cells. Organisation for Economic Co-operation and Development (OECD)

International Energy Agency (IEA), Parijs.

Ohrstrom, E., A. Skanberg, H. Svensson, A. Gidlof Gunnarsson (2006) Effects of road traffic noise and the benefit of access to quietness. Journal of Sound and Vibration, 295(1-2), 40-59.

Orsato, R. J., P. Wells (2006) The Automobile Industry & Sustainability. Journal of Cleaner Production, In Press, Corrected Proof.

Ozbay, K., D. Ozmen, J. Berechman (2006) Modeling and analysis of the link between accessibility and employment growth. Journal of Transportation Engineering Asce, 132(5), 385-393.

Postema (1998) Automated Highway Systems; Incremental Deployment as a Solution for The Future of Transportation. IEEE, Institute of Electrical and Electronics Engineers, Washington.

Pro, Boyd H., Roel Hammerschlag, Patrick Mazza (2005) Energy and land use impacts of sustainable transportation scenarios. Journal of Cleaner Production, 13(13-14), 1309-1319.

Ran, B., K.Y.K. Lee, H. Dong (1997) Cost-Benefit Analysis on Deployment of Automated Highway Systems. Transportation Research Record, No.1588.

RAND Europe (2005) The value of reliability in transport; provisional values for the Netherlands. Rand Europe, Leiden.
Redmond, L.S., P.L. Mokhtarian (2001) The positive utility of the commute: modeling ideal commute time and relative desired commute amount. Transport, 28 (2), 179-205.
Robinson, J.B. (1990) Futures under glass. A recipe for people who hate to predict. Futures(October 1990), pp. 820-842.
SCAG/PATH (1993) Highway Electrification and Automation Technologies -Regional Impacts Analysis Project. Institute of Transportation Studies University of California, Berkely.
Schade, Wolfgang, Martin Wietschel (2007) Shifting transport towards hydrogen: scenarios and sustainability impact assessment. 11th World Conference on Transport Research, Berkely, USA.
Schafer, A., D. Victor (1997) The Past and Future of Global Mobility. Scientific American(October 1997), pp. 36-39.
Schoon, C.C. (2000) Verkeersveiligheidsanalyse van het concept-NVVP. Deel 1: Effectiviteit van maatregelen. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.
Schwarz, P. (1991) The Art of the Long View, planning for the future in an uncertain world Currency and Doubleday, New York.
Sergent, Lundy (2003) Assesment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts. NREL, Golden, Colorado, USA.
Smeets, Edward, Martin Junginger, André Faaij, Arnaldo Walter, Paulo Dolzan (2006) Sustainability of Brazilian bio-ethanol. Copernicus Institute, Utrecht.
Spiegel, R. J. (2004) Platinum and fuel cells. Transportation Research Part D Transport and Environment, 9(5), 357-371.
SRU (2005) Reducing CO2 Emissions from Cars. German Advisory Council on the Environment, Berlin.
Steg, L., R. Gifford (2005) Sustainable transportation and quality of life. Journal of Transport Geography, 13(1), 59-69.
Stern, N., S. Peters, V. Bakhshi, A. Bowen, C. Cameron, et al. (2006) Stern Review: The Economics of Climate Change. HM Treasury, London.
Stopher, P.R. (2004) Reducing road congestion: a reality check. Transport Policy, 11(2), 117-131.
SWOV (2007) Institute for road safety research. Leidschendam, web: http://www.swov.nl/index_uk.htm.
Tillema, T., G.P. van Wee, J. Rouwendal, J. van Ommeren (2007) Firms: chamges in trip patterns, product prices, locations and in the human recource policy due to road pricing. In: Pricing in Road Transport: A Multi-Disciplinary Perspective., E. T. Verhoef, G. P. v. Wee, E. M. StegM. C. J. Bliemer, eds., Edward Elgar Publishing.
Tomic, Jasna, Willett Kempton (2007) Using fleets of electric-drive vehicles for grid support. Journal of Power Sources, 168(2), 459-468.
Trieb, F. (2006) Trans-Mediterranean Interconnection for Concentrating Solar Power. DLR.
UBA (2007) Ökonomische Bewertung von Umweltschäden; Methodenkonvention zur Schätzung externer Umweltkosten. Umwelt Bundes Amt, Dessau.
UNDP (2000) World Energy Assesment: energy and the challenge of sustainability. United Nations Development Programme, New York.
van 't Klooster, Susan A., Marjolein B. A. van Asselt (2006) Practising the scenario-axes technique. Futures, 38(1), 15-30.
VenW (2006) Verkeersveiligheid op het hoofdwegennet 2005. Ministerie van Verkeer en Waterstaat.
Vermeulen, J.P.L., B.H. Boon, H.P. van Essen, L.C. den Boer, J.M.W. Dings, F.R. Bruinsma, M.J. Koetse (2004) The price of transport. Overview of the social costs of transport. CE, Delft.

Vision 2030, Consortium (2003) Vision 2030 - An investigation into the long-term challenges and opportunities for the UK s strategic highway network. Highways Agency for England, available at http://www.transportvisions.org.
Visser, E. de, R. van den Hoed, H. Barten (2006) Concentrating Solar Power for Fuel cell vehicles. Ecofys, Utrecht.
Ward, Jerry D. (1997) Step by step to an automated highway system - and beyond. Automated Highway Systems, P. Ioannou, ed., Springer.
WBCSD (2004) Mobility 2030. Meeting the challenges to sustainability. Full Report 2004. World Business Council for Sustainable Development.
WCED (1987) Our Common Future (The Brundtland Report). World Commission on Environment and Development. Oxford University Press., Oxford.
Wedlock, Mark, Gwen Chu, Jakub Rajnoch (2006) UOBU: Final Analysis of Costs and Benefits. European Comission.
Wee, G.P. Van, M. Dijst (2002) Verkeer en vervoer in hoofdlijnen [Traffic and Transport. Basic issues] Coutinho, Bussum.
Wegman, F.C.M. (2001) Veilig, wat heet veilig? SWOV, Leidschendam.
Wegman, F.C.M. , L.T. Aarts (2006) Advancing sustainable safety : National Road Safety Outlook for 2005-2020. SWOV Institute for Road Safety Research, Leidschendam.
Wesemann, P. (2000a) Kosten van de verkeersonveiligheid in Nederland, 1997. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.
Wesemann, P. (2000b) Verkeersveiligheidsanalyse van het concept-NVVP. Deel 2: kosten en kosteneffectiviteit. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.
Wesemann, P., A.T. de Blaeij, P. Rietveld (2005) De waardering van bespaarde verkeersdoden. R-2005-4, Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.
Wesemann, P., E.L.C. Devillers (2003) Kosten-batenanalyse van verkeersveiligheidsmaatregelen. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.
WHO (2001) Guidelines for community noise. World Health Organization (WHO), Geneva.
Wietschel, Martin, Ulrike Hasenauer, Arend de Groot (2006) Development of European hydrogen infrastructure scenarios--CO2 reduction potential and infrastructure investment. Energy Policy Hydrogen, 34(11), 1284-1298.
Wilde, Rein de (2000) De voorspellers: een kritiek op de toekomst industrie (in Dutch). De Balie, Amsterdam. .
Wit, J. de, H. van Gent (1996) Economie en Transport [Guidebook on Transport and Economy]. Uitgeverij Lemma BV - Utrecht.
Wouters, P.J., J.M.J Bos (1997) The impact of driver monitoring with vehicle data recorders on accident occurrence SWOV, Leidschendam.
Zwaneveld, P.J., B. van Arem (1997) Traffic effects of Automated Vehicle Guidance. A literature survey. TNO Inro., Delft.

Appendix I Scenario writing methods

What are scenarios?

The word ‘scenario’ originally comes from the theatre world. A scenario is a brief description of an event or a series of events. For a play it tells about the outline of entrances, exits and actions describing the plot. But nowadays the word scenario is also used a lot in strategic planning. And the scenario meant in this strategic planning is what I am interested in for this paper. Although it is different, it is still a description of an event or a series of events. However, these are descriptions of the future and should enable change, anticipation and preparedness, and evaluation and risk assessment across possible environments. Some decades ago Kahn and Wiener (1967) gave a definition of these new type of scenarios: “scenarios are hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points”. Other commonly cited and more recent definitions are: “Scenarios as archetypal descriptions of alternative images of the future created from mental maps or models that reflect different perspectives on past, present and future developments” (Asselt et al., 1998), or “Images of the future, or alternative futures that are neither predictions nor forecast, but an alternative image of how the future might unfold” (Alcamo, 2001).

All these definitions make clear that scenario writing is not about predicting. After all we all know one thing for sure, the future is not for sure. Although, we still discuss the future and even study it. We make weather forecasts, we plan in advance and we also let our strategies depend on possible futures. So is the future totally uncertain, or do we consider at least something predictable? Van der Heijden (2000) says the following about this: “A disciplined approach towards separating the predictable form the uncertain is clearly helpful for understanding. This is what the scenario technique aims to do. It starts from the premise hat if the future is uncertain there are, in fact, multiple equally plausible futures, which we call scenarios. A total set of scenarios about the future reflects our understanding of what we believe to be fundamentally indeterminate.”

Figure I.1 is an attempt of Greeuw et al. (2000) to visualise the scenario concept, starting from a historical or the current situation, extending till the chosen time horizon.

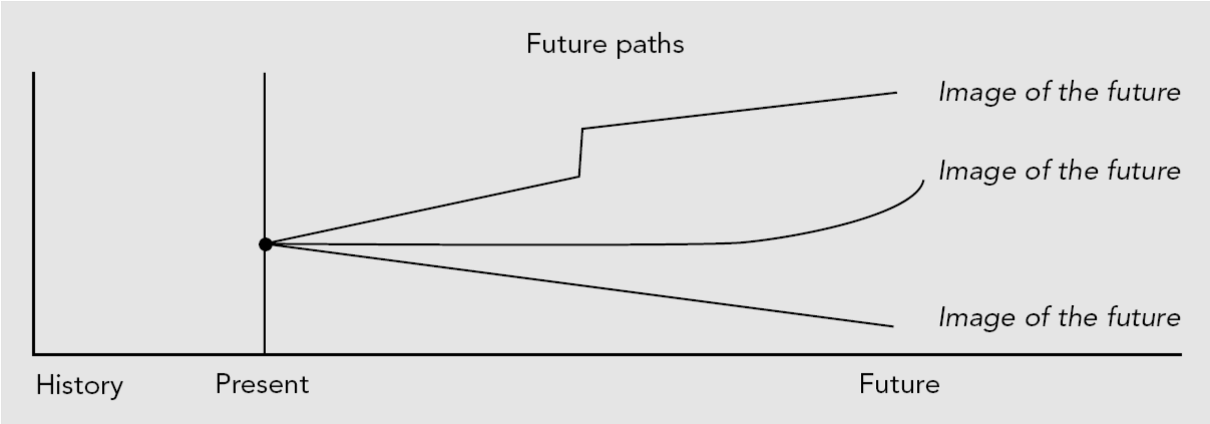

Figure I.1 Elements in scenarios and the time horizon (source: Greeuw et al. 2000)

The word scenario or other similar words are used at leisure. Instead of scenario the words, forecasts, backcasts, explorations, ideals or dreams are often used. To get some clearance in the world of scenarios, the next chapter will discuss different scenario methodologies.

Scenario methods

Not only there are many definitions of scenarios, there are also many types of scenarios. According to Greeuw et al. (2000) four subdivisions can be made, namely: forecasting versus backcasting, descriptive versus normative, quantitative versus qualitative and trend versus peripheral scenarios.

Forecasting versus backcasting

In fact forecasting is the construction of projective scenarios. And a projective scenario's starting point is the current situation; extrapolation of current trends results in future images (Geurs and Van Wee, 2004). Most recent scenario studies are projective scenarios and those are also very common in transport studies.

Backcasting is the construction of prospective scenarios. According to Geurs and Van Wee (2004) a prospective scenario's starting-point is a possible or desirable future situation, usually described by a set of goals or targets established by assumed events between the current and future situations. They also say that backcasting is therefore capable of highlighting discrepancies between the current and desirable future, and incorporating large and even disruptive changes. Figure I.2 by Bannister and Hickman (2005) shows the main features of the backcasting process. Instead of starting with the present situation and prevailing trends, the backcasting approach designs images of the future representing desirable solutions to societal problems. Possible paths back to the present are then developed - 'casting back' from the future - in 25, 20, 15, 10 and 5 years time. The term 'scenario' covers both the images of the future and the trajectory leading back to the present.

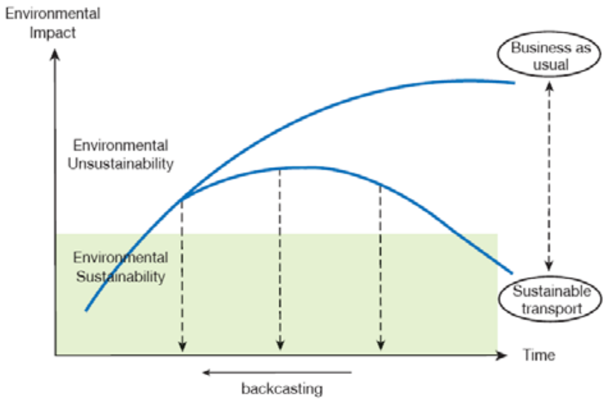

Figure I.2 Backcasting process (source: Bannister and Hickman, 2005)

Typically backcasting is applied on long-term complex issues, involving many aspects of society as well as technological innovation (Dreborg, 1996). To see a complete overview of the differences between forecasting and backasting one can take a look at table I.1.

Table I.1: Differences between forecasting and backcasting.

Measure	Forecasting	Backcasting
Philosophy	Justification as the context Causality determinism	Discovery as the context Causality and intentions
Perspective	Dominant trends Likely futures Possible marginal adjustments Focus on adapting to trends	Societal problem in need of a solution Desirable futures Scope of human choice Strategic decisions Retain freedom of action
Approach	Extrapolate trends into future Sensitivity analysis	Define interesting futures Analyse consequences and conditions for these futures to materialise
Method and technique	Various econometric models Mathematical algorithms	Partial and conditional extrapolations Normative models, system dynamic models, Delphi methods, expert judgement

Source: based on Geurs and Van Wee (2004) and Bannister and Hickman (2005), adapted from Dreborg (1996).

Descriptive versus normative

Descriptive scenarios sketch an ordered set of possible events irrespective of their desirability or undesirability, while normative scenarios take values and interests into account (Greeuw et al, 2000). Instead of descriptive scenarios one can also speak about exploratory scenarios. Alcamo (2001) gives another definition, exploratory scenarios are those that begin in the present and explore trends into the future. Normative scenarios are also called anticipatory or prescriptive scenarios. By contrast, anticipatory scenarios start with a prescribed vision of the future (either optimistic, pessimistic or neutral) and then work backwards in time to visualise how this future could emerge (Alcamo, 2001). The exploratory approach is according to Alcamo (2001) more “value free” than the anticipatory approach. He also acknowledges that in practice the differences between the approaches blur from time to time. Most current scenario studies have a descriptive character or are only implicitly normative.

Quantitative versus qualitative

Alcamo (2001) describes qualitative scenarios as scenarios which describe possible futures in the form of words or visual symbols rather than numerical estimates. He adds that they can take the shape of diagrams, phrases, or outlines, but more commonly they are made up of narrative texts. According to Greeuw et al. (2000) Narrative scenarios are usually deployed in cases where data is weak or missing. It can be seen as a benefit that there is no data needed, but by naming no other benefits Greeuw et al. go short on other benefits of the qualitative method. According to Alcamo (2001) the qualitative scenarios have the advantage of being able to represent the views of several different stakeholders and experts at the same time. Also it can be an understandable and interesting way of communicating information about the future, at least as compared with dry tables of numbers or confusing graphs. However, there is often a demand for numbers, which cannot be delivered by a qualitative method.

Giving numbers is something that a quantitative method does. According to Alcoma (2001) quantitative scenarios provide needed numerical information in the form of tables and graphs. But these numbers also come with disadvantages. Quantitative methods are often based on computer models, and these models contain many implicit assumptions about the future. It has been argued that these models tend to represent only one point of view about how the future will unfold, and in this way produce scenarios that are unnecessarily narrow in view (Alcamo, 2001). Furthermore the exactness of the used numbers in these models is often taken as a sign that we know more about the future than we actually do. And where the qualitative method was easier to understand by non-specialists, the quantitative method is often hard to understand for non-specialists.

Trend versus peripheral scenarios

Ducot and Lubben (1980) describe a trend scenario as a scenario that represents the extrapolation of the current trends, while a peripheral scenario includes unlikely and extreme events. According to Schwartz (1991) scenarios should include surprises in order to break with old stereotypes. From this point of view trend scenarios are no real scenarios and will therefore be called trend stories (Greeuw et al, 2000).

History shows us that historical trends are characterised by strong fluctuations rather than smooth curves, this implies that surprises are important in scenarios. Surprises can be categorised in the following way (van Asselt et al, 1998):

- Unimaginable surprises (like a journey to the Earth's centre in the time of Jules Verne)
- Imaginable surprises that are improbable (like a global nuclear war)
- Imaginable surprises that are probable (like a oil price shock and ecological refugees)
- Certain surprises (like earthquakes, economic recession)

Use of scenarios

Scenarios can be used in different situations. They can be useful tools to (EC-DGXI, 1996); (Rotmans and Van Asselt, 2000), (van Asselt, 2000):

- help us articulate or to think through our key considerations and assumptions: scenarios can help us to imagine a range of possible futures if we follow a key set of assumptions and considerations;
- identify gaps, inconsistencies, dilemmas, uncertainties and indeterminacies and to understand complexity;
- help us expand and improve our thinking, take on and explore possibilities that are new, or challenge conventional thinking;
- blend quantitative and qualitative knowledge; scenarios are in principal powerful frameworks for using both data and model-produced output in combination with qualitative knowledge elements.

Characteristics of scenarios

Next to the different types of scenarios, Greeuw et al. (2000) mention different characteristics of scenarios. On of them is the geographical scale on which a scenario is carried out. This can be global, international, national or sub-national. It is also possible to make comprises about the scale by choosing a scale but taking notice of developments on a larger scale. Next to the scale scenarios can have different time-horizons. They can be worked out on a short term scale less, than 20 years and a long term scale, longer than 20 years. Taking different perspectives into account is also an important character. Taking more perspectives into account makes the idea behind scenarios more transparent. Furthermore the level of integration plays a role in scenarios. With the level of integration is meant the level of exploration of the manual interplay between social, economic, environmental and institutional developments.

Alternative typology

Börjeson et al. (2006) call the area of future studies and approaches a ‘very fuzzy multi-field’. To make the future studies easier to overview they introduced a new typology which is based on the scenario user’s needs to know what will happen, what can happen, and/or how a predefined target can be achieved. They distinguish three main categories of scenario studies. And their classification is based on the principal questions they believe the user may want to pose about the future. The category with the question “what will happen?” is called predictive, the category with the question “what can happen?” is called explorative and the last category with the question “how can a specific target be reached?” is called normative. These categories are distinguished by different angles of approach to the questions defining the categories, see figure I.3.

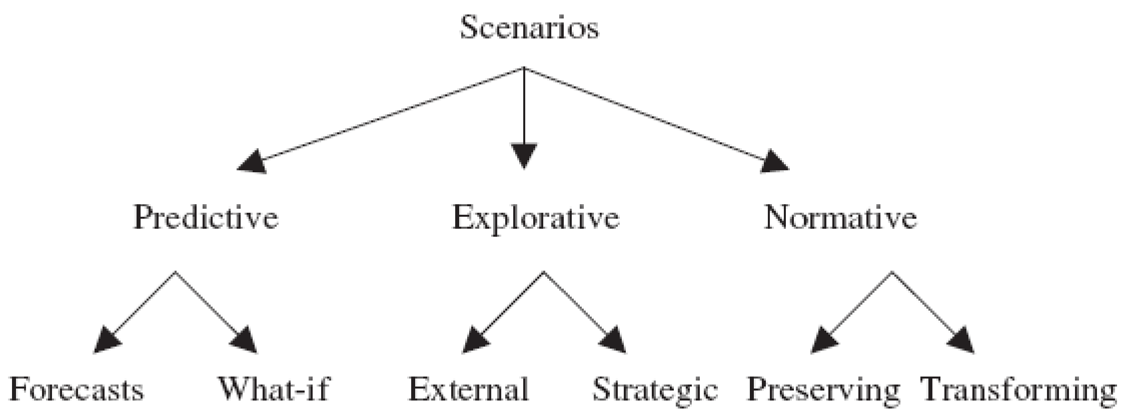

Figure I.3: Scenario typology with three categories and six types (Börjeson et al., 2006)

Predictive scenarios aim at making an attempt to predict what is going to happen in the future. They are primarily drawn up to make it possible to plan and adapt to situations that are expected to occur. The predictive scenarios are distinguished in forecasts and what-if scenarios. Forecasts are conditioned by what will happen if the most likely development unfolds. What-if scenarios investigate what will happen on the condition of some specific near-future events of great importance for future development. The difference with forecasts is more than a matter of degree regarding a single exogenous variable. A good example is an important referendum with a ‘yes’ or ‘no’ question, from where the future can develop in different ways.

The explorative scenarios aim at exploring situations or developments that are regarded as possible to happen, usually from a variety of perspectives. Furthermore, they are elaborated with a long time-horizon and often have a starting point in the future. Te explorative scenarios are distinguished in external and strategic scenarios. External scenarios focus only on factors beyond the control of the relevant actors. They can help the user to develop robust strategies, i.e. strategies that will survive several kinds of external development. Strategic scenarios incorporate policy measures at the hand of the intended scenario user to cope with the issue at stake. The aim of strategic scenarios is to describe a range of possible consequences of strategic decisions. Strategic scenarios focus on internal factors (i.e. factors it can possibly affect), and consider external aspects. They describe how the consequences of a decision can vary on depending on which future development unfolds.

Normative scenarios consist of two different types, distinguished by how the system structure is treated. Preserving scenarios respond to the question: How can the target be reached, by adjustments to current situation? In preserving scenarios, the task is to find out how a certain target can be efficiently met, with efficiently usually meaning cost-efficiently. Transforming scenarios respond to the question: How can the target be reached, when the prevailing structure blocks necessary changes? In transforming scenario studies, such as backcasting, the starting point is a high-level and highly prioritised target, but this target seems to be unreachable if the ongoing development continues.

A summary of the key aspects of scenarios according to Börjeson et al. theirs typology can be found in table I.2.

Table I.2: Summary of key aspects of scenario types (Börjeson et al., 2006)

Scenario category/type	Quantitative/qualitative	Time-frame	System structure	Focus on internal or external factors
PREDICTIVE—what will happen?				
Forecasts	Typically quantitative, sometimes qualitative	Often short	Typically one	Typically external
What-if	Typically quantitative, sometimes qualitative	Often short	One to several	External and, possibly, internal
EXPLORATIVE—what can happen?				
External	Typically qualitative, quantitatively possible	Often long	Often several	External
Strategic	Qualitative and quantitative	Often long	Often several	Internal under influence of the external
NORMATIVE—how can a certain target be reached?				
Preserving	Typically quantitative	Often long	One	Both external and internal
Transforming	Typically qualitative with quantitative elements	Often very long	Changing, can be several	Not applicable

Pitfalls and problems with scenario writing

Although scenarios are used a lot these days, there are also some critiques on it. Some critical points are harder to handle with than others. In this chapter pitfalls and problems with and critiques on scenario writing will be discussed.

Elzen et al. (2002) describe six problems in technological forecasting. These problems are summarised here:

1. Too much attention for quantitative, reductionist methods, and a lack of attention for qualitative methods.
2. Forecasts were to much based on extrapolations and the assumption of incremental change. There was too little attention for discontinuity and radical change.
3. Forecasting methods focused too narrowly on specific topics, without looking at the broader system.
4. Forecasting methods are based too narrowly on neo-classical economic approaches.
5. Many technology-scenarios look at (emerging) technologies independently. Technical trajectories area analysed and characterised with learning curves as if they were independent. In reality, however, these trajectories influence each other.
6. Scenarios can have a ‘macro-bias’(Geels & Kemp, 2000). This means that the dynamics and outcomes of the scenarios depend too much on such macro-aspects (e.g. economic growth, environmental awareness, oil price).

Next to detecting these problems, Elzen et al. (2002) also gave directions for improvement:

- Include more qualitative elements in the future explorations, even if this leads to methods, which are ‘looser’.
- Focus more on radical technological change. A range of analysts identifies this as an important challenge, although they also signal some problems, particularly the lack of appropriate theories.
- Explore radical technological changes; a broader systematic viewpoint is needed. The future exploration should not focus on individual technologies, but at the interactions between technologies, e.g. competition, complementary, hybridizations. Furthermore, the exploration should not only look at technologies and markets, but also at possible changes in user preferences, policy, cultural changes, and infrastructure. These changes do not occur independently, but in interaction.
- Develop a future methodology, which allows for meso- and micro-dynamics, next to macro-dynamics.

Some critiques are given by De Wilde (2000). He claims that people expect too much from technique. You often hear that new technology will fix the problems. He calls this the technological fix. But this technological fix is hard to realize. It is often hard to foresee the potential usage of new techniques. If a technique is successful, it often gets a new but unpredictable function. More of those techniques and their unknown functions can be the basis for a new theory. Thus, new techniques often do not do what they were intended to do. Just to indicate how hard it is to say something useful about the future and to expect the technique to solve everything. Not even mentioning the new problems that occur because of new technologies. Often the possible side effects of technological innovations are not thought through. E.g., it was said the computer should take all the hard work out of our hands, but nothing was said about the stress and RSI coming along with it. Another point of critique is about culture and technology. You cannot see them separately. According to De Wilde (2000) we have to get culture involved in speaking about technology if we want to get a step a head about future thinking.

De Wilde (2000) also acknowledges that future predictions tell more about today than about tomorrow. By saying this he means that the future stories or scenarios are very much dependent on how people think at that moment of writing it. He compares futures with holiday destinations. It makes no sense traveling to the future if there are no new chances on a better live. For centuries, our desire to enjoyment and luck is so strong that we are pleased to put the official apprenticeship of the church or the state aside for it. The paradise must and shall be ‘regained’, and anyone who caters to that desire can count on a willing ear.

Just like De Wilde (2000), Geels and Smit (2000) mention that expectations may be biased by the broader cultural concerns of that time. This is the first recurring key feature in images of the future-role of new technologies they have distilled from historical futures. These key features are factors that can cause future images to go wrong. Beside this one, Geels and Smit (2000) mention six more key features:

1. Sudden new trajectories in technological developments may trigger shifts in future images.
2. The role of a new technology is often phrased in terms of replacing or substituting the old technology, that is, in terms of winners and losers. In reality, however old and new technologies often co-exist and service different markets and costumer groups.
3. The neglect of the generation of new activities by assuming that the pool of existing social practices and needs remains unchanged.
4. Narrow functional thinking, looking after only one function of an activity and neglecting social, psychological or other aspects involved in an activity.
5. The process of societal embedding of new technologies is viewed as unproblematic in many speculations.
6. Voiced expectations initially promise high societal gains or advantages that in later phases appear to be unrealistic and than have to be scaled down and adjusted.

These six key features are translated into possible pitfalls for future expectations. This is done by Geels and Smit (2000) and can be seen in table I.3.

Table I.3 Possible pitfalls

Pitfalls	Neglected aspects	Examples
Expectations have cultural biases, reflecting current beliefs, hopes, fears	Cultural changes or alternative directions of technological development	Centralised steering computer traffic systems in 1960/70s. Decentralised informative telematic systems from mid-1980s on.
Focus on current technological trajectories	Alternative technological futures	Same example as above
Potential of new technology is phrased in terms of substitution of old technology	Co-existence of old and new technologies. Generation next to substitution	Replacement of paper products by computer systems (paperless society vs printing office)
Pool of existing social practices is assumed to remain constant in spite of the introduction of a new technology	Co-evolution of technology and society. Generation next to substitution	Tele-conferencing and business travels. Tele-working and impact on both commuting and recreational traffic subsystems
Functional thinking	Other social needs	Tele-shopping and sociable shopping
Overestimation of speed of societal embedding of new technology	Practical problems and adjustment processes	Telematics in traffic and transport. Tele-working
Initial promises in future expectations are too high and have to be scaled down in later periods.	The role of promises in technological development	Transport telematics and improvements of road efficiency. Tele-conferencing and substitution of business travels. Growth of tele-working.

Source: Geels and Smit (2000)

Despite of all these pitfalls and critiques, scenarios are still a useful tool. But while writing scenarios these critiques should be kept in mind.

Scenario writing guide

Where does a scenario consist of?

According to Alcamo (2001) there are some principle elements of typical scenarios used in environmental studies, but those elements are also very well applicable on other scenarios. The five principles adapted from Alcamo (2001) and edited for transport scenario usage can be found below:

- *Description of step-wise changes*; The main element of a scenario is the portrayal of step-wise changes in the future state of society and the environment. For example transport scenarios depict the change in number of cars or trips and change in emission levels over time. These changes can be expressed, for example in the form of a diagram, table, or even as a set of written phrases
- *Driving forces*; These are the main factors or determinants that influence the step-wise changes described in a scenario. As an example, some of the driving forces of transport scenarios are assumed population, economic growth, and the rate at which fuel use becomes more efficient. The values for these driving forces (along with most of the other elements of scenarios) must be assumed by the developers, or taken from other studies.
- *Base year*; The base year is the beginning of the scenario. For quantitative scenarios, the base year is usually the most recent year in which adequate data are available to describe the starting point of the scenarios.

- *Time horizon and time steps*; The time horizon describes the most distant future year covered by a scenario. The selection of an appropriate time horizon for a scenario depends very much on the objectives of the scenario. If the scenario aims to reduce car emissions, then the appropriate time horizon might be 10 to 20 years. If they describe longer term effects of the situation if nothing is done about those emissions, then it could be 100 years or more. The number of time steps is often kept to a minimum because of the large analytical effort needed to describe each year.
- *Storyline*; A storyline is a narrative description of a scenario which highlights its main features and the relationship between scenario's driving forces and its main features. These storylines can be newly constructed for each new scenario study, or they can be taken from previous scenario exercises. Since the storylines require intensive discussions and compromises between the different people involved in the scenario exercise, a large amount of time and effort can be saved by using storylines from previous exercises. (Moreover, some of the acceptance of these existing storylines might be transferred over the new scenarios.)

Rules of thumb

Schwartz (1991) gives some rules of thumb for scenario development:

- Beware of ending up with three scenarios, though in practice we often do. People not familiar with scenarios or their use will be tempted to identify one of the three as the "middle" or "most likely" scenario and then will treat it as a single-point forecast, and all the advantages of multiple-scenario methodology will be lost. But also avoid having too many scenarios. When one is working with more than four scenarios, they begin to blur and lose their meaningful distinctions as decision tools.
- In general, avoid assigning probabilities to different scenarios, because of the temptation to consider seriously only the scenario with the highest probability. It may take sense to develop a pair of equally highly probable scenarios, and a pair of potentially high-impact but relatively low-probability "wild card" scenarios. In no case does it make good sense to compare the probability of an event in one scenario against the probability of another event in another scenario, because the two events are assumed to take place in radically different environments, and the assignment of probabilities depends on very different assumptions about the future.
- Pay a great deal of attention to naming your scenarios. Names should succeed in telegraphing the scenarios logistic. If the names are vivid and memorable, the scenarios will have a much better chance of making their way into the decision-making and decision-implementing process across the company. Because the name evoked such a powerful and evocative concept, Shell's "World of Internal Contradictions" (WIC) scenario survived for more than a decade as a useful tool even as the world changed.
- Selection of the scenario development team should be guided by three major considerations. First, support and participation from the highest levels of management is

essential. Those who make an implement decision-making. Second, a broad range of functions and divisions should be represented on the scenario development team. Third, look for imaginative people with open minds who can work well together as a team.

- You can tell you have good scenarios when they are both plausible and surprising, when they have the power to break old stereotypes; and when the makers assume ownership of them and put them to work. Scenario making is intensely participatory, or it fails.

Next to these rules of thumb the critiques and pitfalls in the previous chapter should be taken into account.

Scenario-axes technique

In literature, the scenario axes are often recommended as a useful and straightforward tool to construct images of the future in a coherent and systematic way. Driving forces, which serve as scenario axes, are those developments that score on both indicators ‘uncertainty’ and ‘impact’ (van 't Klooster & van Asselt, 2006).

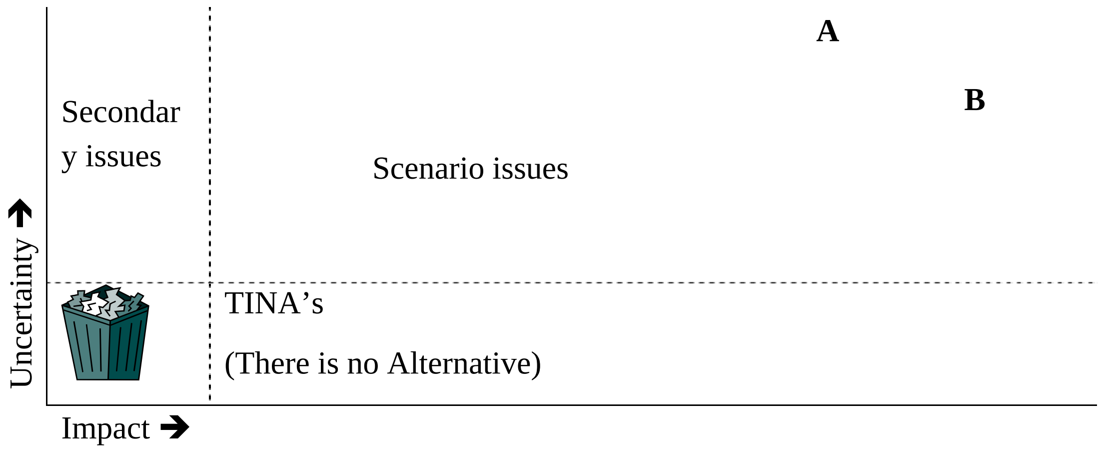

Figure I.4 Uncertainty/ impact matrix

Figure I.4 helps to decide which issues should be used as driving forces for the scenarios. The least interesting issues are those with a low uncertainty and a low impact. Those issues can go into the trash bin immediately. Secondary issues have a high uncertainty and a low impact. They don’t form a scenario but they can be used to decorate a scenario and to take the reader with you into this future. TINA which stand for “there is no alternative” have a low uncertainty and a high impact, these things will happen almost for sure and will have a high impact. An example of a TINA is the development of IT or the climate change. These will play a role in scenarios but don’t make a difference. Scenario issues are those which have a high uncertainty and a high impact. These issues can be used to make different scenarios with.

When using the scenario-axes technique, the two most important developments (A and B in figure 2) are to be plotted on two axes. This way four scenario quadrants appear—each representing a different perspective on how the future may unfold (figure I.5) (Van ‘t Klooster and Van Asselt, 2005).

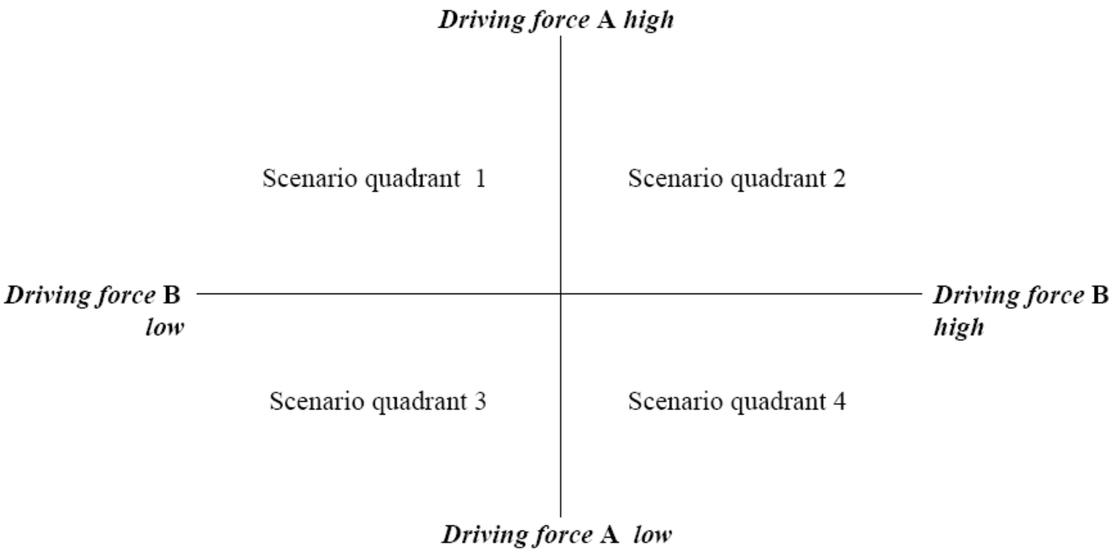

Figure I.5 Scenario landscape

Van 't Klooster and Van Asselt (2005) found some criteria for the driving forces one the scenario-axes. First, a driving force should have a strong relation with the topics in the scenarios study and it should change significantly over a certain period of time. Second a driving force should be a structural, not a secondary, development (such as disasters, which were considered as a possible outcome or consequence of other structural developments). Finally, it was argued that both driving forces should be independent of each other.

Socio technical scenarios

Elzen et al. (2002) describe a way to write scenarios which take the problems with the current methods mentioned by them earlier into account. They call the scenarios "social technical scenarios (STSc)". A STSc is a story that describes possible future developments, making use of the patterns and mechanisms of the transition theory. In the appendix the description of this method is added. The following steps will be clarified:

- Step 1: Design choices
- Step 2: First inventory of promising elements for a transition
- Step 3: Regime characteristics, problems, strategies and trends
- Step 4: Landscape factors and 'enabling technologies'
- Step 5: Relevant niches: opportunities and barriers for transition
- Step 6: Scenario-skeleton
- Step 7: Make the scenario

In short it comes to the following (Elzen et al., 2002):

- Address all three levels to some extent. Use the regime-level as the thread through the story. Discuss a limited number of exemplary niches. Indicate how a limited number of landscape developments affected expectations and subsequent developments in the regime and the niches discussed.
- In the niches, pay attention to articulation processes. When a niche ‘breaks through’, make plausible all relevant ‘articulation barriers’ have been overcome. A niche is not only a technology but also a domain of use that should be described. Within a niche, an ‘ordering principle’ could either be specific technologies or a specific domain of use.
- Watch out for (too) linear stories. Also introduce some cross-links, bifurcations, hybridisations, etc.
- Make the role of various actors clear (producers, users, gvt.). Describe how they are guided by their expectations and how their expectations are influenced by developments and experiences at the three levels.
- Treat technical and social/behavioural issues ‘symmetrically’; pay serious attention to co-evolution. Describe, e.g., how new technology leads to new experiences and then to new behaviour.
- Patterns and mechanisms; the theory provides a wide range; use them selectively and name them explicitly.

Appendix II Influencing mobility

This appendix gives a brief overview of the possibilities for influencing mobility.

In figure II.1, an overview is given of effects that are important for developing sustainable mobility.

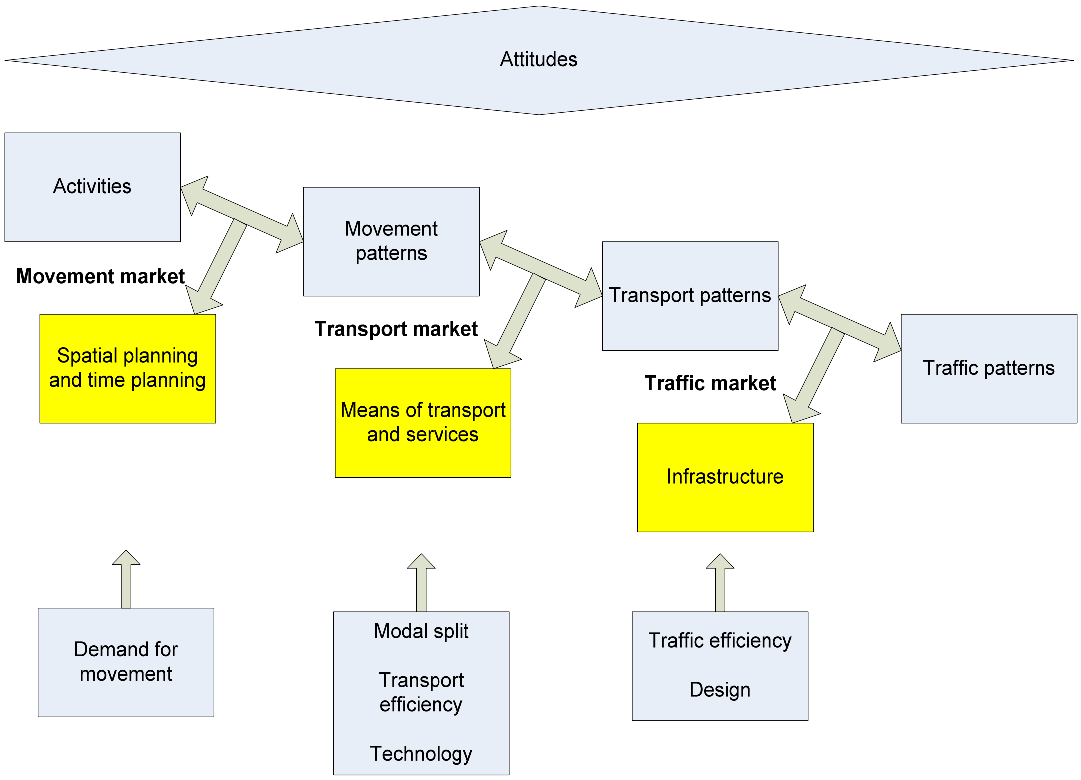

Figure II.1 The three markets and the excuses for policy (Adapted from Immers and Stada, 2004)

Mainly based on Immers and Stada (2004), mobility can be influenced on the next markets and topics:

- Movement market
  - Demand for movement; spatial patterns of living, working, shopping and recreation can be changed by emphasising on spatial nearness. This means focussing spatial planning on a better balance between origins and destinations. By doing this the demand for movement can be influenced. Another option is to emphasise on organising movements based on time. Peak loads are reason for an overload of the transport network and could result in dimensions of infrastructure, which are unused during off-peak hours. Influencing possibilities are variable working hours, implementing shorter workweeks or telecommuting.

- Transport market
    - Modal choice; the modal choice can be influence by increasing the availability and the attractiveness of other modalities. Other options to relieve the road network are carpooling or ‘carsharing’. In addition, expanding possibilities for multimodal transport can influence the modal choice.
    - Transport efficiency (occupancy rate); the occupancy rate of passenger cars are very low, policy could emphasise on this in order to influence the movement patterns.
    - Technology; technological means can help reducing negative effects of mobility. Measures could focus on more silent, cleaner, safer and more economical technologies. In addition, intelligent transport system can influence the usage of the vehicle, improve safety, and increase network capacity.
- Traffic market
    - Traffic efficiency (route choice, use potential capacity); the degree to which the potential capacity of a network is used can be increased. Dynamic Traffic Management can play an important role in this, for example by giving road users up-to-date information on incidents and congestion.
    - Infrastructural design; many measures can increase the sustainability of the transport network by improving infrastructural design. On a network scale, infrastructural design can increase liveability (layout, design speed, capacity), traffic safety (functional design, homogeneity, recognisable) and accessibility (design speed, connectivity, road categories), and in addition fall back options in case of incidents. On a local scale, noise abatement measures, barriers (viaduct for fauna) social safety (lights) and safety measures (design speed, forgivingness) can be influenced by the infrastructural design.
- Attitude

A sustainable development of a transport system requires the right embedding in society. This attitude can be realised by:

- Pricing measures; incentives can influence behaviour in a sustainable direction. Externalities of car usage can be internalised by a variety of charges like a (differentiated) kilometre charges.
- Giving of rules and education; in addition to the pricing measures, desired behaviour can be enforced. Traffic rules like a maximum speed for example. These rules can be strengthened by monitoring and enforcement. Finally, informing and educating can play an important role in acceptance of measures, understanding of undesired behaviour and improving traffic safety.

Appendix III Calculation methods

This appendix includes some general calculation or calculation methods, which are used in all the scenarios calculations.

Extrapolation method

In the WLO, numbers were available until 2040. These numbers mainly show a linear development. Because of that, they were linear extrapolated until 2050. Sometimes, for example, the PM_{10} and NO_x emissions, showed a sudden decrease followed by a linear development. If this was the case, points lying prior to the sudden decrease, where kept out of the analysis.

Fossil fuel bandwidth

In the calculations, two oil prices were used. The oil-price in the WLO is 32 dollar per barrel after extrapolation to 2050. Recent highest oil-price was found to be above 75 dollar per barrel. Since these values differ much, and a focus on only 32 dollar seemed to be unlikely for the future, a bandwidth of 32 – 80 dollar per barrel was used for this study.

One barrel contains 159 litres. A conversion resulted in 0.15 – 0.37 euro per litre (based on 2007 dollars). By 2050, 58% of the vehicles kilometres are driven by diesel and 42% by gasoline vehicles (leaving 1% LPG driven kilometres out of sight). Currently taxes are 0.51 and 0.87 for respectively diesel and gasoline. In order to get an average price for fossil fuels, these taxes are multiplied by their expected shares in driven vehicle kilometres. This resulted in an average tax of 0.66 eurocent (0.87 * 0.42 + 0.51 * 0.58 = 0.66). Adding this to the crude oil price per litre, results in a fossil fuel bandwidth of 0.81 – 1.03 euro per litre.

Noise nuisance of the engine

All the used vehicle technologies can profit from a noise nuisance reduction, due to a more silent engine. To valuate this benefit the costs per engine/fuel type are calculated. Since engines have the upper hand in noise nuisance only when speeds are below 30 km/h, it is assumed that the share of the engine noise of the total noise in urban areas is 0.5. Multiplying this with the number of vehicle kilometres per fuel type and with the related noise costs according to CE (Vermeleun, 2004), resulted in a total noise costs of 174 million euro (table III.1).

Table III.1 Engine noise costs per fuel type

Fuel type	Number of vkm per fuel type (WLO, 2006)	Noise costs (CE, 2004) €ct per vkm	Share of engine noise of total noise in an urban area (assumption)	Noise costs per fuel type
benzine	16338520000	0,9	0,5	73523340
diesel	17903700000	1,1	0,5	98470350
lpg	367282000	0,9	0,5	1652769
			Total noise costs	173.646.459

Appendix IV Scenario TT

This appendix includes a more comprehensive description of the used measures, and in addition, some more comprehensive scenario related calculations.

Automated highway system

An automated highway system (AHS) is a lane or set of lanes where specially equipped cars can travel together under computer control. The vehicles are equipped with vehicle lateral control, vehicle longitudinal control, vehicle route guidance and a vehicle system for AHS. The longitudinal control is equipped with a ‘platoon’ capability, to move within 60 – 90 centimetres of the next vehicle (Ward, 1997). Vehicles that are in a platoon operate as one, like a short train. This means vehicles take up less freeway space, so it can carry more vehicles. The lateral control includes automated lane change (figure IV.1). This enables the entire freeway trip to be automated: entry into the freeway, movement to the desired lane, then subsequent exit from the freeway (Ward, 1997). AHS also offers the potential for substantial improvements in trip predictability, level of service, inclement weather operation, and mobility and air quality (Vision 2030, 2003).

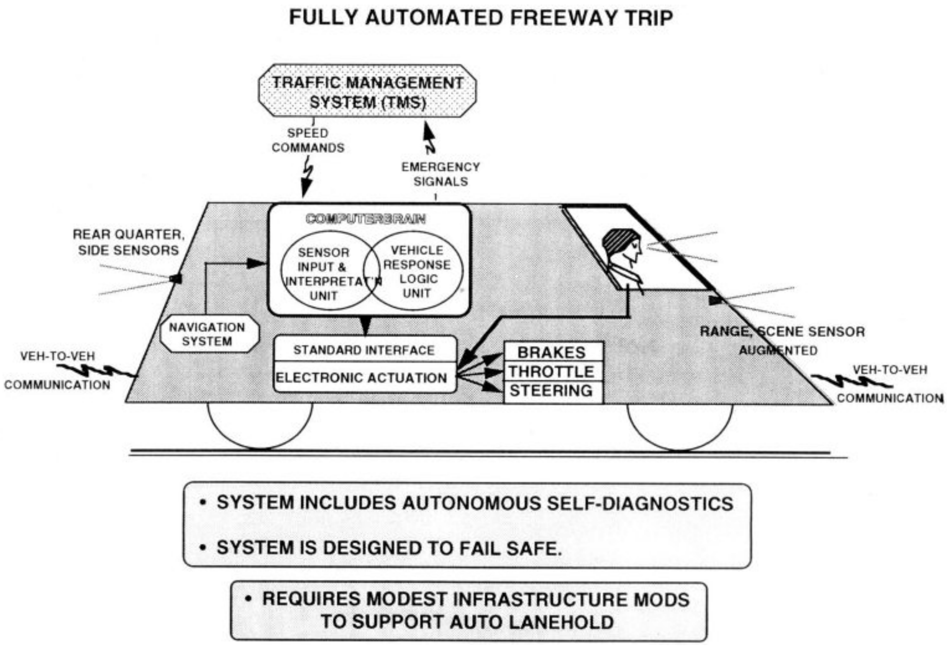

Figure IV.1 Schematic of automated vehicle (Ward, 1997)

- *Entering and exiting AHS*

Coordination of entering and exiting vehicles is recommended to avoid traffic flow disruptions. According to Zwaneveld and Van Arem (1997) there is agreement on the need for separate on- and off-ramps with a corresponding accelerating or decelerating lane for entering and exiting vehicles. The coordination of entering and exiting on special ramps has to avoid traffic flow disruptions that cause a decrease in maximum achievable flow, in safety and in driver comfort.

- *Travel time reliability*

The reliability is an important factor now a day and AHS is increasing the predictability of travel time. Since no literature was found with specific numbers about the improvement in reliability, it is assumed that travel times predictability is increased with 80 per cent on the highway.

In table IV.1 the travel time variance are given for the different roads. The 2001 and 2020 figures are adapted from Hilbers et al. (2004). Since the growth rate until 2020 seem to be comparable to the growth rate of lost vehicle hours in the GE scenario, the 2050 figures are based on an extrapolation according to the same growth as in lost vehicle hours in the GE scenario. Furthermore, it can be noticed that the difference in travel time variances for peak and off-peak hours changed from 2000 to 2020 to a minimum. Here it assumed that both values are equal in 2050.

Table IV.1 Travel time variance per road kilometre

Traveltime variance per road kilometre						
	2001		2020		2050	
	Peak	Off-peak	Peak	Off-peak	Average	AHS
Highway	32%	25%	42%	41%	64%	13%
Other roads	16%	11%	21%	17%	32%	32%
Total	20%	14%	26%	22%	40%	19%
Based on (Hilbers et al., 2004)						

With an increase of travel time predictability on highways with 80 per cent this means these travel time variances on the highway come down to 13 per cent. And for the total in 2050 this comes down to 19 per cent. This is an increase in predictability of 52 per cent.

- *Traffic safety*

How safe is “safe”? Of course, we are dealing with a system that can fail. Ward (1997) gives a well explanation in his article. He refers to an exceedingly rare event like a piano falling from an aircraft. If we want to avoid the piano falling, we have precluded AHS. Absolute safety is impossible to achieve for either human driver or automated system. But he says, it seems perfectly feasible to achieve levels of safety with an automated system that are substantially better that those that obtain today with human drivers. A big part (say 90 per cent) of all vehicle accidents, result from driver-related factors. Inattentiveness, inability to respond quickly enough, or bad driving decisions are examples of the driver-related factors. AHS will eliminate this driver related factor and thus realize a safer traffic. According to Postema (1998) the fatalities can be reduced by at least 50 per cent and the casualties by 31-85 per cent.

- *Fuel consumption*

Because vehicles can drive in platoons there is a reduction of drag. This reduction results in a 25 per cent reduction of fuel usage (Browland et al., 1997). Since this reduction can only be achieved on the highways, the overall reduction of fuel consumption comes down to 14 per cent. AHS also takes account of smoother traffic. According to Browland et al. the difference in fuel usage between congested and uncongested highway travel is about 30 per cent. Multiplying this with the chance on congestion (norm 2-5%) on highway and the share of vehicle kilometres on the highway gives such a small percentage that this isn't taken into account for this study.

Battery electric vehicles

Battery electric vehicles can realise zero emission vehicles when the electricity used is generated on a sustainable manner. For example if the energy conversion is done by wind turbines or if solar power is used. BEVs have the same comfort as ICEVs, they are even a bit quicker in reaction and speed. A big pro is the good energy efficiency ratio. They do however have a big problem as well; the BEVs have a much shorter action radius compared to ICEVs. Another problem might be the availability of lithium, which is necessary to produce batteries.

- *Best efficiency ratio*

A comparison of internal combustion vehicles (ICEV), battery electric vehicles (BEV) and fuell cell vehicle (FCEV) by Gilbert and Perl (2007) teaches us that the BEV has a far better efficiency ratio than the other two. Compared with the BEV, the FCEV and the ICEV use two and three times as much energy, respectively. Based on this economic advantage of the BEV, Gilbert and Perl see a bright future for the BEV.

- *Actions radius*

To realise a prospect for the battery electric vehicle, its action radius needs to be improved. Currently the action radius of a BEV is about 250 km. To overcome this action radius problem electrified roads can be implemented. This electrification is only necessary at highways since the current action radius is sufficient for urban travel. See figure III.2 for a schematic.

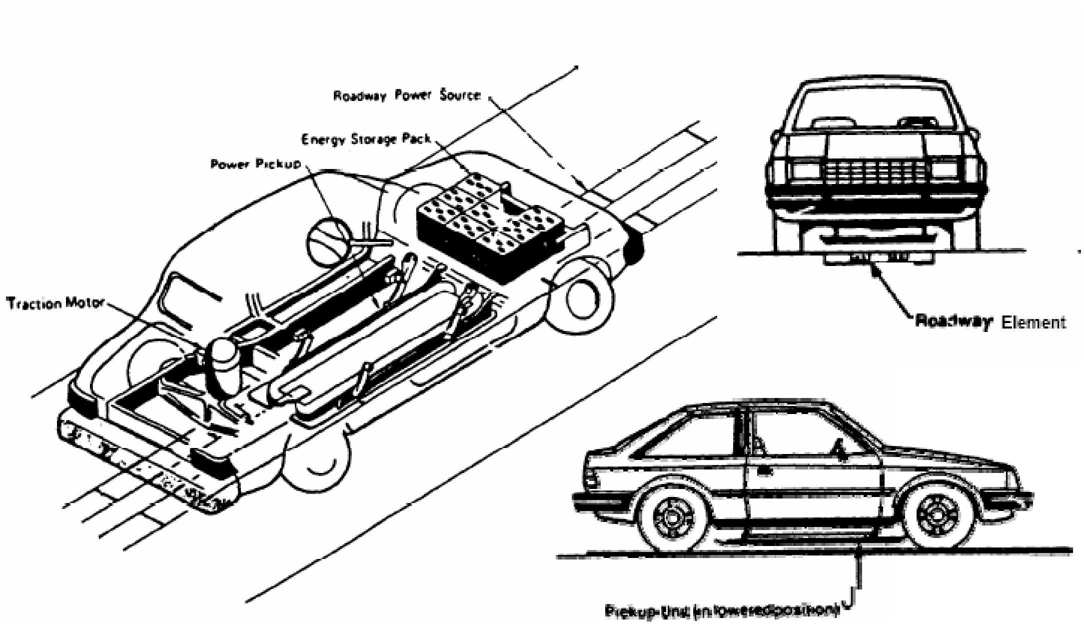

Figure IV.2 Schematic of a vehicle with electrification (SCAG/PATH, 1993)

In 1993 a study after highway electrification was carried out by SCAG/PATH (1993). In this study they also analysed the lifecycle costs of such an infrastructure. They used the following figures; 2.5 million dollar per lane-mile of powered roadway. And 2.5% of the roadway costs for annual operations and maintenance (O&M). Since these figures are somewhat outdated here a bandwidth is used of 1.5 – 4.5 million dollar per lane-mile (also used in their sensitivity analysis). In euro per km this comes down to 1.8 – 5.4 million. Multiplying this with the number of lane-km HWN (24200) and dividing it by 20 years of operation this gives ***2.2 – 6.5 billion*** euro. It is assumed that these costs for electrifying roads can be significantly lower, if work is combined with building an automated highway system.

Charging units for using electrified roads are assumed to have no additional cost if they are assembled during car manufacturing. Since the car fleet is to be replaced for other measures as well, no extra costs will be charged for the connection between the car and the electrified road.

One should note that not many recent references were found for electrifying roads. Gilbert and Perl (2007) sketch a pathway towards en-route powering of vehicles but don't go into details. The study by SCAG/PATH (1993) does, but it is expected to be outdated.

If electrified roads seem to be unrealistic, another solution needs to be found for the action radius of battery electric cars. A 'simple' solution would need a change in vehicle design speed. When cars are designed to drive no faster than for example 100 km/h, they can be designed much lighter. And a lighter vehicle needs much less energy. In contrast with the 'strange' energy usage of an ICEV (figure IV.3), the energy use of a BEV increases quadratic with every increase in speed from the beginning on. This means that driving 100 instead of 120 reduces the energy usage with 44 per cent. Based on the speed reduction in combination with the weight reduction, the range of the BEV could more than double.

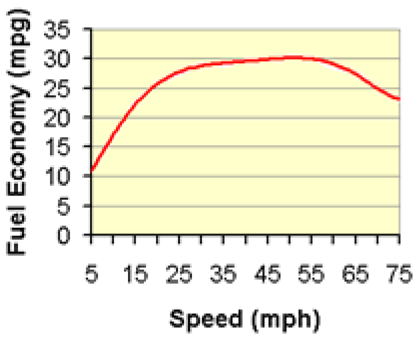

Figure IV.3 Fuel economy of an ICEV

- *Electric vehicles for grid power support (V2G)*

Electric driven vehicles have another opportunity to reduce air pollution and at the same time increase the reliability and efficiency of the electric power system. This opportunity is based on using electric storage capacity of a battery vehicle to send power to the grid. Kempton et al. (2001) call this "vehicle-to-grid" power or V2G. Supplying energy for the base load is not competitive. For peak hours and especially for reducing spinning reserves and regulation power BEVs can have a big contribution.

To fully understand this, some explanation about the power market, based on Kempton et al. (2001), will be given. Peak power is generated or purchased at times of day during which high levels of power consumption are expected—for example, on a summer afternoon predicted to be especially warm. This is typically generated by power plants that can be quickly switched on or off, such as gas turbines. Since peak power is typically needed only a few hundred of hours per year, it is economically sensible to draw on generators, which are low in capital cost, even if they are more expensive per kWh generated. Spinning and regulation are ancillary services and their main function is to maintain the reliability and stability of the grid. Ancillary services are not straight kWhs of energy; they are contracted as reserve power ready to go on-line, as adjustments in voltage or frequency and other services.

Back to the V2G, BEVs can charge during low demand times and discharge when power is needed, see figure III.4 for a daily charge and discharge schedule.

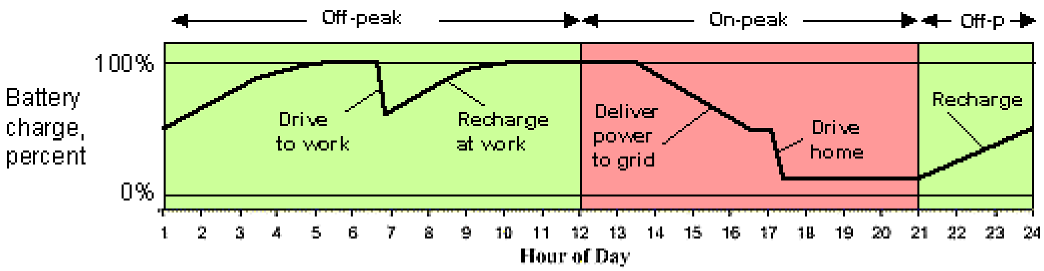

Figure IV.4 Daily charge and discharge schedule (Kempton et al., 2001)

To avoid an empty battery when one needs the car, any vehicle using V2G would have to include a controller with which the driver would limit discharge to insure sufficient charge to meet his or her driving needs, for an example see figure III.5.

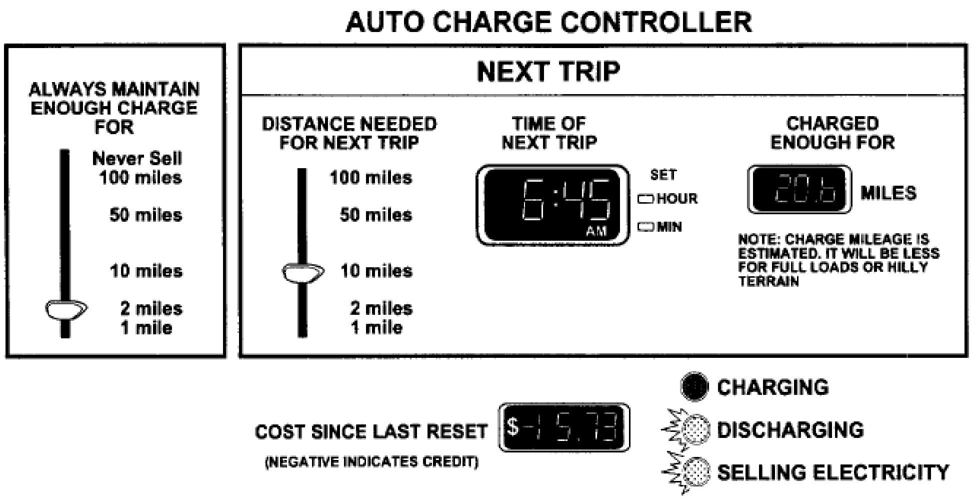

Figure IV.5 Figure 2.2. Suggested design of vehicle dashboard control, allowing driver to limit loss of range of vehicle and monitor power transactions (source: Kempton and Letendre (1997)).

For a schematic of the system see figure III.6, in this figure one can also see wind turbines. V2G has an extra advantage, because they make wide scale wind power possible. Normally wind power conversion is never constant due to changing wind speeds. This instability can easily be compensated by V2G because the can be the required storage facilities. In addition, the usage of solar power in combination with V2G is also advantageous.

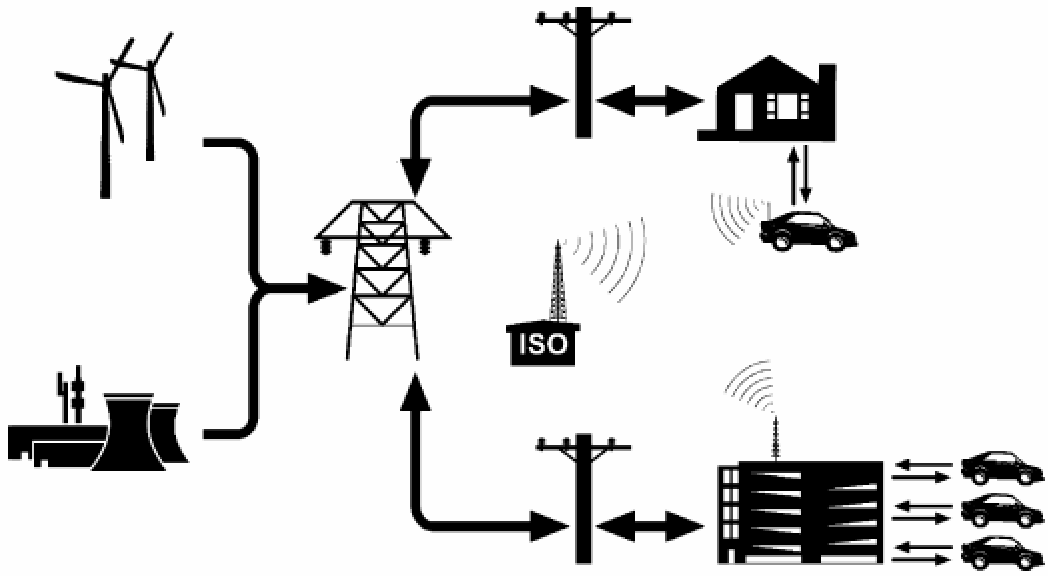

Figure IV.6 An overview of the V2G system (Tomic & Kempton, 2007)

According to Tomic and Kempton (2007) a number of institutional barriers should be addressed as well. These include: (1) lack of vehicles aggregators to manage multiple fleets and individual vehicles, (2) regulation signal is not broadcasted by all ISOs, (3) rates for regulation services are not available at the retail level, (4) no mass production of V2G capable vehicles, and (5) need for standards for V2G provision quality. [5]

- *Comprehensive cost calculation of wind power and/ or solar power*

Prices for wind energy are hard to compare, in other words, using statistics from one area is not a reliable guide to costs in another area (DWIA, 2003a). According to EWEA (Morthorst & Chandler, 2004) the energy costs depend on investments costs, average wind speeds, operation and maintenance costs, turbine lifetime and the discount rate. Considering these factors, they come to 5-6 eurocents/kWh for medium wind speeds. Other ranges in literature are 5-8 eurocent/kWh (PDE, 2002 in Van den Brink (2003)) and 4-5 eurocent/kWh (Ampere, 2000). Costs have declined by 30%, or around 3% per year from 1989-2001 (EWEA, 2004)). Using those learning curves make EWEA imply a cost range of 3.9 – 5.2 Eurocents/kWh in 2010. If the turbine is located in a coastal area with a higher wind speed (an average of 6.9 m/s at a height of 50m) the costs per kWh produced in 2010 could be as low as 3.1-4.4 eurocents/kWh. According to the wind map of Western Europe (DWIA, 2003b) a big part of the Netherlands can be counted as an area with higher wind speed. Also the UNDP (2000)

[5] For more information and reports about Vehicle-to-grid, one can go to www.udel.edu/V2G.

expect that the cost price of wind energy will decrease with 35-45% between 1997 and 2020. This comes down to 2-2,5% reduction in price per year. For this study, the assumption is made that the cost price in 2050 will be between the lowest price mentioned in 2020 and a price when the price per year keeps reducing with 2% per year. This results in a range of 2.0 – 2.5 eurocents/kWh.

One could also realise clean energy by using solar thermal electricity. The cost price for solar power is currently much higher than the cost price of wind power: 0.30 – 1.50 USD/kWh (UNDP, 2000). According to UNDP (2000) the costs of solar thermal electricity (STE) will quickly drop to the cost level of wind energy. That price however, is the current cost price of wind. Also Shell has the ambition to let the cost price drop with 5% per year (Van den Brink, 2003). The costs for solar power in 2020 are expected to be 5.0-6.0 Eurocents/kWh (Sargent and Lundy (2003) in: Nagelhout and Ros (2006)). The American SunLab (in: (Visser et al., 2006) and the Algemene Energieraad (2006) (in: Nagelhout and Ros (2006)) even come to lower values, respectively 3.5 – 4.3 dollar cents/kWh and 4.5 eurocents/kWh . These values are based on the sunniest areas in the world and take an increase in production, up scaling of installations and technological development, into account. For the Netherlands, were the sun is not so active, energy can be imported. Transport by a HVDC (high-voltage, direct current) network will lead to extra costs of 1.0 eurocents/kWh ((Trieb, 2006) in: Nagelhout and Ros (2006)). Here it is assumed that these cost values keep reducing at least until 2050. When the electricity is imported from the Sahara a range of 3.0 – 4.0 eurocents/kWh seem to be reasonable for the Netherlands in 2050. Again, these figures are production costs only.

Appendix V Scenario CC

This appendix includes a more comprehensive description of the used measures, and in addition, some more comprehensive scenario related calculations.

Low speed automation (LSA)

Low Speed Automation (LSA), is a natural outgrowth of lane keeping and car following technology (Bishop, 2005). An integration of those and some necessary additional smarts offer the driver a full hands-off, feet-off experience when in traffic jams. The system could rely on laser-radar for forward ranging and image processing to detect lane position. Its upper speed range is set for 40 mph (Bishop, 2005). This system can be seen as a stepping-stone towards the fully automated highway used in the TT scenario.

- *Perception of lost hours*

According to Stopher (2004) there are three negative effects of congestion; (1) non-productive time, (2) increase in emissions and (3) unreliable travel times. When giving a monetary value to lost hours, especially the first and third points are considered important. Low speed automation will make it possible to do some small things in the car. With LSA activated, one can play a game, browse the internet, check email or watch television during the congestion drive. This can have influence on the perception of lost hours. One can perceive less lost hours because the hours can partly be rewarded as productive time. Redmond and Mokhtarian (2001) even show that many commuters do not perceive congestion as necessarily an evil of their daily commute. Based on their study, Nasser (2002) notes that, in these modern times, many people can find complete privacy in only two places, the car or the toilet. Jains and Lyons (2007) even go a step further by calling travel time a gift.

The implementation of LSA combined with a campaign emphasising that congestion driving is fun (and the fact that people already do not perceive congestion as necessarily an evil), suggests that it would be possible to downgrade the value of time for lost vehicle hours. The reliability issue however still exists.

- *Campaign*

As mentioned in appendix II, soft measures are the base of success for hard measures. In this case the soft measure has to make people aware of the possibilities of congestion driving. It has to make clear what becomes possible with LSA. Costs are expected to be marginal and won’t be taken into account for this study.

Sustainable safe infrastructure[6]

Sustainable Safety is an integral approach of the traffic system consisting of 'human', 'vehicle', and 'road'. Road and vehicle should be tuned to a person's capabilities, and need to

[6] The following text is taken from the SWOV (2007) website, where they explain the principles of sustainable safety

provide protection. Education must prepare the human for the traffic task, and finally he should be checked to see if he participates safely. Sustainable Safety aims at road safety measures that intervene as early as possible in the chain from system design to ultimate traffic behaviour. This is necessary because it is the gaps in the traffic system that lead to unsafe behaviour, such as errors and offences, and can eventually lead to crashes. By intervening in the system as early as possible, unsafe actions are made minimally dependent on the individual road user's choice.

In Sustainable Safety there are five main principles:

1. Functionality of roads,
2. Homogeneity of mass, speed, and direction,
3. Recognisability of the road design and predictability of the road course and road user behaviour,
4. Forgivingness of the physical surroundings and socially between road users,
5. State awareness by the road user.

These five principles are based on scientific road engineering theory, biomechanics, and psychology. They are explained in more detail in the book entitled Advancing Sustainable Safety for the areas of: infrastructure, vehicles, intelligent transport systems, education, and regulations and enforcement. The principles have also been worked out for specific subjects and target groups: speeding, alcohol and drugs, the young, cyclists, pedestrians, motorized two-wheelers, and lorries.

Functionality

A sustainable safe road network has a functional layout, based on three main road types. The two 'extreme' types are main roads, for traffic dispersion, and access roads, for access to the destination. The third type, the distributor roads, is for a good link between the two extreme types, both literally and figuratively.

Homogeneity

Sustainable Safety aims at homogeneity in mass, speed, and direction. This means that vehicles with large differences in mass, speed, and direction must be physically separated from each other. For example, cars and vulnerable road users are incompatible, but so are lorries and other vehicles, or motor vehicles driving in opposite directions. Conflicts between these vehicle types will almost inevitably have severe consequences. This sort of conflict can be avoided by having separate infrastructures or dual carriageways. When physical separation is not possible, for example at junctions at grade level, the speed must be reduced. It should be so low that all possible conflicts would end safely, i.e. without any severe consequences. Measures that can be used here are a lowering of the speed limit and speed reduction by e.g. roundabouts or raised junctions and raised pedestrian crossings.

Recognisability

Road users should know which driving behaviour is expected of them and what they can expect from others. In a sustainable safe traffic system, road users should 'automatically' drive appropriately. Generally, people make fewer mistakes when engaging in automatic behaviour, than when they drive using reasoned actions. The desired driving behaviour can only be incited with a uniform road design, which is well tuned to it. People need to recognize the road type and drive accordingly. This must apply to the whole road network, which should also be predictable, just like others' driving behaviour.

Forgivingness

The 2005 update now includes the Sustainable Safety principle of forgivingness. Forgivingness in the physical sense means that the road design is such that any crashes will end as good as possible. A vehicle that goes off the road should not hit any obstacles or other fixed objects, because this leads to severe injury. The vehicle itself should provide equal protection to both its occupants and the collision opponent. Forgivingness in Sustainable Safety also has a social meaning. The more experienced drivers should, by displaying anticipatory behaviour, offer room to the less experienced drivers. This prevents mistakes by the inexperienced being 'punished' by a collision.

State awareness

The 2005 update of Sustainable Safety also includes the principle of state awareness. State awareness refers to the capacity or possibility of the road user to correctly estimate his own fitness to drive. This means that he must know which skills he possesses and if they are sufficient to drive safely. Road users should also know themselves if they are, temporarily, unfit to drive because of alcohol, stress, or fatigue.

- *Reduction potential*

In spite of the reasonable road safety prospects in the NTTP, the Traffic and Transport Board and SWOV wonder whether more should be done to improve road safety. SWOV introduced the term 'avoidable crashes': crashes of which it is known how to prevent them and, for which, the necessary measures are also cost-effective. Tackling these avoidable crashes would not save only 350 deaths a year, but 700. This is twice as much as the goal of the current policy for 2010. In table V.1, the reduction potentials per measure are presented (unfortunately in Dutch).

Table *V.1* *Effect of the intended measures (Wegman, 2001)*

Maatregel	Probleem-omvang (aantal doden)	Effect maatregel	Besparing (aantal doden)		Reductiefactor
Doorgerekend NVVP-pakket	1066	33%	350		0,67
Sub-Totaal				*350*	0,67
Infrastructuur					
Versnelling invoering DV-infrastructuur	1066	19%	200		0,81
Categorisering / hogere kwaliteit DV	1066	4%	40		0,96
Autosnelwegen (ROA-aanpak; telematica)	132	30%	40		0,96
Wegbermen erftoegangswegen bubeko	130	19%	25		0,98
Sub-Totaal				*305*	0,73
Snelheidsbeheersing					
Rijsnelheid=limietsnelheid (gecorrigeerd voor het NVVP-effect van de toezichtprojecten)	1066	21%	225		0,79
Sub-Totaal				*225*	0,79
Voertuigen en telematica					
Blackbox lease-auto's en navigatiesystemen	350	7%	25		0,98
Sub-Totaal				*25*	0,98
Aanpak doelgroepen met hoge risico's					
Nachtelijk rijverbod beginnende bestuurders	58	69%	40		0,96
Brom-/snorfiets vanaf 18 jr	89	39%	35		0,97
Sub-Totaal				*75*	0,93
SUB-TOTAAL bespaard aantal slachtoffers				***980***	
Correctie voor overlap				279	
TOTAAL bespaard aantal slachtoffers na correctie				701	
RESTEREND aantal slachtoffers in Nederland na NVVP-pakket + SWOV-pakket				365	

Fuel Cell Electric Vehicles

Fuel cells use hydrogen and oxygen to produce electricity through an electrochemical process. Hydrogen is an energy carrier and can be produced from fossil fuels, nuclear and renewable energy by a number of processes, such as water electrolysis, natural gas reforming, gasification of coal and biomass, water splitting by high-temperature heat, photo-electrolysis, and biological processes (OECD/IEA, 2005b). For this study, only renewable resources are considered. Electrolysis is a well-known process that converts water into hydrogen and oxygen using electricity. Electrolysis opens the door to hydrogen production from any primary energy source that can be used for electricity generation. This process is applied in this study to use wind-generated electricity.

- *Hydrogen production costs*

The hydrogen production costs were already discussed; an overview of the costs used by DOE (2003) is presented here (Table V.2).

Table V.2 Summary of hydrogen cost (w/ 500 mile transmission), availability, and usage for each resource predicted by a model for 2050.

Resource	Abbrev.	Cost ($/kg)	Potential (quads*/yr)	Usage (quads/yr)
Wind Class 4	WC4	$4.54	18.1	5.3
Wind Class 5	WC5	$4.40	3.1	0.48
Wind Class 6	WC6	$4.13	1.7	0.98
Photovoltaic Solar	Solar	$6.91	5.9	0.0
Geothermal	GeoT	$4.14	0.43	0.43
Dedicated Energy	DEcrops	$2.84	0.57	0.57
Agricultural Residue	AgriRes	$2.77	0.81	0.81
Wood Waste	WoodWaste	$2.77	0.73	0.74
Municipal Solid Waste	MSW	$2.53	0.18	0.18
Livestock Manure	Manure	$2.40	0.29	0.29
Landfill Gas	LFGas	$2.70	0.13	0.13

(Source: DOE, 2003) * 1 quad = 1.055×10^{18} joule = 1.055 exajoule (EJ)

Appendix VI Scenario ECT

This appendix includes a more comprehensive description of the used measures, and in addition, some more comprehensive scenario related calculations.

A kilometre and emission based charge

In this scenario, it is tried to reduce lost vehicle hours to a minimum by applying pricing measures. There are many ways one can reduce demand by applying pricing measures. Main reason for this measure is reducing lost vehicle hours. The most effective charge for this is a kilometre charge in combination with a congestion charge, also referred to as variant 5 (LogicaCMG et al., 2005) and (Besseling et al., 2005). This dynamic charge will be used in this study. Besseling et al. come for this variant to a reduction of 45 per cent in lost vehicle hours and 14.2 per cent reduction in the number of vehicle kilometres. The CPB (2006) also used this variant to calculate the effects on congestion especially for all the WLO scenario's. If implemented well before 2020, they come to comparable figures.

Black Box[7]

Human behaviour is a determining factor in road safety. For this reason, it is of crucial importance to encourage people to behave safely in traffic. It is known that people aware of being observed tend to modify their behaviour. By observing and recording the behaviours of drivers, it might then be possible to confront them with their behaviour. This could mean that drivers who realise that this can happen will adjust their behaviour ahead of time. They can also react this way because of an actual confrontation. A 'black box' or an 'event data recorder' is a system, which records all driver actions. This data can be communicated with federal organisations in order to confront people with their behaviour. This form of behaviour influence is proved to be effective and according to Wouters and Bos (1997) it result in 20% fewer road traffic accidents.

ICEV optimisation and bio fuels (and kilometre plus emission charge)

In this scenario zero emissions for passenger cars is achieved by a combination of several measures. First measures that reduce the required fuel will be applied, followed by more environment-friendly fuels.

Firstly a reduction in vehicle kilometres of 10 per cent will be realised based on the kilometre charging used in the same scenario under the accessibility target. This equally reduces the CO2 and other emissions with 10 per cent.

The second package of measures is to optimise the conventional ICEV. In a literature review of Van den Brink and Annema (2007) they found that applying the newest technologies for internal combustion engine vehicles, a reduction of 30-40 per cent in fuel usage is possible.

[7] This part is largely based on the text found on the SWOV website, http://www.swov.nl/uk/research/swovschrift/inhoud/08/black_box_study_shows_a_reduction_in_the_number_of_accidents.htm

Johansson and Ahman (2002) even come to a 50 per cent reduction of the environmental costs. These technologies do not only include improved combustion but also weight, drag and rolling resistance reducing measures. For this package of measures the total bandwidth of 30-50 per cent is used.[8]

The third type of measures that reduce the required fuel are concerning consumer behaviour and driving habits. Measures could be promoting fuel-efficiency driving or the introduction of speed limits. The OECD/IEA (2005) expects an efficiency improvement of 5-10 per cent for driving lessons emphasised on fuel efficiency. The German Advisory Council on the Environment (SRU, 2005) comes to CO2 reduction potential between 6 and 17 per cent for measures that promote fuel-efficient driving habits. The effects will probably be less when other efficiency measures are taken as well. Because of this possible interference the lower bandwidth of the OECD, 5-10 per cent is used here.

All the fuel-reducing measures together have no interference with each other or the interferences are already taken into account. However, this does not mean the percentages can be summed. A combined efficiency calculation is derived from a multiplication of the remaining fractions (Brink & Annema, 2007). This means that a combination of two technologies with an effect of 20 per cent each, have a combined effect of 36 per cent and not 40 per cent. This calculation method gives a reduction potential of 40-60 per cent compared to the reference scenario. This means that there is 40-60 per cent of the CO2 of the reference scenario left as well.

To minimise this, a fourth measure contains the implementation of bio fuels. Most currently available bio fuels appear not to have the potential to meet this reduction demand. There are however a number of future bio fuels that might come onto the market in the next 10 to 15 years. The three bio fuels which are most promising (highest greenhouse gas reduction potentials) are used here. According to CE (Kampman et al., 2005) these are cellulosic ethanol, FT diesel and HTU diesel. An even more recent Ecofys study (Hamelink and Hoogwijk, 2007) however shows that the first generation sugar cane ethanol has the best future reduction possibilities. Compared to other bio fuels, especially the fuel consumption needed for conversion is very low for sugar cane. This is because bagasse residues (the biomass remaining after sugarcane stalks are crushed to extract their juice) are used during production and because of a high yield per hectare. If one looks after production possibilities in the Netherlands, the three bio fuels produced from woody residues or cultivated wood mentioned in (Kampman et al., 2005) are sufficient to replace about 10% of transport fuel. This reference however does not take account of possible fuel demand reduction discussed above. Taking this reduction of 40-60 percent into account this means that 16,7 – 25% of the required fuels in this scenario can be replaced by bio fuels produced in the Netherlands. The

[8] Even higher savings are possible according to Loremo (2007). Loremo, a ‘low resistance mobility’ concept is being developed by a German manufacturer, and they have two models due for release in 2009. With a vehicle weight of only 450 kg and a drag coefficient of 0.20 they have designed a vehicle with a quoted fuel efficiency of 1.5l/100km. This equals 50g CO2 per km. Compared to current average emissions (160 g CO2 per km) this means a reduction of 70 per cent.

resulting gap, about 75 – 83,3 per cent (30-50 per cent of the original demanded energy in GE 2050) needs to be replaced by sugar cane ethanol produced in foreign countries, e.g. Brazil.

- *Use of bio fuels or renewable energy for bio fuel production*

In well-to-wheel approaches, it is widely accepted to assume that the energy needed in the process of making a clean fuel or energy is itself not clean (references). This results in emission on the overall process, even with so-called clean fuels. To be able to realise zero emission transport it is assumed that clean fuels and clean energy are also used in other sectors involved in production and transportation process. Of course there can still be emissions on the well-to-wheel cycle, e.g. for using fertilisers in the biomass production or for recycling or breaking down materials.