SUSTAINABLE INNOVATIONS IN ROAD TRANSPORT: ASSESSING THE IMPACT OF NEW TECHNOLOGY ON ENERGY USE AND EMISSIONS

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1. INTRODUCTION

In line with the European climate policy and going even further, the Dutch government has set ambitious climate targets for 2020. The policy programme 'Clean and Efficient' (VROM, 2007) aspires a greenhouse gas emission reduction of 30% below 1990 levels, an annual energy saving rate of 2%, and a 20% share of renewable energy in 2020. These overall targets will have important consequences for the transport sector, which contributes to approximately 20% of the greenhouse gas emissions in the Netherlands. Without additional policies, greenhouse gas emissions in the transport sector are projected to grow up to 55% above 1990 levels in 2020 (CPB/MNP/RPB, 2006). Based on an overall assessment of policies and measures (Menkveld et al, 2007), specific reduction targets of 13-17 Mton have been indicated for the Dutch transport sector, corresponding with a range of 0- 13% above 1990 levels in 2020.

Generally, there are four ways of reducing the greenhouse gas emissions of the transport sector. The policy programme Clean & Efficient has proposed measures in all these four categories.

- *Reduce the demand for transport services.* A road tax, differentiated along time, location and environmental aspects has been announced, and implementation will start in 2011/2012. Part of the fixed purchase tax on passenger cars will be replaced with a price per kilometre.
- *Improve driving behaviour*. The Ecodriving programme will be continued, not only for passenger cars, but also for freight transport.
- *Improve vehicle efficiency.* Here the programme links up to proposed Community strategy on CO_2 emissions from light duty vehicles. The Dutch ambition is to achieve average CO_2 emissions of 120-130 gr/km for new cars in 2012, and 80 gr/km in 2020, and comparable levels for vans. Furthermore, fiscal incentives are proposed to encourage the purchase of efficient cars, and innovative public bus transport will be stimulated.
- *Use low carbon fuels*. A 20% biofuels share in transport fuels will be investigated. This would double the 10% target set in the EU energy and climate policy package of January 2008 (EC, 2008). Strong measures will be implemented for the introduction of 2^{nd} generation biofuels. Other alternative fuels, including natural gas, will also be stimulated.

On top of these measures, the programme announces the innovation programme ‘Car of the Future’ which aims at accelerating the market penetration of innovative technologies, such as plug-in hybrids or fuel cell cars for sustainable mobility. In this paper, we quantify the emission reduction and costs of several innovations in fuels and drive trains, combined in two distinct innovation scenarios.

2. DESCRIPTION OF SCENARIOS

In the context of the Dutch road transport sector, the two innovation scenarios illustrate the prospects of technical innovations in drive trains and alternative fuels. The options considered are (plug-in) hybrids, efficient tyres, energy saving ICT, biofuels, CNG/biogas and hydrogen. The scenarios have each been based on an ambitious, but considered realistic, coherent vision of the future road transport sector in which innovation will be one of the key elements to further reduce CO_2 emissions.

For the innovation scenarios, the energy use and CO_2 emissions of road transport will be compared to the reference scenario, representing the implementation of the most important measures from Clean & Efficient, assuming the CO_2 regulation for cars is only implemented in 2015, and a moderate oil price[1]. These have been calculated with the TEMPO simulation model (Transport Emission Model for POlicy evaluation) for sight years 2020 and 2030. The model includes the vehicle stock and indicates what penetration rates could be realisable. The following scenarios have been developed.

Table 1 Scenario overview

Clean and Efficient policy scenario with moderate EU policy	Scenario 1: generic innovation in the Netherlands and the EU	Scenario 2: specific innovation (hydrogen) in the Netherlands and the EU
Policy as announced in the Dutch programme 'Clean and Efficient': • Road pricing • European CO_2 regulation for passenger cars at 130 g/km in 2015, moderate CO_2 regulation for vans • Fiscal measures, e.g. for drivers of company cars and registration tax differentiation • Promotion of ecodriving	This scenario includes the following, on top of the 'Clean and Efficient policy': • Large penetration of hybrid cars; in 2020 is over 80% of newly sold cars a hybrid; 9% of these is a plug-in hybrid • CNG for vans and buses • Limited number of hydrogen buses • Heavy duty vehicles: 15% hybrids	This scenario includes the following, on top of the 'Clean and Efficient policy': • Quick market penetration of the fuel cell car (20% in 2030) • Hydrogen in vans and buses • 60% of newly sold cars is hybrid in 2020, 8% of these is plug-in hybrid. • Heavy duty vehicles: 15% hybrids
Biofuels[2]: 10% in 2020 and beyond	20% in 2020, 30% in 2030	15% in 2020, 20% in 2030
Efficient tyres: 25% at passenger cars	Market share efficient tyres and energy saving ICT of 50% in 2020 increasing to over 90% (tyres) and 75% (ICT)	Complete penetration of efficient tyres in 2030, high penetration of energy saving ICT (90% in 2030)

The first innovation scenario corresponds to the situation in which innovation is considered important at national and European level. Due to lack of strong and coordinated (focussed) policies, the barriers for major breakthroughs such as hydrogen and/or all-electric transport have not been successfully removed. Other 'easier-to-implement' energy saving innovative technologies, including hybridization, have been successfully stimulated. Also biofuels play a substantial role in pursuing emission reductions, assuming possible negative side effects can be minimized by having more emphasis on 2nd generation fuels after 2015, combined with additional policies on sustainability.

The second innovation scenario assumes a similar ambition level for innovation, but accompanied with a strong and focussed approach at European level, that results in the breakthrough of hydrogen in the road transport sector. For this scenario, the hydrogen fuel cell technology was selected, assuming the required technological breakthroughs including a smooth transition (including infrastructure) all succeed. An alternative scenario in which all-electric transport (instead of hydrogen) breaks through is currently under investigation and will be published in a follow-up study as a separate innovation scenario (scenario 3).

The detailed modelling of the vehicle stock, including their replacement, guarantees a realistic penetration of the new technologies. For hydrogen, the market share of 20% in the amount of kilometres travelled of passenger cars, is the result of an ambitiously, but perceived realistic, increased market share in newly sold passenger cars from 0% in 2015, via 15% in 2020 to 30% in 2030 for original petrol car drivers. For original diesel car drivers a slightly slower penetration is used (5% in 2020, 25% in 2030).

3. EMISSION REDUCTION

Figure 1 presents the direct CO_2 emissions under different scenarios based on the IPCC methodology, where the 'well-to-tank' emissions of production and transport of (bio)fuels are not ascribed to the transport sector. If both Dutch and European policy stimulate innovation and achieve the market penetrations assumed in these scenarios, the CO_2 emissions of road transport can be reduced with some 6 Mton in 2020, and about 13 Mton in 2030. The largest emission reductions are achieved with passenger cars, followed by delivery vans. In relative terms, buses show the largest emission reductions, because alternative fuels and drive trains can be introduced relatively easy in captive fleets.

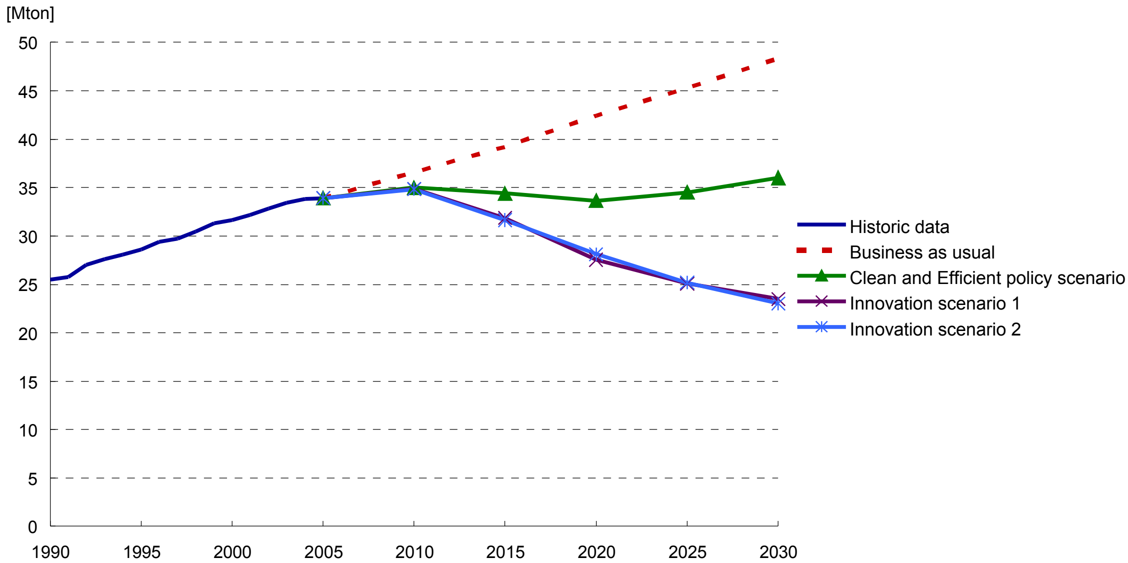

Figure 1 CO_2 emission road transport

The direct CO_2 emissions, also referred to as tank-to-wheel emissions, have been determined using the CO_2 emission factors of the involved fuels. One special case concerns biofuels. For biofuels the direct CO_2 emissions are considered zero as, like all biomass-based options, the CO_2 that is emitted when combusting biofuels has shortly before been stored in organic matter. To assess the system-wide impact on CO_2 emissions caused by the road transport sector, also the indirect emissions caused during the production chain of the involved fuels should be considered. These 'well-to-tank' emissions include the emissions from mining, production, conversion and distribution of the transport fuel.

For our study, an additional analysis was made on total well-to-wheel CO_2 emissions of the Dutch road transport sector. The results are analogous to the direct CO_2 emissions: although the absolute level of emissions is about 6 Mton higher for the complete road transport sector, the expected emission reductions are only slightly higher (0-0.5 Mton). The reason for this is that the two alternative fuels with increasing market share (biofuels and hydrogen) have well-to-tank emissions that are comparable to the current fossil fuels they replace. These results could change in case more CO_2 intensive production routes are chosen than the ones used in our scenarios, a large share of 2nd generation biofuels, and hydrogen production based on natural gas with application of CCS.

Table 1 shows the emission reduction due to innovations per traffic mode. Although quite similar, the reductions per traffic mode slightly differ between the two innovation scenarios, and therefore a range is provided for the reduction. Some conclusions based on the table:

- Innovations in the passenger car stock, including fuel substitution, provide the largest emission reduction, about 60% of the total emission reduction. The main reason is the stronger penetration and higher saving potential of the energy saving technologies (hybridisation, tyres and ICT) compared to other transport modes.
- Although delivery vans have relatively similar reductions as passenger cars, they provide, due to their smaller share in the overall emissions, only 15% to 20% of the total emission reduction, comparable to their emission share in the reference scenario.
- Trucks (including lorries) account almost completely for the remaining part of the total emission reduction (15% to 20%), as buses have a really small share in the total emissions of transport.

The following table summarizes the average emission reduction per traffic mode, the percentages provide the relative reduction within the traffic mode's emissions compared to their emissions in the reference scenario for the same year.

Table 2 Direct CO_2 emission reduction by modes

	2020			2030		
Traffic mode	Reference emission [Mton]	Reduction by innovation per traffic mode [%]	[Mton]	Reference emission [Mton]	Reduction by innovation per traffic mode [%]	[Mton]
Passenger car	17.5	15-20	3	17.5	40-45	7
Delivery van	6	20-25	1	7	40-45	3
Truck	9	10-15	1	10.5	20-30	2
Bus	0.5	25-30	0.1	0.5	40-60	0.3
Total	33	15-20	5-6	36	35-40	12-13

For all traffic modes except for trucks, the maximum of the provided range for the reduction corresponds to the reduction achieved in innovation scenario 2. Only for trucks, innovation scenario 1 provides the largest reduction as result of the higher biofuel share. Note that for both scenarios and for all traffic modes the emission reductions roughly double between 2020 and 2030.

A separate sensitivity analysis showed that a substantial part of the emission reduction - some 2 Mton (15%) - can be allocated to the fuel savings resulting from efficient tyres and ICT. These two innovations can be implemented for all transport modes and already have a substantial penetration as of 2020.

4. COSTS AND BENEFITS

To complete our study with an assessment of the financial impact of innovation, an analysis was made on the costs and benefits of the innovation scenarios. This analysis was based on the *National costs* approach (VROM, 1998), ignoring any financial transfers between government and other actors (e.g. subsidies and taxes). Only two cost components were included: vehicle costs and fuel.

The vehicle costs have been determined based on literature and are documented in (Uyterlinde et al, 2008). It should be noted that for some technologies, cost ranges of 30%-50% were found, indicating that the results should be used carefully. For new technologies estimates were made for cost reductions as result of economies of scale and further progress on the learning curve based on the scenario characteristics. Investments were annualized by depreciation factors (10 years, discount rate 4%).

Fuel prices (excluding taxes) were based on oil price projections ranging from 65-70 USD_{2007}/barrel between 2020-2030, resulting in gasoline and diesel prices of 10% below 2007 levels (see also the sensitivity analysis further below). Other variable costs such as maintenance and insurance were not assessed given their uncertainty in combination with their order of magnitude; no substantial impact on the results was expected

Figure 2 shows that the annual fuel costs of both innovation scenarios, is lower than the reference scenario. The reason for this is that the lower fuel consumption resulting from the energy saving measures, outweighs the additional cost as result of more expensive alternative fuels. In 2030, the yearly savings on fuel consumption are about 10% (0.7 bln $€_{2005}$) of the fuel costs of the reference scenario for the same year.

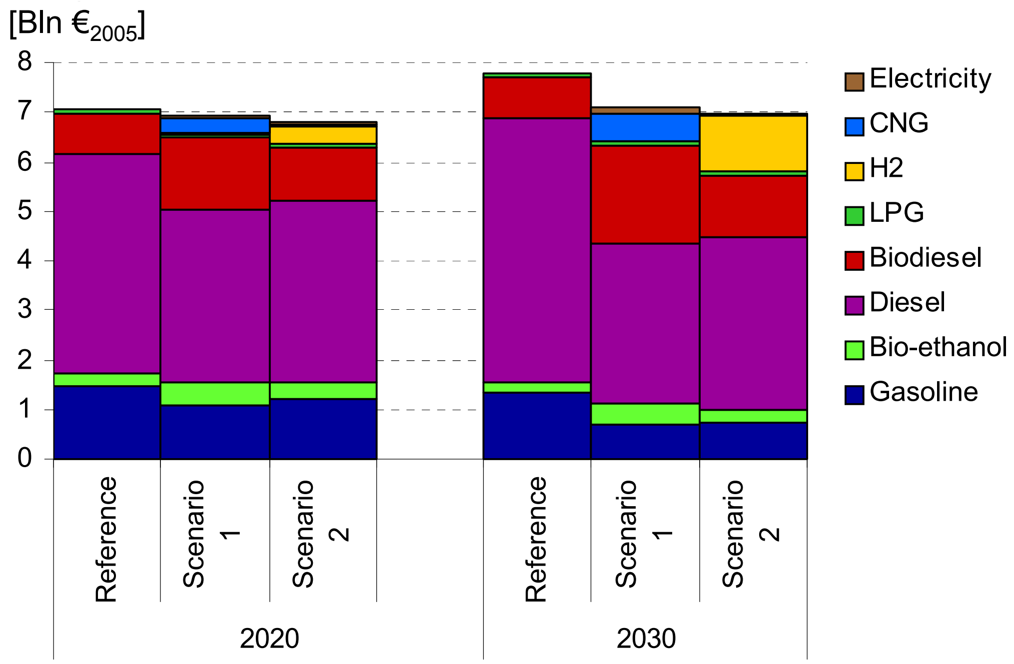

Figure 2 Annual fuel costs road transport

Figure 3 provides an overview of the additional cost for vehicles. For both innovations the additional vehicle costs correspond to € 2 bln, about 12% of the average yearly vehicle costs of the reference scenario. This also includes the costs of energy saving ICT and fuel efficient tyres. In innovation scenario 1, the major part of the additional costs are related to the hybridisation, leaving a small share for CNG vehicles. In scenario 2, the additional costs are almost equally shared between hybrids and hydrogen fuel cell vehicles.

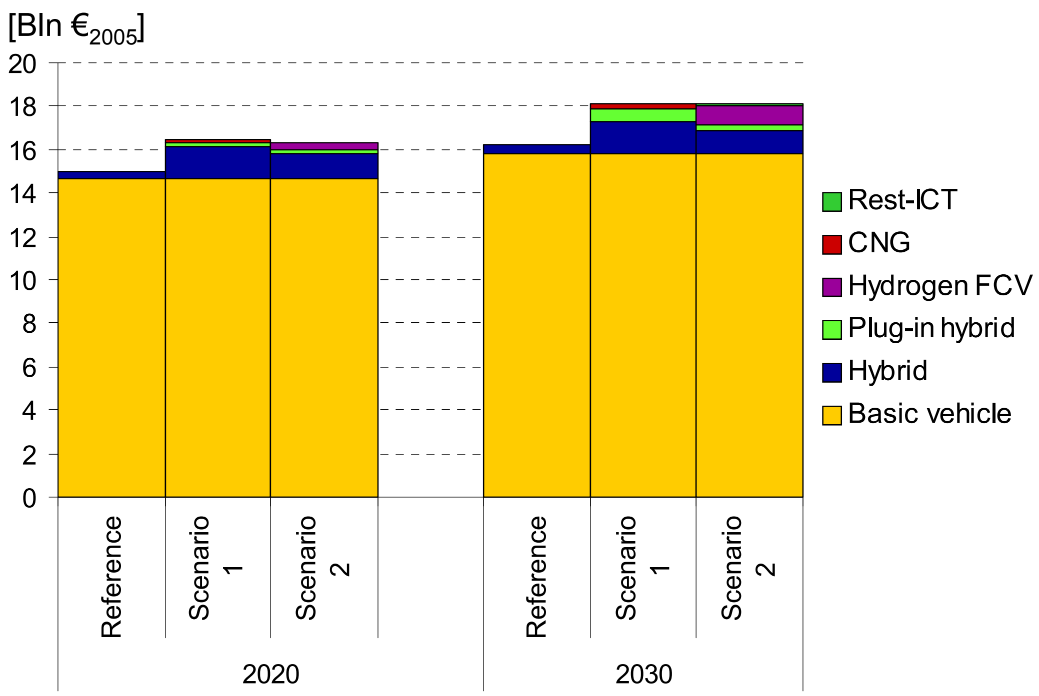

Figure 3 Annual costs vehicle stock[3]

By deducting the expected fuel savings from the additional vehicle costs, the overall costs of the innovation scenarios are obtained. These additional costs vary, dependent on the chosen innovation scenario and sight year, between € 1.1 bln and € 1.4 bln per year.

The above cost analysis excludes a number of benefits that are harder to quantify such as:

- Local air quality: positive effect of fuel savings on emissions of NO_x, SO_x etc.
- Reduced dependency on fossil fuels.
- Improved comfort and safety (ICT, fuel cell, hybrid).

Without including these benefits, the cost effectiveness of innovation from a national cost perspective is about € 200 / ton avoided CO_2 in 2020. It improves further to about € 100 / ton avoided CO_2 in 2030, mainly as result of decreasing vehicle costs for the new technologies. Dependent on how the innovation is supported by government, the cost effectiveness from an end-consumer perspective might even be lower. Note that these cost effectiveness values are based on a mix of measures, and are not one-on-one comparable to other studies without a more detailed analysis.

Two separate sensitivity analyses were done to assess some of the uncertainties underlying the cost analysis shown above.

First, with respect to the uncertainty around the future vehicle costs, which are based on a European wide breakthrough of the technologies. If solely The Netherlands would pursue innovation, the technological learning and economy of scale advantages would take place at a much slower rate. A sensitivity analysis showed that in this situation the cost effectiveness would be around € 175 / ton avoided CO_2 in 2030.

Second, the cost effectiveness has been determined for the situation in which the future prices of crude oil and natural gas are 50% higher than those currently used. Based on this price increase, the fuel costs of all fuels were reassessed, leading to limited cost increases for biofuels and electricity (3% to 5%)[4], and substantial cost increases for the other fuels including hydrogen (25% to 35%). Using these new prices to value the already estimated fuel savings of the innovation scenarios the cost effectiveness improved to € 50 / ton CO_2 in 2030 (€ 160 in 2020). Note that this excludes the effects of a possible reduction of traffic given the increased prices.

5. STRATEGIC CHOICES

Stimulating innovation is particularly important from a long term perspective. Setting up a new fuel distribution infrastructure and having new vehicle types penetrate the current stock takes a considerable amount of time. Even in the innovation scenarios, by 2030, 60-70% of the transport fuel demand is still based on gasoline, diesel or LPG. Although, as shown in Figure 1, the two innovation scenarios appear to achieve comparable emission reductions in the period until 2030, the long term perspective of these scenarios greatly differs.

Scenario 1, *generic innovation*, remains dominated by the internal combustion engine, implying a large dependency on alternative fuels, such as biofuels, biogas and fossil alternatives such as CNG. This scenario illustrates the quick impact of introducing cleaner fuels in the current vehicle stock, because biofuels are the only fuel substitution option that hardly requires any changes in fuel distribution infrastructure and in vehicle technologies. However, after 2030, there is not much potential for further emission reduction along the fuel substitution route. A share of biofuels far above the projected 30% in 2030 is not likely, because of the expected pressure on the availability of sustainably grown biomass due to food-fuel issues and indirect land use change impacts. Moreover, the price of CNG might continue to increase, linked to the natural gas and possibly the oil price. All in all, stronger emission reductions beyond 2030 would have to come from energy efficient vehicle technology or a switch to electricity or hydrogen after all.

Scenario 2, *technology specific innovation*, on the other hand, offers a better long term perspective. The production of hydrogen is flexible in feedstock choice and therefore more suitable for diversification of energy sources. The costs of hydrogen production are relatively stable, because the costs of production from coal or natural gas with CCS are comparable with those based on biomass. (Hyways, 2007) If, conform the assumptions in this scenario, the costs of driving a fuel cell car in 2030 are comparable to those of a regular car, the share of fuel cell cars could increase quickly in the years beyond, which would have sizable climate mitigation and environmental benefits.

The study gives rise to several observations, which may provide direction to strategic choices and prioritization of policies. As already indicated before, policy should aim at reducing emissions of passenger cars and vans, because these amount to 75% of today's CO_2 emissions in Dutch road transport. Particularly for vans, there is untapped energy saving potential, because until now no specific policies are in place for this mode. For buses, on the other hand, the reduction potential may be limited in absolute terms, but as captive fleets, they provide a strategic innovation niche in which experience can be gained with new fuels and drive trains. Moreover, the air quality in cities provides an additional incentive to speed up the introduction of sustainable public bus transport.

Furthermore, options such as efficient tyres, biofuels, and energy efficient ICT can be introduced on short notice, and implemented in the complete vehicle stock, thereby having a relatively large impact in absolute terms. Last but not least, demand reduction should always have priority, because less fuel is needed to satisfy the remaining demand.

The Netherlands relies partly on European policies for achieving a more sustainable road transport sector. The efficiency of the Dutch vehicle stock will depend on the pace and extent to which CO_2 regulation is introduced by the European Commission. At the time of writing, the European Parliament is discussing the concrete implementation and time frame of these binding CO_2 regulations. This is a lengthy process with high stakes for the car industry. The Dutch government can use fiscal incentives to stimulate the purchase of the most efficient models within the European supply of cars. European coordination is also needed to ensure the availability of flexifuel cars on the market, allowing the use of high blends of bioethanol.

6. CONCLUDING REMARKS

We conclude that technical innovations in drive trains and alternative fuels can achieve substantial CO_2 emission reductions in the Dutch road transport sector. Innovation scenario 1 builds on technologies already on the market, or close to the market, and is therefore less uncertain than the 'hydrogen scenario'. However, it heavily relies on biofuels, of which the sustainability is only assured under strict conditions. Due to the limited potential for biofuels, and its suitability for freight transport, further emission reduction in passenger cars will probably require a successful market introduction of either hydrogen or electric vehicles.

Since it takes 20-30 years to really achieve a transition towards a more sustainable transport sector, early action is necessary, but should be based on a long-term strategy with clear priorities. This requires a balancing of different policy objectives, such as CO_2 emissions reduction, energy savings, air quality and reduction of the dependency on imported oil. It also requires an international effort to stimulate innovation at a scale sufficiently large to induce technology learning and thus cost decreases.

7. REFERENCES

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8. NOTES

[1] Results of a sensitivity analysis on high oil prices are given in paragraph 1.4.
[2] Expressed as share of total gasoline and diesel volume including biofuels (i.e. excluding other alternative fuels).
[3] Costs for ICT have been included in the additional costs for alternative technologies (e.g. hybrid or CNG). For cars that are replaced by a car without an alternative drive train and/or fuel, the additional costs for ICT improvements have been grouped under Rest-ICT.
[4] For biofuels the impact of the fossil fuel price is limited, given the relative share of energy costs in the total production costs. For electricity the large cost component related to the distribution reduces the price impact.