EU Transport GHG: Routes to 2050?

Identifying transport's potential contributions to future GHG reduction

Magdalena Jozwicka and Tinus Pulles (TNO)

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This paper analyses existing scenarios with time horizons of 2050 and beyond as a starting point for the analyses on specific developments in the transport sector. The paper starts from the scenarios of the latest IPCC assessment report as developed in the IPCC Special Report on Emission Scenarios and links these to the transport scenarios as developed by in the latest IEA Energy Technology Perspectives report.

The paper derives the emission reductions that are needed in the transport sector against the background of the developments in other sectors and source categories. The paper clearly shows that additional measures are needed above those assumed in the respective scenarios, to meet the ambitious targets of overall 80% reductions of greenhouse gas emissions, relative to 1990, that are foreseen for 2050.

1 Introduction

Since 1990, the transport sector's carbon dioxide (CO_2) emissions worldwide have increased by 36%. In 2005, transport accounted for 23% of global energy-related CO_2 emissions, up from 21% in 1990. On a well-to-wheel basis (*i.e.* including emissions from feedstock and fuel production and distribution to vehicles) transport's greenhouse gas (GHG) emissions account for close to 27% of total emissions[1].

The transport sector's projected emissions overtake the emissions reductions required across the whole EU economy (assuming that the EU sets a GHG reduction target of at least 60% compared to 1990) within the timescale of this project. By sector, GHG emissions from transport are proving to be the most problematic. Transport's growth in GHG emissions is already proving to be challenging for many Member States in meeting their GHG reduction targets under the 1997 Kyoto Protocol[2].

Looking further ahead, as EU leaders have taken the unilateral decision to commit to a new target of 20% GHG reduction compared to 1990 by 2020, and have pledged to increase this to 30% if other countries follow suit, then the pressure on the transport sector to reduce its GHG emissions is going to increase. In the longer-term, emission reductions of at least 60% by 2050 have been proposed (e.g. by the IPCC[3]). To date GHG emissions have been reduced in other sectors of the economy and, while some policies are addressing transport's GHG emissions, there will come a time when emissions from transport will have to be addressed in a more comprehensive manner. The required reductions depend in part on what is possible within the transport sector at different abatement cost levels and in part on what other sectors can contribute to meeting the overall targets.

However, the possible GHG reductions in the non-transport sectors that will be needed to comply with the overall reduction target are dependent on the success of the revised EU Emissions Trading Scheme (ETS), the implementation of the Renewable Energy Packages and energy efficiency measures, etc[4]. Or put another way: the potential emission reductions in the transport sector will have an impact on the need for ETS, renewables and energy efficiency to deliver more or less than expected. In other words, we are talking here about a "reservoir" of necessary emission reductions and when one sector cannot deliver an equal share, all other sectors need to deliver more or can jointly deliver less.

This paper is a deliverable under Task 2 of the *EU Transport GHG: Routes to 2050?* project. It was presented at the first stakeholder event on 27 March 2009 in Brussels and was subsequently subject to minor amendments. It aims to quantify, as far as is possible, these interrelated sectoral emission reduction targets in the context of potential EU economy-wide GHG reduction targets for 2050. At this stage, it is fundamental to understand the broader context in which transport GHG emissions will have to be reduced.

Furthermore, the aim is to identify transport's, as well as other sectors', potential contributions to these emission reductions by identifying what is happening, and what might happen, in terms of GHG emissions reductions in these economic sectors. Moreover, it is important to identify what the introduction of long-term reduction targets might mean for transport in reference to the recent and possibly continuing reduction in emissions from other sectors. The role that transport should play in this context will also be investigated.

As already mentioned, fossil fuels are the main source of CO_2 emissions. Therefore, it is expected that future CO_2 emission levels will depend primarily on the total fossil energy

[1] IEA (2008), Energy Technology Perspectives - Scenarios & Strategies to 2050.
[2] http://themes.eea.europa.eu/Sectors_and_activities/transport/indicators/TERM02,2006.12
[3] http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter12.pdf
[4] It is worth noting that the Renewables Directive contains a 10% target for renewables for transport for 2020.

consumption and the structure of energy supply, with some additional possibilities to limit CO_2 emissions by Carbon Capture and Storage (CCS) at large point sources.

In order to meet the task's objectives a scenario analysis approach was chosen. This exercise is based on investigation of the IPCC energy scenarios and the IEA ETP BLUE scenarios while linking the storylines of both scenario approaches. The results are compared with the potential EU 2050 economy-wide emission reduction targets. This is a top-down approach which quantifies the available amount of transportation within future existing energy in relation to the long term CO_2 targets and expected developments in other sectors.

The paper helps to understand the broader context in which transport GHG emissions will have to be reduced and gives an overview of available transport related scenarios. First, the paper analyses and describes the two main energy scenario approaches which were presented by IEA ETP and IPCC SRES. In comparing the philosophies underlying these scenarios, we were able to quantify the energy use and GHG emissions for the EU-27. These results were then compared to the trends in transportation growth and CO_2 emissions from transport growth. This information helped in the assessment of whether additional effort is needed to meet potential EU 2050 targets.

2 Brief review of the IPCC SRES scenarios

2.1 Introduction & storylines description

The IPCC developed a set of emissions scenarios which are described in its Special Report on Emission Scenarios (SRES)[5]. These scenarios cover a wide range of developments of the main driving forces of future emissions, from demographic to technological and economic developments that might influence GHG sources and sinks. The approach involved the development of a set of four alternative scenario 'families', each based on a different storyline, comprising 40 SRES scenarios subdivided into seven scenario groups. Within each of the families a so-called marker scenario is defined as a typical representative of this scenario family. For each storyline, one modelling group was given principal responsibility, and the quantification produced by that group is referred to as the "marker scenario" for that storyline.

None of the scenarios in the set includes any future policies that explicitly address additional climate change initiatives, GHG emissions are directly affected by non-climate change policies designed for a wide range of other purpose[5]. This makes these scenarios in principle fit for purpose to study different policy options for transport against a background of general developments. Each scenario however implicitly assumes autonomous technology developments that might include transport options.

Each storyline assumes a distinctly different direction for future developments, such that the four storylines differ in increasingly irreversible ways. Together they describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces.

- The A1 storyline and scenario family describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. The A1 scenario family develops into four groups that describe alternative directions of technological change in the energy system. A1B-AIM is the marker scenario.
- The A2 storyline and scenario family describes a very heterogeneous world with high population growth. The underlying theme is self-reliance and preservation of local identities. Economic development is primarily regionally oriented and per capita

[5] IPCC (2000), IPCC Special Report on Emissions Scenarios (http://www.ipcc.ch/ipccreports/sres/emission/010.htm)

economic growth and technological changes are more fragmented and slower than in other storylines. A2-ASF is the marker scenario.

- The B1 storyline and scenario family describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives. B1-IMAGE is the marker scenario.
- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels. B2-MESSAGE is the marker scenario.

Table 1 Overview of SRES scenarios quantification[5]

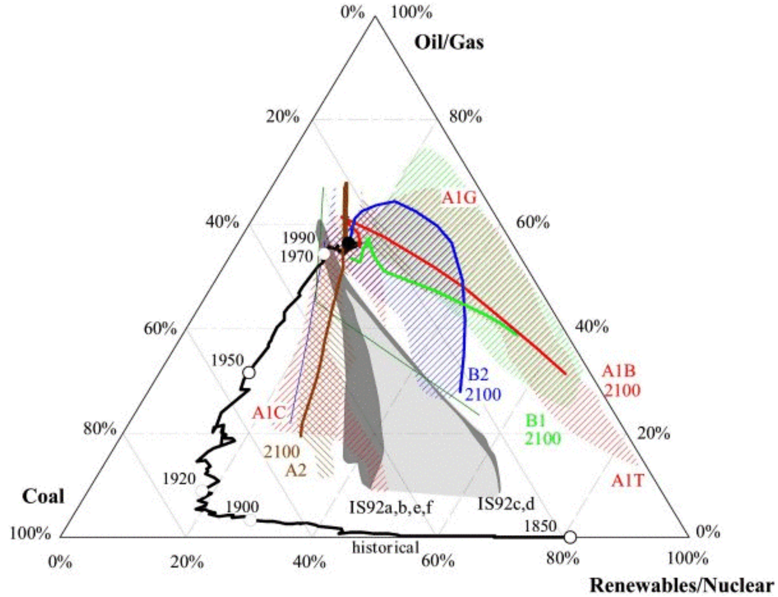
Family	A1				A2	B1	B2
Scenario Group	**A1C**	**A1G**	**A1B**	**A1T**	**A2**	**B1**	**B2**
Scenario characteristics:							
Population growth	low	low	low	low	high	low	medium
GDP growth	very high	very high	very high	very high	medium	high	medium
Energy use	very high	very high	very high	high	high	low	medium
Land- use changes	low-medium	low-medium	low	low	medium/high	high	medium
Resource availability	high	high	medium	medium	low	low	medium
Pace and direction of technological	rapid	rapid	rapid	rapid	slow	medium	medium
change favouring	coal	oil & gas	balanced	non-fossils	regional	efficiency & dematerialization	"dynamics as usual"

Source: IPCC (2000), IPCC Special Report on Emissions Scenarios (Table 4-2)

2.2 Structure of Energy Use

Figure 1 illustrates global primary energy structure, shares (%) of oil and gas, coal, and non-fossil (zero-carbon) energy sources over time and future changes in SRES scenarios. Each corner of the triangle corresponds to a hypothetical situation in which all primary energy is supplied by a single source – oil/gas on the top, coal to the left, and non-fossil sources (renewables and nuclear) to the right. Constant market shares of these energies are denoted by their respective isoshare lines. For 1990 to 2100, alternative trajectories show the changes in the energy systems structures across SRES scenarios. They are grouped by shaded areas for the scenario families A1, A2, B1, and B2 with respective markers shown as lines.

Figure 1 Global primary energy structure[5]



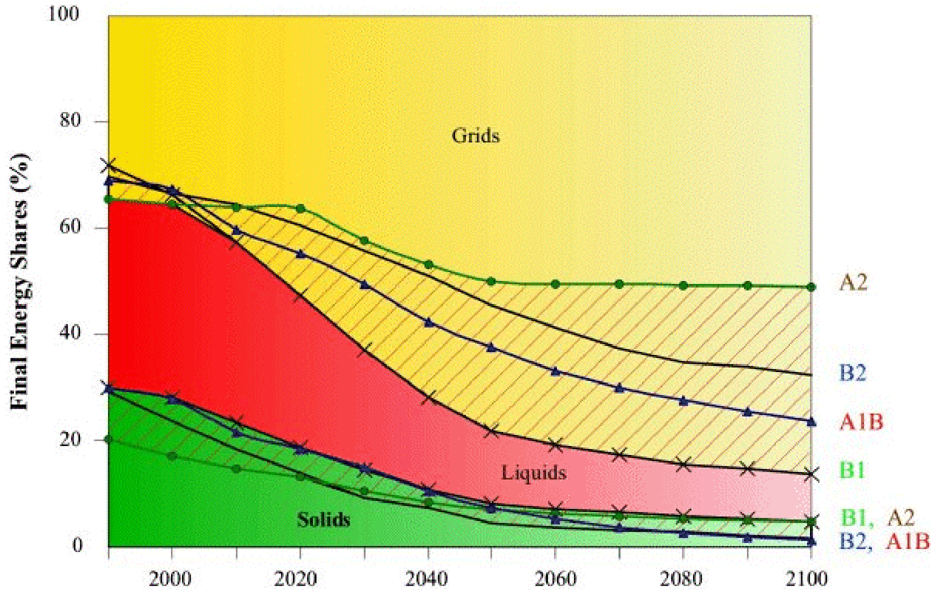
Source: IPCC (2000), IPCC Special Report on Emissions Scenarios (Figure 6-3)

Historically, the primary energy structure has evolved clockwise according to the two "grand transitions" that are shown by the two segments of the "thick black" curve. From 1850 to 1920 the first transition can be characterized as the substitution of traditional (non-fossil) energy sources by coal. The share of coal increased from 20% to about 70%, while the share of non-fossils declined from 80% to about 20%. The second transition, from 1920 to 1990, can be characterized as the replacement of coal by oil and gas (while the share of non-fossils remained essentially constant). The share of oil and gas increased to about 50% and the share of coal declined to about 30%

The SRES scenarios cover a wide range of energy structures that reflects advances in knowledge on the uncertainty ranges of future fossil resource availability and technological change. Scenarios B1, B2, A1T, and to some extent A1B follow a trend toward increasing shares of zero-carbon options in the long term. A1G more or less follows an oil-gas isoshare line that perpetuates the current dominance of oil and gas in the global energy balance far into the 21st century. Scenarios in group A1C indicate a near doubling of coal's share in primary energy use. Also of interest is the trajectory of the A2 marker scenario, which returns in its energy structure by 2100 (over 50% coal share) to the situation that prevailed almost 200 years before (i.e., around 1900). However, even with similar fuel shares, the technologies, end-use fuels, and applications projected in the A2 scenario are radically different from those of the past.

An interesting observation (considering the SRES multi-model approach) is that the changes in structure of final energy are similar in the four marker scenarios of the SRES scenario families, even though these are derived from four different modelling approaches and describe very different futures in terms of demographic, socio-economic, and energy development (see Figure 2).

Figure 2 World final energy (%) by form of delivery* [5]



* Direct use of solids, direct use of liquids, and delivery of grids (gas, district heat, electricity, and hydrogen) for the four SRES marker scenarios. Overlapping shaded areas indicate variation across the four marker scenarios. Liquids include oil products, methanol, and ethanol. Solids include coal and biomass.

The trend is toward energy reaching the consumer in more flexible, more convenient, and cleaner forms. This reflects that people with higher incomes are willing to pay more for more convenient energy forms (e.g., even if coal were cheaper than gas, everybody would rather heat with gas than coal). Therefore, the final energy mix is characterized by growing importance and dominance of grid-dependent fuels, such as electricity, district heat, and gas. Consistent with the storylines and the higher income levels of A1 and B1, this change in final energy structure is faster in these scenario families than in the other two scenario families. The structural shift is slowest in scenario A2, with scenario B2 taking an intermediate position. These scenario differences mainly reflect differences in per capita income levels.

2.3 Primary and final energy use by fuel

For the purpose of this paper, primary energy use in the EU 27 for the four SRES marker scenarios was derived from energy scenario data for the combined OECD90 and REF regions in the SRES report[6]. We assume homogenous per capita energy consumption over the whole of the Annex 1 parties[7]. The EU 27 population is 492 million or 41% of the Annex 1 population[8,9]. These figures are used in the subsequent analysis to re-estimate the numbers for Annex 1 countries for the estimates for the EU-27 countries. Table 2 presents recalculated final and primary energy use in 2050 for the EU-27 countries.

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[6] For the purpose of this paper it was calculated that in 2005 all countries, which were included in OECD90 and REF but not in Annex I, were responsible for 1.3% of the world final energy use. It means that error introduced with the assumption that OECD90+REF= ~Annex I for estimating the share of EU-27 is considered to be acceptable. Please see Appendix I for the world region definition and Appendix II for the final and primary energy use.

[7] This means that every citizen of every country included in Annex I consumes the same amount of energy.

[8] National submissions to UNFCCC for the 25 EU Annex I parties (excludes Malta and Cyprus)

[9] IEA Energy database (http://www.iea.org/Textbase/stats/index.asp)

Table 2 Final and primary energy use in 2050 for marker scenarios[5]

EU 27		A1 AIM	A2 ASF	B1 IMAGE	B2 MESSAGE
Final Energy [EJ]					
	Non-commercial	0	0	2	0
	Solids	4	10	4	0
	Liquids	34	45	17	39
	Gas	47	32	15	23
	Electricity	40	32	32	32
	Others	0	0	10	9
	Total	125	120	80	104
Primary Energy [EJ]					
	Coal	16	47	16	13
	Oil	25	29	24	35
	Gas	62	45	23	62
	Nuclear	14	11	17	8
	Biomass	15	10	11	6
	Other Renewables	21	6	5	14
	Total	153	149	95	138
WORLD	Primary energy use	1347 (913-1611)	971 (679-1059)	813 (642-1090)	869 (679-966)

Source: Calculation for the need of this report based on IPCC (2000), IPCC Special Report on Emissions Scenarios (Appendix VII)

2.4 General assumption for transport

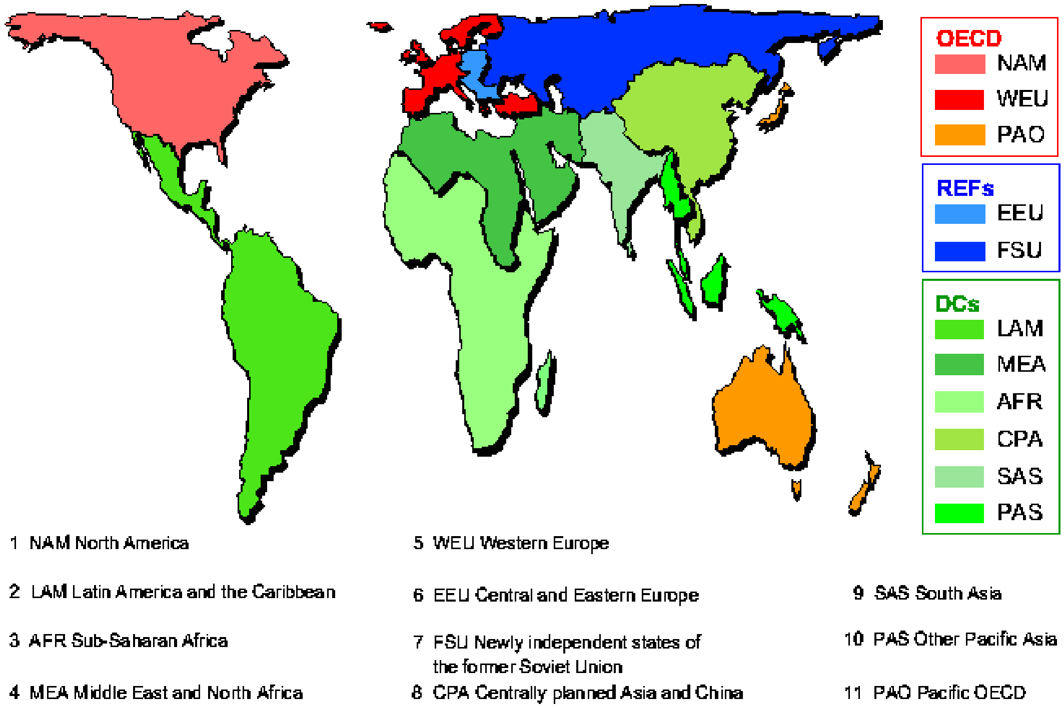
As, the SRES scenarios make no specific assumptions for transport, it is necessary to refer to other scenarios in other to obtain information on transport. Our starting point, in this respect, is a set of scenarios developed by IIASA (which are part of SRES scenarios). Moreover, as the next step, the scenarios of IEA ETP will be used. It is also worth noting, however, that UNFCCC transport categories cover civil aviation, road transport, railways and navigation and not international bunker fuels. Given that the use of the latter are also growing, then transport GHG emissions in total are likely to be even higher than the emissions presented later in this report.

2.4.1 Final energy consumption in transport based on IIASA scenarios

For application in European studies, IIASA has developed a series of scenarios [[10]] that to a certain extent are consistent with the IPCC scenarios but provide more detail at the level of the European Union. Figure 3 provides the geographical regions as defined in the IIASA scenarios.

[10] WEC/IIASA (1998), Global energy perspectives to 2050 and beyond, World Energy Council, London.

Figure 3 World region used in the IIASA study[10]



Source: http://www.iiasa.ac.at/Research/ECS/docs/book_st/node1.html

In the IIASA scenarios three cases of future developments are presented: Case A, B and C. The key basic assumptions for the driving forces are presented in the Table 3 below.

- The high-growth Case A presents a future of high resource availability, high technology dynamics at low technology cost. It includes three scenarios:
  - A1 focuses on tapping the vast potential of conventional and unconventional oil and gas occurrences.
  - Scenario A2, on the other hand, is a world in which the global warming debate is resolved in favour of coal; so it is assumed that coal gasification and liquefaction are applied at a large scale.
  - A3 (Bio-Nuc) relies mainly on biomass, other renewables, nuclear energy, and natural gas.
- The single scenario of Case B is more modest in economic growth and technological development, and in several aspects could be considered to lie between Cases A and C.
- Case C is as optimistic about technology as Case A, in particular about non-fossil fuels, but unlike Case A it assumes unprecedented progressive international cooperation focused explicitly on environmental protection and on international equity, and on policies to reduce carbon emissions in 2100 to one third of today's level. There are two scenarios:
  - C1 presuming a slow phasing out of nuclear power, and
  - C2 with a nuclear share comparable to the scenarios of Case A3.

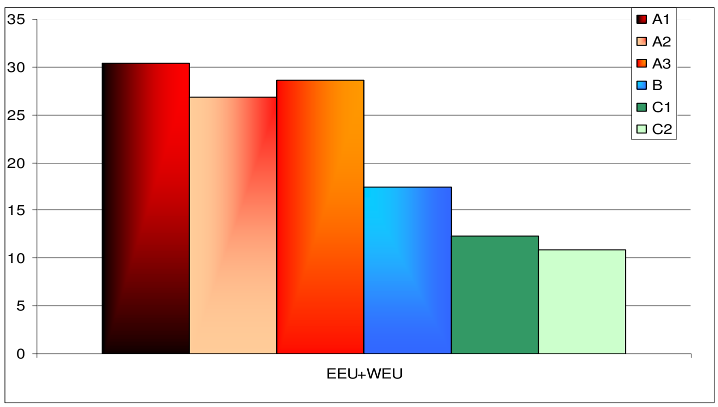
The IIASA scenarios provide estimates for energy use in the transport sector (see Table 3).

Table 3 IIASA scenario assumptions[10]]

	Case A High Growth	Case B Middle Course	Case C Ecologically Driven
World population	10.1×10^9	10.1×10^9	10.1×10^9
GWP (Gross World Product), trillion US(1990)$ in 2050	100	75	75
Global primary energy intensity improvement, percent, per year 1990 to 2050	-0.9	-0.8	-1.4
Primary energy demand, Gtoe (Gigatonnes oil equivalent) in 2050	25	20	14
CO_2 emission constraint	No	No	Yes

Source: based on WEC/IIASA (1998), Global energy perspectives to 2050 and beyond, World Energy Council, London (table 2.1)

Figure 4 Final energy consumption in transport [EJ] in 2050 for different scenarios[10]



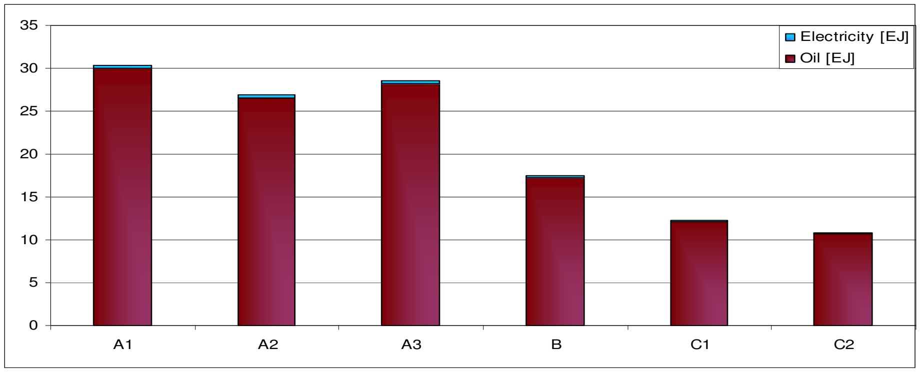
Source: Made for the purpose of this paper, based on information from: WEC/IIASA (1998), Global energy perspectives to 2050 and beyond, World Energy Council, London.

2.4.2 Final energy consumption in Transport (Electricity and Oil) based on EPA 98 scenarios.

The U.S. Environmental Protection Agency (EPA) made scenarios for final energy consumption in transport (electricity and oil) for 2050[11]. For the purpose of this paper the simple analysis was done. The results show that the transport sector will be driven almost completely by oil.

[11] EPA (1998), Alexei Sankovski, ICF's unpublished data file.

Figure 5 Distribution of total energy consumption in transport in 2050 for EU34 (EEU+WEU)[11]



This section gave an overview of the possible energy consumption and energy distribution in 2050. Further, the energy consumption in transport was introduced and analyzed. However, this does not enable us to draw a conclusion about the GHG emissions from transport in 2050. So it was needed to examine other group of scenarios which more detailed look into transport assumptions.

3 Brief review of the IEA ETP scenarios

3.1 Introduction

The IEA study "Energy Technology Perspectives – Scenarios & Strategies to 2050" (ETP[1]) presents an in-depth review of the status and outlook for existing and advanced clean energy technologies. The report offers scenario analyses on how a mix of these technologies can make the difference. Several scenarios are presented:

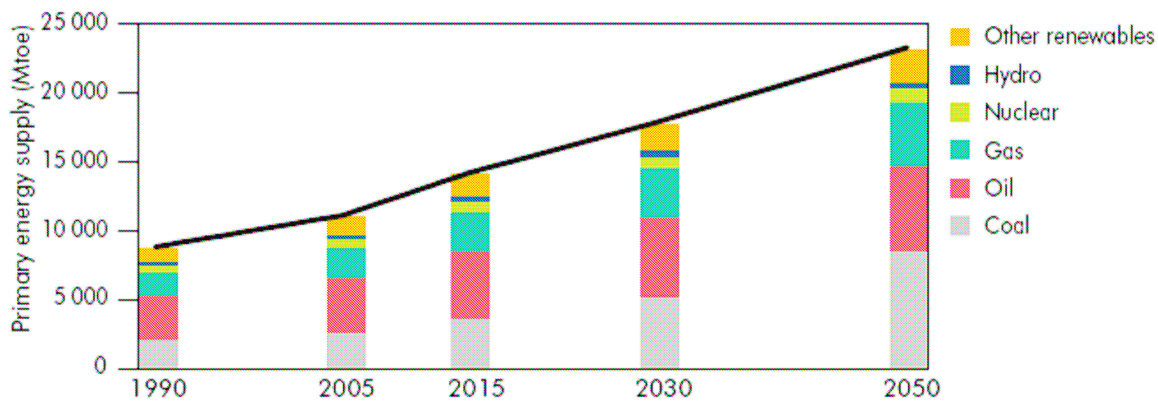
- The set of ETP 2008 "ACT Scenarios" shows how global CO_2 emissions could be decreased to current levels by 2050.
- The set of ETP 2008 "BLUE Scenarios" targets a 50% reduction in CO_2 emissions by 2050. The IPCC has concluded that emissions must be reduced by 50% to 85% by 2050 if global warming is to be confined to between 2℃ and 2.4℃.

The ACT and BLUE scenarios are based on the same macro-economic assumptions as the Baseline scenario developed within ETP. In this section we will link the IEA ETP scenarios with the IPCC SRES storylines. In all scenarios, world economic growth is a robust 3.3% per year between 2005 and 2050. In all scenarios too, the underlying demand for energy services is the same, *i.e.* the analysis does not consider scenarios for reducing the demand for energy services (such as by reducing indoor room temperatures or restricting personal travel activity).

The BLUE scenario implies a very rapid change of direction. Costs are not only substantially higher, but also much more uncertain, because the BLUE scenarios demand deployment of technologies still under development, whose progress and ultimate success are hard to predict. These scenarios require urgent implementation of unprecedented and far-reaching new policies in the energy sector.

The 40 SRES scenarios of IPCC show a range of 642-1611EJ for the global primary energy use in 2050. For the IEA ETP Baseline scenario this use is 23,200 Mtoe = 971 EJ (see Figure 6) which fits the SRES scenarios range and is exactly the same as for A2 marker scenario. The IEA ETP baseline scenario thus can be seen as consistent with the IPCC SRES A2 family of scenarios.

Figure 6 World total primary energy supply [Mtoe][12] by fuel in the Baseline scenario[1]



Source: IEA (2008), Energy Technology Perspectives - Scenarios & Strategies to 2050 (figure 2.37)

The energy use in transport in 2050 (Baseline IEA scenario) is 4430 Mtoe =186 EJ[12] which also corresponds to the IIASA scenarios (see Table 4).

Table 4 Global final energy consumption [EJ] in transport in 2050[10]

	A1	A2	A3	B	C1	C2
World	223.0	211.8	212.4	159.0	123.1	121.5

3.2 Requirements for transport sector

As part of the IEA ETP scenario development process, given the high degree of uncertainty surrounding key technological developments, a multi-scenario approach was used to depict several possible futures that could achieve the target GHG emissions reductions implicit in the BLUE scenario. The BLUE Map scenario is very challenging for the transport sector and requires significant decarbonisation of transport. Low-carbon biofuels are expected to play a significant role in the BLUE Map scenario, within the limits of sustainable production and cropping. Trucks, navigation and aviation are assumed to be the main users of biofuels, on the basis of the assumption that other non-hydrocarbon options are likely to be very expensive to apply to these transport modes.

Electric batteries and hydrogen fuel cells are the main alternatives for cars. It is however difficult to judge at this stage which of these technologies – or which combination of them – will be the most competitive. Based on fairly optimistic assumptions about technology progress and cost reductions, electric and fuel cell vehicles are expected to cost around USD 6 500 more in 2050 than conventional vehicles. In the BLUE Map scenario, nearly one billion electric and fuel cell vehicles need to be on the roads by 2050. Transport represents the largest single area of investment in the scenarios. Additional investment needs in transport are USD 33 trillion in BLUE Map and USD 17 trillion in ACT Map.

Three sets of assumptions were made in these BLUE scenario variants: (a) the technological and economic success of fuel-cell vehicles (“FCV success”), (b) the success of electric vehicles (“EV success”), and (c) the long-term potential (given both technology and land use constraints) for the production of biofuels for transport.

Four variants for BLUE have been analyzed for this paper:

- BLUE Map (a combination of high efficiency, biofuels, electric vehicles and hydrogen fuel cell vehicles).

[12] Million tones of oil equivalent Mtoe=4.1868*10^{-2} [EJ]

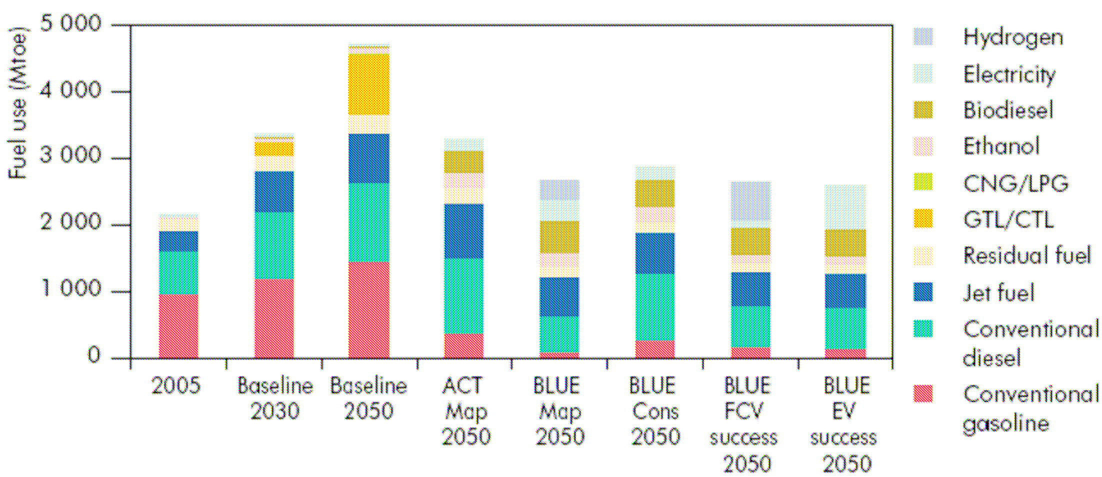
- BLUE EV success: a variant that is optimistic with regard to the development of electric vehicles.
- BLUE FCV success: a variant that is optimistic with regard to the development of H2 fuel-cell vehicles.
- BLUE conservative: a variant where neither EVs nor FCVs are assumed to achieve cost reductions sufficient for them to begin deployment. As a result, this scenario has higher transport CO_2 emissions than the other BLUE variant scenarios.

The detailed assumptions used in each variant are shown in Appendix III.

According to the IEA ETP Baseline scenario, energy demand in the transport sector increases by 120% between 2005 and 2050 (Figure 7). Demand for oil products in 2050 is 37% above the 2005 level in the ACT Map scenario, and 5% above to 38% below the 2005 level in the BLUE cases. The transport energy use in 2050 in different scenarios is as follows:

- Baseline 197 EJ
- BLUE Map 113 EJ
- BLUE Cons 119 EJ
- BLUE FCV 112 EJ
- BLUE EV 109 EJ

Figure 7 Transport energy use [Mtoe] in the Baseline, ACT Map and BLUE Map scenarios, 2005-2050[1]



Source: IEA (2008), Energy Technology Perspectives - Scenarios & Strategies to 2050 (figure 2.21)

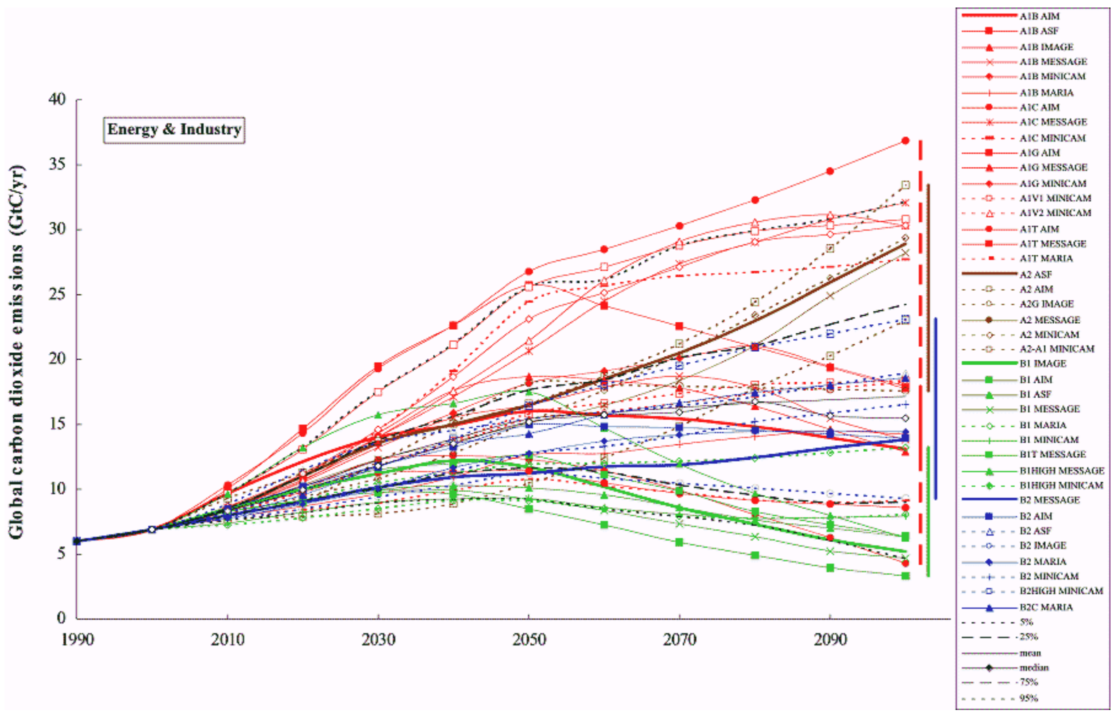
This section introduced the IEA ETP scenarios, and especially the IEA ETP BLUE scenarios, which require urgent implementation of unprecedented and far-reaching new policies in the energy sector as well as new technologies. They are very challenging for the transport sector and require significant decarbonisation of transport. Energy use in transport in BLUE scenarios is in average 45% lower than in the Baseline scenario.

4 CO_2 emissions in SRES and IEA ETP scenarios

4.1 CO_2 emissions from SRES scenarios

Figure 8 below presents standardised carbon[13] emissions from fossil energy and industry for the 40 SRES scenarios, classified into four scenario families (each denoted by a different colour code: A1-red; A2-brown; B1-green; B2-blue). Marker scenarios are shown with thick lines without ticks, globally harmonized scenarios with thin lines, and non-harmonized scenarios with thin, dotted lines. Black lines show percentiles, means, and medians for the 40 SRES scenarios. It is important to recall at this point that the SRES scenarios assumed that no policies to mitigate climate change were put in place.

Figure 8 Standardized global energy-related and industrial CO_2 emissions for 40 SRES scenarios[5]



Source: IPCC (2000), IPCC Special Report on Emissions Scenarios (Figure 5-2)

The SRES scenarios project a wide range of annual emissions, and the uncertainties in future emission levels increase with time. Up to the 2050s, emissions increase in all scenarios, albeit at different rates. Across scenarios this reflects changes in the underlying driving forces, such as population, economic output, energy demand, and the share of fossil fuels in energy supply.

By 2050, the emissions range covered by the 40 SRES scenarios is from about 33 to 99 Gt CO_2 (9 to 27 GtC), with the mean and median values equal to about 55 Gt CO_2 (15 GtC). The range between the 25th and 75th percentiles of emissions (the "central tendencies") extends from 44 to 66 Gt CO_2 (i.e. from two to three times those in 1990). Three of the four marker scenarios lie within this interval. However, a fair number of scenarios (eight out of 40)

[13] The CO_2 emissions in Figure 8 are expressed as mass of carbon. The mass of carbon is 12/44 of the mass of CO_2 (atomic mass of C = 12, O = 16).

also indicate the possibility of much higher emissions (in the 66 to 99 Gt CO_2 range) that reflect an increase by a factor of up to 4.5 over 60 years (1990 to 2050). Another eight SRES scenarios have 2050 emissions below the 25th percentile.

Different model specifications make it impossible to draw up a consistent comparison between CO_2 sectoral emissions. Table 5 presents the results of one of the models[5] for energy and industrial sources.

Table 5 Global CO_2 [Gt CO_2] emissions from transport sector for seven SRES scenarios for 2050[5]

	1990	2050						
		A1B	A2	B1	B2	A1T	A1G	A1C
Supply Side								
Direct Use of Fuels by Sector								
Transportation	4.80	14.02	10.82	9.79	9.49	12.63	16.55	20.49
TOTAL*	26.81	61.56	55.16	30.68	40.27	46.20	79.94	77.32
Demand Side								
Transportation	5.58	21.27	17.54	15.28	12.17	17.96	26.63	35.78
TOTAL**	26.81	61.56	55.16	30.68	40.27	46.20	79.94	77.32

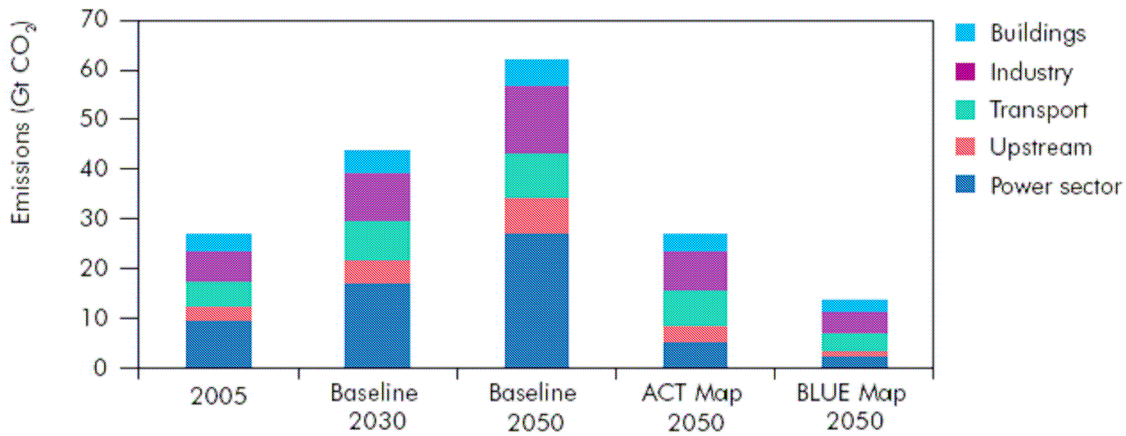
* Total for supply side includes: energy supply/transformation (electric generation, synfuels production, and other conversion), direct use of fuels by sector (residential/commercial, industry, transportation, feedstocks) and non-energy emissions (cement production/gas flaring, land-use change).
** Total for demand side includes: residential/commercial, industry, transportation, land-use change.

Source: Calculation for the need of this report based on IPCC (2000), IPCC Special Report on Emissions Scenarios (Appendix VII)

4.2 CO_2 emissions from IEA ETP scenarios

The IEA ETP scenario analysis (Figure 9) shows that BLUE Map implies impressive emission reductions across all sectors. In this scenario, emissions are 48 Gt CO_2 lower in 2050 than in the Baseline scenario. In the BLUE variants CO_2 emissions are between 24% and 51% lower than in the baseline scenario for 2050.

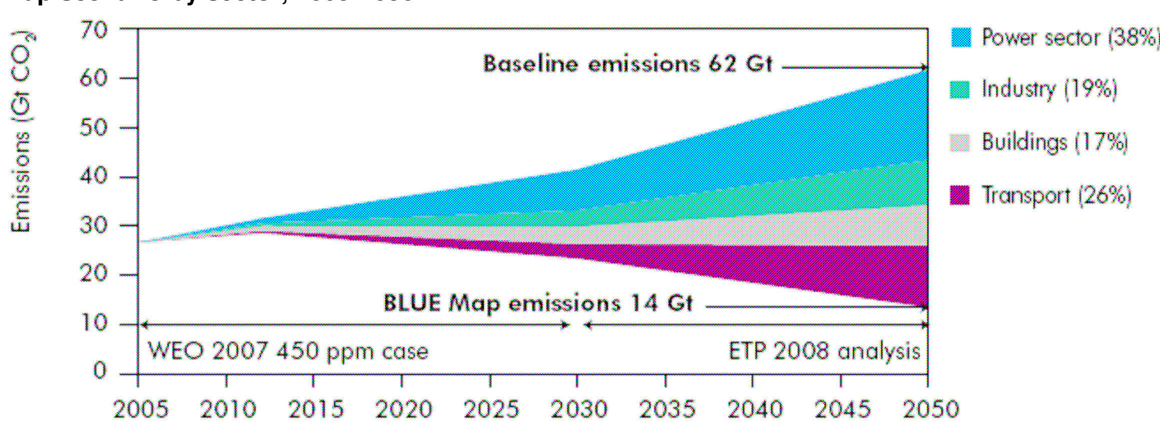
Figure 9 Global CO_2 emissions in the baseline, ACT Map and BLUE Map scenarios[1]



Source: IEA (2008), Energy Technology Perspectives - Scenarios & Strategies to 2050 (figure 2.1)

Figure 10 shows the emission reductions by sector for the period 2005-2050 for the BLUE Map scenario. The share of end-use sectors in emission reduction increases between 2030 and 2050. The BLUE Map scenario is consistent with the World Energy Outlook 2007 450 ppm case[14].

Figure 10 Reduction of energy-related CO_2 emissions from the Baseline scenario in the BLUE Map scenario by sector, 2005-2050[1]



Source: IEA (2008), Energy Technology Perspectives - Scenarios & Strategies to 2050 (figure 2.3)

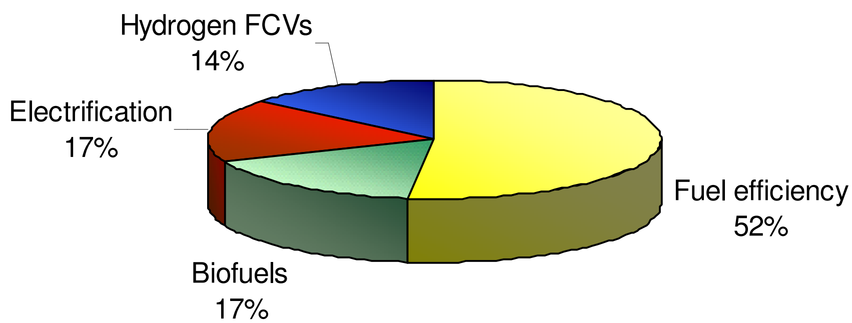
In the ACT Map and BLUE Map scenarios, OECD countries account for 30% of the total global emissions reduction compared to the Baseline scenario. In BLUE Map the OECD countries reduce their emissions by more than half compared to 2005 levels, while non-OECD countries reduce their emissions by less than half.

[14] IEA (2007), World Energy Outlook 2007, OECD/IEA, Paris.

4.3 CO_2 from transport

In the BLUE Map scenario, transport-wide CO_2 emissions are reduced overall to about 30% below the 2005 level by 2050 (i.e. about 70% below the Baseline scenario in 2050). In BLUE Map scenario, nearly all biofuels after 2020 are assumed to be advanced "second-generation", low-GHG types, and hydrogen and electricity come increasingly from near-zero-GHG-generation sources. Alternative fuels play a large role in the BLUE Map scenarios (see Figure 11).

Figure 11 Emission reductions in transportation compared to Baseline for the BLUE Map scenarios, 2050 – BLUE Map 12.5 Gt CO_2 reductions[1]

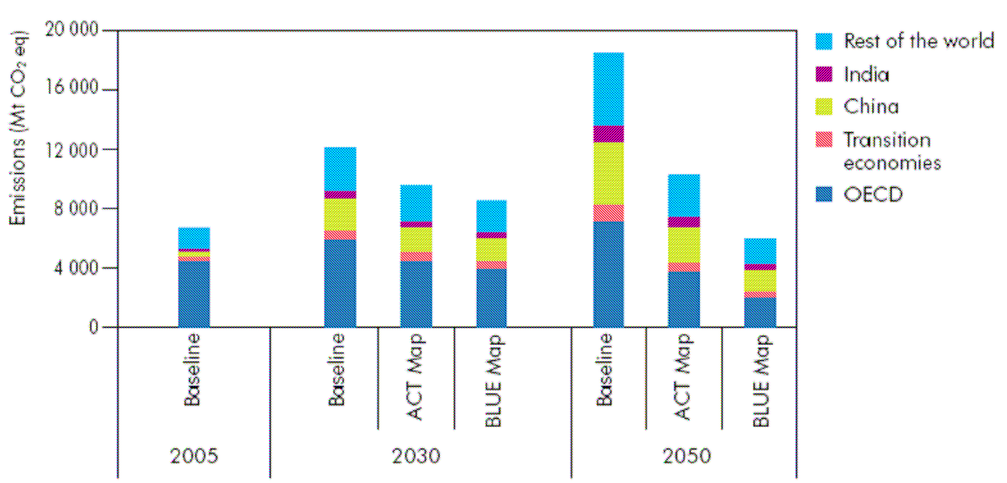


Source: Figure made for the purpose of this studies based on the information from IEA (2008), Energy Technology Perspectives - Scenarios & Strategies to 2050

In the BLUE Map scenarios, fuel use in 2050 is up to 47% lower than in the Baseline. BLUE Map uses the most biofuels, representing 26% of total transport fuel demand. The use of conventional oil products is 35% below the 2005 level in the BLUE Map scenario. In the BLUE Map scenario, hydrogen plays an important role. Fuel cell vehicle sales and the construction of a hydrogen infrastructure gear up after 2020 and grow steadily over time. In "BLUE FC", fuel cell vehicles are assumed to reach a commercial scale by 2030 and to dominate vehicle sales in OECD countries by 2050. Electricity gains ground in all variants through plug-in hybrids, but it reaches a much more prominent position in the EV variant – in which pure-electric vehicles are assumed to become fully commercial by 2030 and dominate vehicle sales by 2050.

As a result, the GHG profiles of the different scenarios closely follow their relative fossil-fuel use levels. Figure 12 presents the CO_2-equivalent greenhouse gas emissions for the transport sector.

Figure 12 CO_2 emissions [Mt CO_2 eq][15] for all scenarios and all regions in 2050[1]



Source: IEA (2008), Energy Technology Perspectives - Scenarios & Strategies to 2050 (figure 15.3)

Note: The H_2 and electricity contributions include both the fuel-switching benefits and the vehicle efficiency benefits.

CO_2 emissions in 2050 are decreased by about 70% in the BLUE Map scenario, compared to the Baseline scenario. All major regions show fairly similar cuts in CO_2, since by 2050 they have fairly similar stocks of vehicles and benefit from similar improvements in vehicle efficiency and the introduction of low-GHG alternative fuels. Hydrogen fuel cell vehicles and electric vehicles are assumed to penetrate with a five- to ten-year lag in non-OECD countries compared to OECD countries, but by 2050 their overall penetrations are fairly similar. Regional reductions for other BLUE variants are similar to those in the BLUE Map scenario.

Based on Figure 12, the global CO_2-equivalent greenhouse gas emissions in Baseline scenario is 18.5 Gt CO_2 and in BLUE Map scenario is 5.9 Gt CO_2. According to SRES scenarios (Table 5), the global CO_2 emissions from transport sector lie in the range 10 – 36 Gt CO_2. That means that the IEA ETP Baseline scenario has similar assumption as SRES scenarios.

The further analysis was done using the information from the Figure 12 and the EU-27 population share in population of Annex 1 parties[16]. The estimations for the EU-27 in 2050 were made and are as follows: according to Baseline scenario it is 3.0 Gt CO_2 and for BLUE Map scenario it is 0.75 Gt CO_2.

This section gave an overview of CO_2 emissions from the transport sector estimated by different scenarios. Transport accounts for more than half the oil used worldwide and nearly 25% of energy-related CO_2 emissions. According to the ETP Baseline scenario, world transport energy use and emissions will increase by more than 50% by 2030 and will more than double by 2050. The fastest growth is expected to come from air travel, road freight and light-duty vehicle (car, small van and SUV) travel. In the Baseline scenario, nearly all future

[15] Emissions expressed as CO_2, e.g. include also emissions of other GHGs (the most important are CH_4 and N_2O). The CO_2 emissions account for 97% of all GHGs for energy sector and for 98% for transport sector for EU-34 countries.

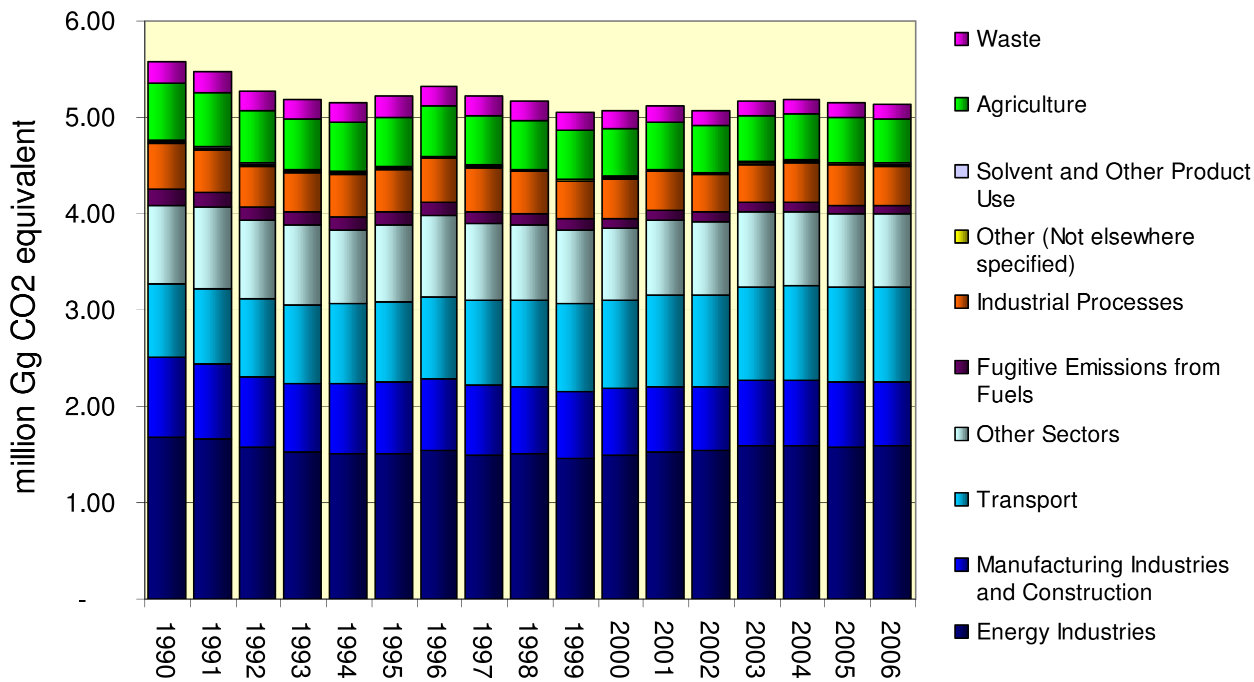
[16] The error introduced with the assumption that OECD+Transition economies = ~Annex I for estimating the share of EU-27 is considered to be acceptable (similar as for OECD and REF regions (see section 2.3))

fuel use in transport will continue to be fossil fuel. The sector presents enormous challenges for achieving deep cuts in fuel use and GHG emissions. Critical technologies such as fuel cells and vehicle on-board energy storage (e.g. via batteries, ultra-capacitors and H2 storage) are not yet technically mature or cost-effective, and it may be many years before they can deliver CO_2 reductions at a reasonable cost. Alternative fuels are likely to play an important role in getting to very low GHG emissions levels in transport by 2050.

5 Comparison with the trend

Figure 13 presents National submissions to UNFCCC for the 25 EU Annex I parties (excludes Malta and Cyprus since these Member States are non-Annex I countries). The GHG emissions from transport for these counties were 0.78 Gt CO_2 in 1990 and increased to 0.99 Gt CO_2 in 2006.

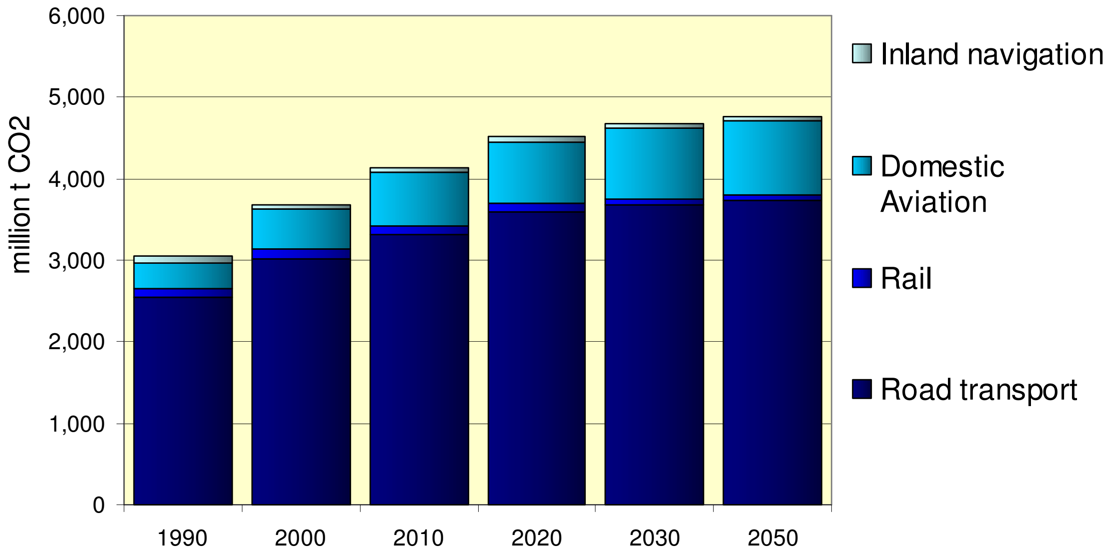
Figure 13 GHG emissions [million Gg CO_2 eq] [12] excluding LULUCUF[8]



Source: Made for the need of this paper based on: National submissions to UNFCCC for the 25 EU Annex I parties (excludes Malta and Cyprus)

The transport sector in the EU as a whole consumed about 17.2 EJ in 2006 (estimated for the purpose of this study). Figure 14 provides an overview of recent and potential growth in transport's CO_2 emissions (not including international bunker fuels). Between 1990 and 2000, CO_2 emissions from transport rose by around a quarter and are projected to continue to do so. Domestic aviation makes up a small, but fast growing source of transport CO_2 emissions; emissions from international aviation are similarly growing and are projected to grow (although it is not shown in this figure). The continued growth in emissions threatens compliance with the Kyoto targets.

Figure 14 CO_2 emissions projections [million t CO_2 =million Gg CO_2] by transport end users EU-27[17]



Source: Figure made for the purpose of this paper, based on: Backcasting approach for sustainable mobility, JRC-EC, 2008 (Table 1).

This section presented the recent trends in transport energy consumption as well as GHG emissions. Transport is one of the largest energy-consuming sectors, accounting for 34% of final energy consumption and transport energy consumption still rises year-by-year. Transport relies almost exclusively on fossil fuels (98%) so greenhouse gas emissions grow roughly parallel to energy consumption.

6 Assessment of additional efforts to meet the EU 2050 targets / Conclusions

If the BLUE Map scenario is fully implemented, the EU-27's GHG emissions from transport are predicted to be 0.75 Gt GHG (measured as CO_2 equivalent, but not including emissions from the use of international bunker fuels) by 2050, which is almost the same as emissions from transport in 1990. Given that the maximum total GHG emissions from the EU-27 by 2050 might need to be around 2 or even 1 Gt GHG (assuming that, respectively, an economy-wide reduction target of 60% or 80% is agreed), total emissions in **all the other sectors** could be no more than 1.3 Gt GHG (assuming a 60% target) or 0.3 Gt GHG (80%). In such a case (i.e. if the BLUE Map scenario is implemented), transport's emission in 2050 would either be 37% or 73% of total economy-wide GHG emissions, which would leave, respectively either 63% or 27% of the total allowable emissions for all of the other sectors, which include the energy industries, households, agriculture, industrial processes, etc.

Looking from another perspective, if the economy-wide EU reduction targets should be met by all sectors reducing their emissions proportionally, then in 2050 the GHG emissions from transport should be 0.31 and 0.16 Gt GHG respectively for targets reduction targets of 60% and 80%. This means that transport would have to reduce GHG emissions between 68%

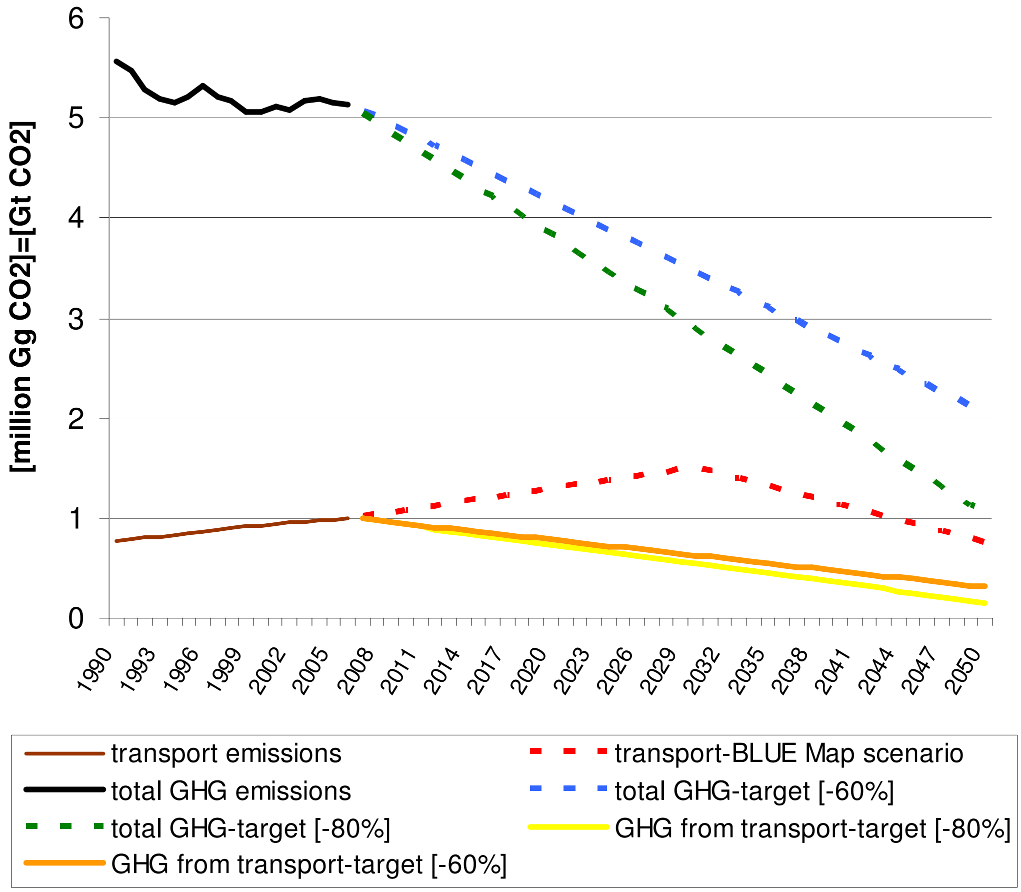
[17] JRC-EC (2008), Backcasting approach for sustainable mobility

and 84% compared to 2006 levels by 2050. Figure 15 illustrates these situations and Table 6 gives a summary of possible future GHG emissions from transport in 2050.

Table 6 Summary of GHG emissions [Gt CO_2 equivalent] from transport in 2050 for EU-27

BLUE MAP	target -60%	target -80%
0.75	0.31	0.16

Figure 15 EU-27 total GHG and GHG from transport emissions trends against EU targets and results from BLUE Map scenario[1,8,18]



[18] EUROSTAT (http://epp.eurostat.ec.europa.eu))

Reference list:

EPA (1998), Alexei Sankovski, ICF's unpublished data file.
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IEA (2007), World Energy Outlook 2007, OECD/IEA, Paris.
IEA (2008), Energy Technology Perspectives - Scenarios & Strategies to 2050.
IEA Energy database (http://www.iea.org/Textbase/stats/index.asp)
IPCC (2000), IPCC Special Report on Emissions Scenarios
JRC-EC (2008), Backcasting approach for sustainable mobility
National submissions to UNFCCC for the 25 EU Annex I parties (excludes Malta and Cyprus)
WEC/IIASA (1998), Global energy perspectives to 2050 and beyond, World Energy Council, London.

Appendix I Definition of world region[5]

1. OECD90 REGION

I.1.1 North America (NAM)

Canada
Guam*
Puerto Rico*
United States of America
Virgin Islands*

I.1.2 Western Europe (WEU)

Andorra
Austria
Azores*
Belgium
Canary Islands*
Channel Islands*
Cyprus*
Denmark
Faeroe*
Islands*
Finland
France
Germany
Gibraltar*
Greece
Greenland*
Iceland
Ireland
Isle of Man*
Italy
Liechtenstein
Luxembourg
Madeira*
Malta*
Monaco
Netherlands
Norway
Portugal
Spain
Sweden
Switzerland
Turkey
United Kingdom

Pacific OECD (PAO)

Australia
Japan
New Zealand

2. REF REGION

(countries undergoing economic reform)

Central and Eastern Europe (EEU)

Albania*
Bosnia and Herzegovina*
Bulgaria
Croatia
Czech Republic
The former Yugoslav Republic of Macedonia*
Hungary
Poland
Romania
Slovak Republic
Slovenia
Yugoslavia*

Newly independent states (NIS) of the former Soviet Union (FSU)

Armenia*
Azerbaijan*
Belarus
Estonia
Georgia*
Kazakhstan*
Kyrgyzstan*
Latvia
Lithuania
Republic of Moldova*
Russian Federation
Tajikistan*
Turkmenistan*
Ukraine
Uzbekistan*

3. Annex I Countries:

Australia
Austria
Belarus
Belgium
Bulgaria
Canada
Croatia
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Iceland
Ireland

Italy
Japan
Latvia
Liechtenstein
Lithuania
Luxembourg
Monaco
Netherlands
New Zealand
Norway
Poland
Portugal
Romania
Russian Federation
Slovakia
Slovenia
Spain
Sweden
Switzerland
Turkey
Ukraine
United Kingdom of Great Britain and Northern Ireland
United States of America

* countries included in REF or OECD90 but not in Annex I countries.

Appendix II Final and primary energy use [EJ] in 2050 for marker scenarios for OECD90 and REF region[5]

OECD90		A1 AIM	A2 ASF	B1 IMAGE	B2 MESSAGE
Final Energy [EJ]					
	Non-commercial	0		3	0
	Solids	6	14	6	0
	Liquids	75	92	32	76
	Gas	68	46	27	35
	Electricity	70	59	57	61
	Others			21	10
	Total	218	211	146	182
	range	(146-245)	(170-217)	(108-175)	(146-183)
Primary Energy [EJ]					
	Coal	28	92	24	20
	Oil	54	49	39	65
	Gas	95	69	37	99
	Nuclear	24	20	35	17
	Biomass	29	23	21	12
	Other Renewables	35	12	10	25
	Total	267	266	166	236
	range	(184-322)	(207-300)	(134-233)	(189-236)

REF		A1 AIM	A2 ASF	B1 IMAGE	B2 MESSAGE
Final Energy [EJ]					
	Non-commercial	0		1	0
	Solids	4	11	4	0
	Liquids	7	17	10	19
	Gas	46	32	9	19
	Electricity	28	19	20	18
	Others			3	12
	Total	84	79	46	68
	range	(58-98)	(37-82)	(41-60)	(36-101)
Primary Energy [EJ]					
	Coal	11	23	14	12
	Oil	6	21	18	20
	Gas	55	40	18	51
	Nuclear	8	6	6	2
	Biomass	8	0	5	4
	Other Renewables	15	3	3	8
	Total	103	93	64	97
	range	(83-267)	(57-116)	(50-79)	(53-117)

Appendix III Assumption in ETP transport scenarios[1]

		BLUE Map	BLUE conservative	BLUE FCV success	BLUE EV success
Definition		Greater use of biofuels, deployment of EVs, FCVs	Stronger efficiency gains than ACT, more biofuels, no pure EVs or FCVs	By 2050, FCVs dominant for cars and light/medium trucks	By 2050, EVs dominant for cars and light/medium trucks
LDVs	New LDV fuel economy improvement	70% reduction in new LDV fuel/km by 2050 from FCVs and EVs	60% reduction in new LDV fuel/km by 2050	70% reduction in new LDV fuel use by 2050 from FCVs	70% reduction in new LDV fuel use by 2050 from EVs
	Gasoline and diesel hybrids	About 70% market share in 2030, dropping to 35% in 2050 due to EVs and FCVs	About 75% sales share in 2030, rising to 100% in 2050	About 60% sales share in 2030, dropping to 10% in 2050 due to FCV sales	About 60% sales share in 2030, dropping to 10% in 2050 due to EV sales
	Electric plug-in hybrids	Beginning in 2015, hybrid vehicles reach 60% electric share by 2050	Beginning in 2015, hybrid vehicles reach 40% electric share by 2050	Beginning in 2020, hybrid vehicles reach 20% electric share by 2050	Beginning in 2015, hybrid vehicles reach 75% electric share by 2050
	Electric vehicles	Reach 20% of LDV sales in 2050	None	None	Reach 90% of LDV sales in 2050
	Fuel cell vehicles	Reach 40% of LDV sales in 2050	None	Reach 90% of LDV sales in 2050	None
	Travel	Same as ACT Map (15% lower in 2050 than Baseline due to modal switch and telematic substitution)	Same as ACT Map (15% lower in 2050 than Baseline due to modal switch and telematic substitution)	Same as ACT Map (15% lower in 2050 than Baseline due to modal switch and telematic substitution)	Same as ACT Map (15% lower in 2050 than Baseline due to modal switch and telematic substitution)
Trucks		FCVs and EVs each reach up to 25% of stock by 2050	Average 45% efficiency improvement; hybrids reach 80% of stock by 2050; no FCVs or EVs	FCVs reach 60% of medium truck stock by 2050, 30% of heavy	EVs reach 50% of medium truck stock by 2050, 25% of heavy
Buses		50% improvement by 2050 including 75% hybrids	Same as BLUE Map	Same as BLUE Map	Same as BLUE Map
Rail		30% more efficient in 2050	25% more efficient in 2050	Same as BLUE Map	Same as BLUE Map
Air		Stock 45% more efficient in 2050 and 10% routing improvement	Stock 40% more efficient in 2050 and 10% routing improvement	Same as BLUE Map	Same as BLUE Map
Water		30% more efficient in 2050, 30% biofuels	30% more efficient in 2050, no biofuels	Same as BLUE Map	Same as BLUE Map

Travel (non-LDV)	Up to 15% reduction for air, trucking; up to 35% increase for buses, rail due to mode switching	Same as BLUE Map	Same as BLUE Map	Same as BLUE Map
Biofuels	About 700 Mtoe in 2050, all 2nd gen, mostly BTL	about 650 Mtoe in 2050, all 2nd gen, mostly BTL	About 540 Mtoe in 2050, mostly BTL	About 520 Mtoe in 2050, mostly BTL
Low GHG hydrogen	260 Mtoe in 2050	No H2	570 Mtoe in 2050	No H2
Low GHG electricity	320 Mtoe in 2050 for plug-ins and pure EVs	170 Mtoe in 2050 for plug-ins	100 Mtoe in 2050 for plug-ins	650 Mtoe in 2050

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