IMPACTS OF THE INCREASING AUTOMOTIVE DIESEL CONSUMPTION IN THE EU

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PREFACE

The objective of the Sustainable Energy Technologies Reference and Information System (SETRIS) of Directorate-General Joint Research Centre – European Commission is to collect, harmonise and validate information on sustainable energy technologies and perform related techno-economic assessments to establish, in collaboration with all relevant national partners, scientific and technical reference information required for the debate on a sustainable energy strategy in an enlarged EU, and in the context of global sustainable development.

In the context of SETRIS, this report investigates the impacts of the increasing automotive diesel consumption in the European Union on the security of energy supply, energy efficiency, environmental performance and fuel production costs by 2010. This includes a critical review of a number of literature sources, complemented by the authors' analysis. The bibliographic indexes of the literature sources or of the sources, where more information can be found on a certain subject, are given in brackets [].

This report has been written by B. Kavalov and S. D. Peteves – Joint Research Centre (JRC), Institute for Energy (IE). The work on the study has been initiated at the time when one of the authors (B. Kavalov) was still employed by another JRC institute – the Institute for Prospective Technological Studies (IPTS). Hence, the database available at the JRC-IPTS has been used in this study.

The authors would like to acknowledge and thank for their contribution the following persons: Marc Steen, Evangelos Tzimas and Fred Starr (JRC-IE), Antonio Soria (JRC-IPTS), Peder Jensen (European Environmental Agency), Jean-François Larivé (CONCAWE) and in particular Ian Hodgson (European Commission, Directorate-General for Energy and Transport).

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LIST OF USED ABBREVIATIONS

ACEA – European Automobile Manufacturers Association

ATEC – average total energy costs

Cxx – length of carbon chain ("xx" indicates the number of carbon atoms in the carbon chain)

CI – compressed-ignited

CIS – Commonwealth of Independent States

CO2 – carbon dioxide

CO2eq – CO2 equivalent

DI – direct injection

EC – European Commission

EU – European Union, (European) Community

EU-15 – the 15 member states of the European Union until 30 April 2004

FSU – Former Soviet Union

g - gram

GHG – greenhouse gas(es)

GJ – Giga Joule

HDV – heavy-duty vehicle(s)

ICE – internal combustion engine

JAMA – Japan Automobile Manufacturers Association

k – thousand

KAMA – Korea Automobile Manufacturers Association

km - kilometre

l - litre

LDV – light-duty vehicle(s)

LPG – liquid petroleum gas

M – million

MJ – Mega Joule

Mtoe – million tonnes oil equivalent

NMS-10 – the 10 new member states of the European Union after 01 May 2004

NOx – nitrogen oxide

PI – port injection

PM – particulate matter

ppm – parts per million

SI – spark-ignited

t – metric tonne (1 tonne = 1000 kilograms)

TTW – tank-to-wheel

v/v – volume per volume

WTT – well-to-tank

WTW – well-to-wheel

US, USA – United States of America

EXECUTIVE SUMMARY

The European Union (EU) is heavily dependent upon energy imports and in particular – oil imports. The EU is also a large emitter of greenhouse gases (GHG), which contribute to global warming and climate changes. Securing the energy supply in an environmentally-friendly way is therefore a prime objective of the EU energy and environmental policies. Transport and in particular – road transport is a main oil consuming and GHG generating sector in the EU. Thus, reducing the energy consumption and GHG emissions from road transport is an important step on the way of reaching these EU policy objectives.

Petrol and diesel, obtained via oil refining, are the main automotive fuels nowadays. Petrol and diesel are however employed in different engine technologies. Due to the difference in engine technologies, diesel cars are more efficient, so – they consume less fuel and emit less GHG per kilometre than petrol cars[1]. Expanding the share of diesel cars, respectively – decreasing the share of petrol cars in total passenger cars' fleet appears as a tool for overall reduction of energy use and GHG emissions in road transport.

For these reasons, a significant shift from petrol to diesel cars has been recently observed in the EU. This shift led to a growing demand for diesel and declining petrol consumption. The goal of this study is to investigate the impacts of the increasing automotive demand for diesel (at the expense of petrol) in the EU on the Community's security of energy supply, energy efficiency, environmental performance and fuel production costs by 2010. For this purpose, a critical review of a range of literature sources is performed, complemented by the author's analysis. The analysis covers conventional automotive fuels (diesel and petrol) and engine technology (internal combustion engine). Besides the EU, the analysis looks at the automotive fuel consumption trends in the United States of America (USA), Former Soviet Union (FSU), as well as in the world.

Based on the analysis, performed in the study, four core probable impacts of the increasing automotive demand for diesel in the EU by 2010 are identified:

1. **Potential adverse impact on the security of energy supply.** World diesel consumption grows faster than world petrol use. The feasible reserves for further increase of world diesel fraction from oil refining appear not to be very large, ranging between 3% and 4% of total oil-refining yield. With recent trends in world automotive fuel consumption, the diesel market tends to become more a sellers' governed market, where the demand from the existing customers is likely to increase along with the appearance of new customers. On the contrary, the petrol market tends to turn more into a buyers' governed market, where the USA are the major customer. The forthcoming increase in demand for cleaner diesel may complicate further the situation with diesel supply.

[1] Medium and heavy-duty vehicles run exclusively on diesel, so they are not considered.

2. **The energy efficiency per kilometre along the diesel fuel chain could be reduced, while the GHG emissions per kilometre could increase.** Trying to respond to the market requirements, the EU refineries most likely will further expand diesel fraction from oil refining, beyond its optimum balance with petrol yield. This will be associated with higher energy losses and GHG emissions at the refineries. Alternatively, the growth in energy losses and GHG emissions for diesel could come from the lower energy and GHG efficiency of the foreign, e.g. FSU refineries, which will supply diesel to the EU, and from the additional transportation. A further reduction in the efficiency gap with petrol most likely will come from the new fuel quality standards, whose meeting is associated with higher energy and GHG cost for diesel than for petrol.
3. **The overall energy consumption and GHG emissions from diesel cars could get higher than those from petrol cars.** Due to the lower taxation of diesel, compared to petrol, and the higher efficiency of diesel engine versus petrol engine, diesel cars have lower fuel cost per km, compared to petrol cars. Hence, the drivers of diesel cars get the economic incentive to do a higher annual mileage than the drivers of petrol cars do. In such a case, the lower GHG and energy use values <u>per kilometre</u> for diesel cars could turn into larger <u>total</u> GHG and energy values, compared to petrol cars. The recently introduced new taxation regulations probably will expand further the fuel cost advantage of diesel over petrol, giving the drivers of diesel cars additional incentives to increase their annual mileage.
4. **Diesel production cost will become higher than petrol production costs.** At present petrol and diesel production costs in the EU are equal. The additional increase of diesel fraction from oil refining, beyond its optimum balance with petrol yield, most probably will result in higher production costs for diesel, compared to petrol. The new fuel quality standards will enlarge in addition the gap between diesel and petrol production costs, since the refinery cost of meeting these standards is higher for diesel than for petrol.

Improving the petrol engine appears to be the most appropriate feasible solution of the above drawbacks. Most recent engine novelties were elaborated for the diesel technology. Hence, petrol engine contains larger unexplored potential for further development than diesel engine. By improving petrol engine and making it competitive to diesel engine in terms of performance parameters, the balance in the automotive fuel supply by fuel brands and thus – on the automotive fuel market, can be re-established. Considering the projected feasible extent of improving petrol engine, the performance gaps between petrol and diesel cars in terms of energy consumption and emissions of greenhouse gases will become negligible.

BACKGROUND

Recently global warming and climate changes, caused by the greenhouse gas (GHG) emissions, became a growing concern in the world. For this reason, under the Kyoto Protocol to the United Nations Framework Convention on Climate Changes (UNFCCC), various countries undertook to reduce their GHG, aiming at improving global environment. The EU committed to reduce within 2008-2012 its GHG emissions by 8% from the level in 1990. However, the GHG decrease achieved between 1990 and 2001 was 2.3% only[2] that is 2.1% less than the needed reduction, if a linear regression within 1990-2010 is assumed. Carbon Dioxide (CO2) is the key GHG, accounting for 82% of total GHG emissions in the EU in 2001. The delayed progress in the GHG reduction in the EU was due mainly to the CO2 emissions, since instead of declining, they were by 1.6% higher in 2001, compared to 1990 [36].

Transport is a main GHG and CO2 generating sector, responsible for 20% of total GHG and 29% of all CO2 emissions in the EU in 2000 [30, 34]. Road transport is the core CO2 emitting transport mode, accounting for 84% of all transportation CO2 emissions [32]. Amongst different sectors of industry, transport was also the only sector that didn't show any improvement in its CO2 performance since 1990 [32]. Hence, over the period 1990-2000 the transportation CO2 emissions, instead of declining, grew by 18%, mainly due to the impact of road transport [34]. With current trends, the baseline projections foresee a further 28% growth in total GHG emissions from transport by 2010 [35]. Drastically reducing the automotive CO2 emissions is therefore a prime goal of the environmental and transport policies in the EU [21].

Passenger cars form the largest share in total automotive fleet – about 80% [32] and thus account for the major share of the automotive CO2 emissions. Aiming at decreasing the GHG emissions from transport, the EC reached voluntary agreements with the associations of automobile manufacturers from Europe (ACEA) [16], Japan (JAMA) [20] and South Korea (KAMA) [19] for reducing the CO2 emissions from passenger cars – Annex 1. Amongst these three automobile manufacturers associations, ACEA holds the largest share in the sales of new passenger cars in the EU – more than 85%. The compliance of ACEA with the targets in its voluntary commitment is therefore crucial for the overall success of the CO2 reduction incentive.

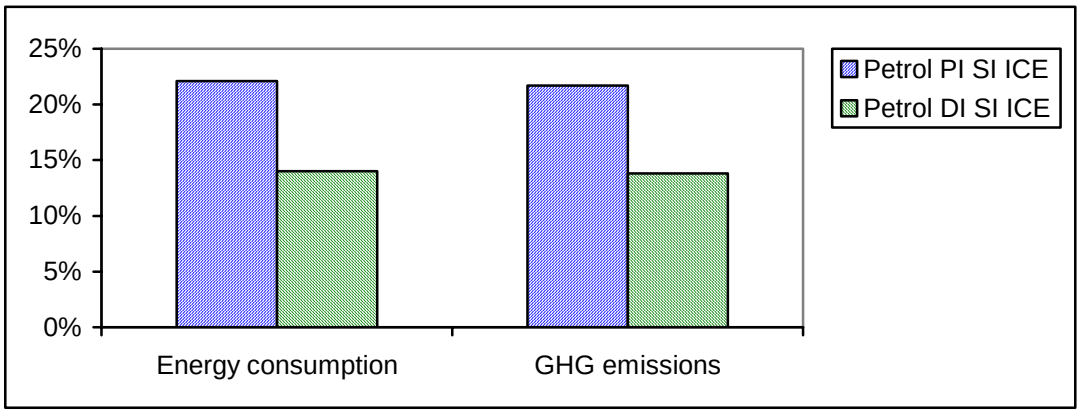
Currently, the most widespread fuels for internal combustion engine (ICE) – the typical automotive power-train technology nowadays – are petrol and diesel. Petrol and diesel engines have different design and performance characteristics, due to different fuel properties of petrol and diesel. Because of these differences, on equal terms the compressed-ignited (CI) ICE on diesel is far more efficient than the spark-ignited (SI) ICE on petrol. The higher efficiency of diesel engine results in lower fuel consumption, compared to petrol engine.

[2] Not considering land-use and forestry

Conversely, until recently diesel cars had a slower acceleration and a lower maximum speed than petrol cars – vehicle characteristics that usually are highly appreciated by the customers of passenger cars. Thus, SI ICE was generally considered as more appropriate for passenger cars, while with CI ICE mainly heavy-duty vehicles were equipped.

In general, the amount of the released CO2 emissions depends on the quantity of carbon that is employed in combustion process. On equal terms, higher fuel consumption or combustion of fuels with larger carbon chains increases CO2 emissions. Petrol has a slightly shorter carbon chain than diesel – C4-C12 [3] versus C11-C25 [5], but this advantage is fully offset by the far less efficient SI ICE, compared to CI ICE. So, on equal footing petrol engines tend to show higher energy consumption and GHG emissions per km., compared to diesel engines (Figure 1).

Figure 1
Prevailing (2002) relative increase in the WTW[3] energy consumption and GHG emissions per km. for petrol in conventional PI SI ICE and advanced DI SI ICE, compared to diesel in modern DI CI ICE as a baseline (%)

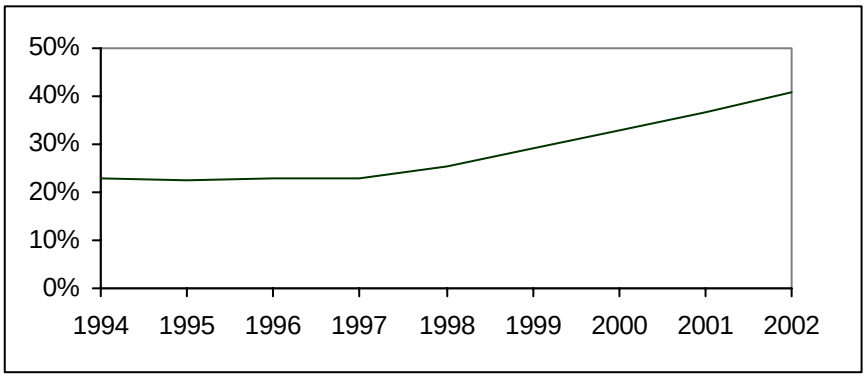


Sources: Adapted from [38]

Consequently, reaching the milestones of the CO2 commitments is easier by diesel cars, rather than by petrol cars. Hence, auto-manufacturers got strong incentives to invest into further improvement of the CI ICE technology [48]. In such a way, diesel cars recently became comparable to and even better than petrol cars in terms of driving performance – maximum speed, acceleration, power, etc. Combined with the lower fuel consumption, driving diesel car became in fact more attractive, than driving a petrol car. As a result, the sales of new diesel cars started to grow fast, at the expense of the sales of petrol cars – Figure 2. The major contribution to this growth came from the members of ACEA. The reason was that the European car manufacturers were and still are more advanced in the CI ICE technology, compared to the Japanese and Korean car manufacturers.

[3] The Well-To-Wheel (WTW) approach calculates the energy consumption and GHG emissions along fuel chains and consists of two parts. The first part – Well-To-Tank (WTT), assesses the stage from the extraction of feedstock until the delivery of fuel to the vehicle tank. The second part – Tank-To-Wheel (TTW), analyses the performance of fuel in the engine. The WTW analysis integrates the WTT and TTW parts. The TTW energy use is crucial for the overall balance, since it accounts for more than 85% of the WTW values on average.

Figure 2
Penetration of diesel passenger cars as share of all newly registered passenger cars in EU-15[4] within 1994-2002 (%)



Source: Adapted from [17]

The WTW benefits of diesel cars, compared to petrol cars (Figure 1) had another advantage for the EU. Besides being a large emitter of GHG, EU is also heavily dependent upon oil imports. The prevailing, already high (76%) import dependence upon oil might reach 90% by 2020, due to depletion of the EU's own oil reserves. The recent enlargement of the EU that took place in May 2004, will not reduce this import dependence either, because the 10 New Member States[5] are already heavily dependent on oil imports (90%). Since world oil reserves are geo-politically concentrated, such an import dependence threatens the security and diversity of the EU oil supply [21]. Transport is a key oil-consuming sector in the EU, responsible for 67% of final oil demand. Transport is also almost fully dependent upon oil-derived products – 98%. Amongst transport modes, road transport has the major share in oil consumption, as most passengers and freight traffic in the EU goes by road [23]. Reducing the energy consumption in transport therefore represents another major policy objective in the EU. Expanding the use of more energy efficient cars, e.g. powered by CI ICE, rather than by SI ICE, is a way of achieving this policy goal.

The shift towards diesel cars in the EU led to a growth in the automotive diesel demand, while petrol consumption declined. In this context, the goal of this study is to investigate the impacts of the increased automotive demand for diesel (at the expense of petrol) in the EU on the Community's security of energy supply, energy efficiency, environmental performance and fuel production costs by 2010.

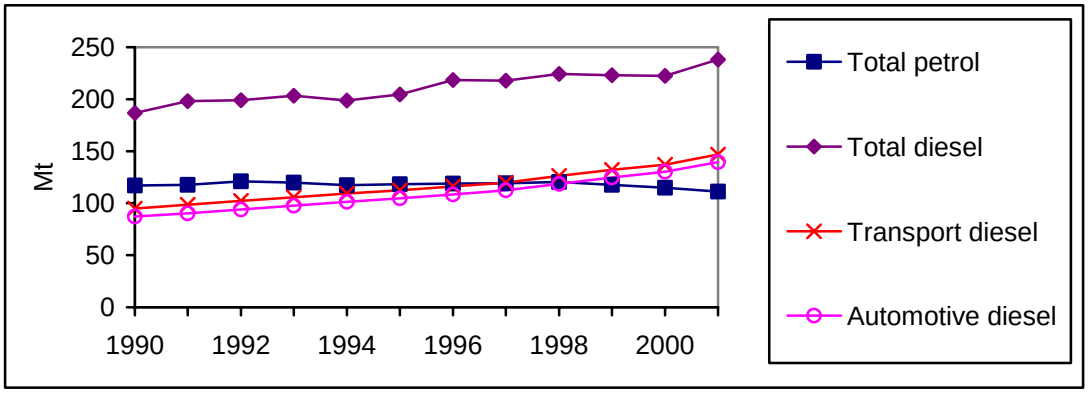
[4] The scope of the EU until 30 April 2004: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Sweden, Spain and United Kingdom.
[5] Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovak Republic and Slovenia

TRENDS IN THE EU MARKET FOR AUTOMOTIVE FUELS

EU-15

Traditionally EU-15 consumes more diesel than petrol (Figure 3). This is partly due to the fact that petrol has basically just one application – as an automotive fuel (more than 98%), while diesel has a number of applications. Road transport is a core, but not the only large diesel-consuming sector – diesel fuel is used also in rail and sea transport, in various industries, etc. Nonetheless, over the period 1990-2001 diesel demand grew continuously, while petrol usage declined, mainly due to the impact of road transport. The recent increase in the sales of diesel cars resulted in an additional growth in the automotive diesel demand and a further reduction in petrol use (Figure 3).

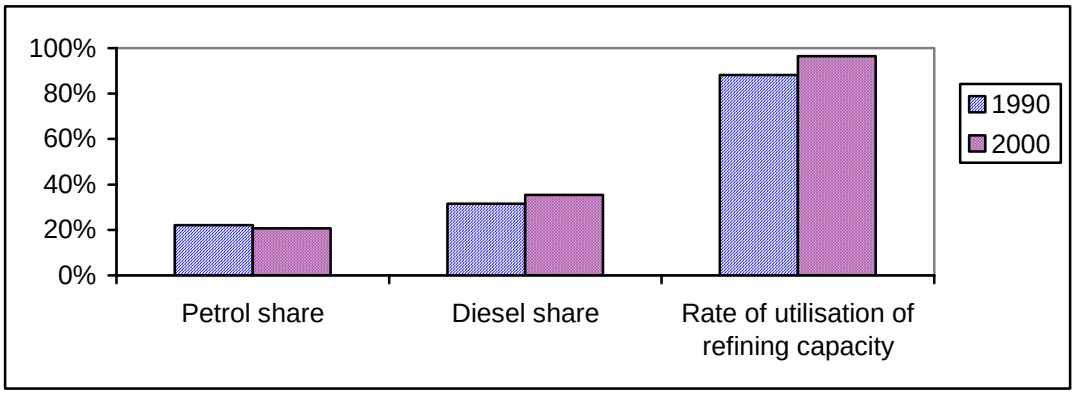
Figure 3
Total consumption of petrol and diesel, diesel consumption in transport and automotive diesel consumption in EU-15 within 1990-2001, (Mt)



Source: Adapted from [15]

So far, the EU refineries were trying to meet the growing diesel demand via increasing diesel fraction, at the expense of petrol fraction, and via optimising the utilisation rate of the refining capacities – Figure 4.

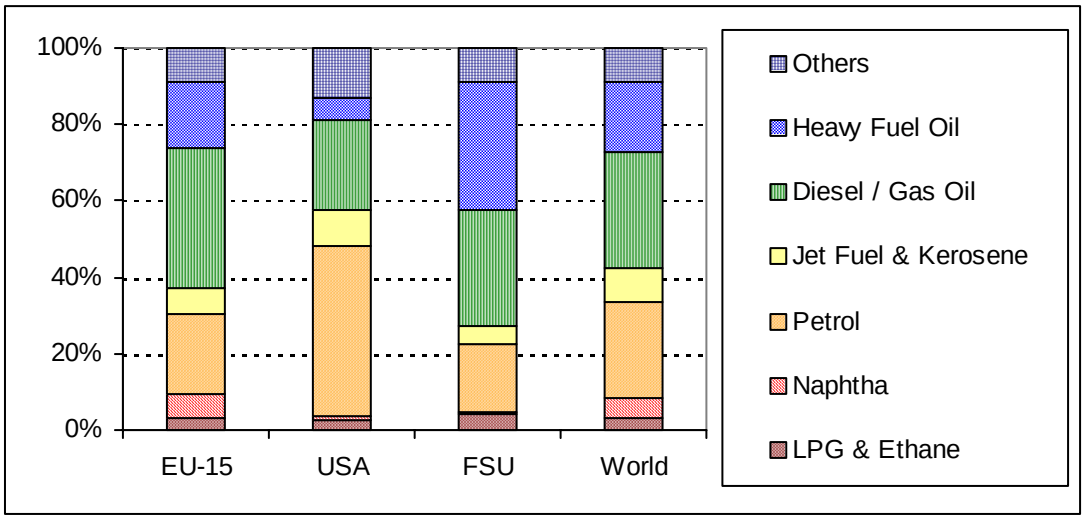
Figure 4
Petrol and diesel refining fractions as shares of gross refinery output, and rate of utilisation of refining capacities in EU-15 in 1990 and 2000, (%)



Source: Adapted from [15]

As a result, EU-15 currently has the largest diesel fraction in the world – Figure 5.

Figure 5
Refinery output breakdown in EU-15, USA, Former Soviet Union (FSU) and in the world in 2001, (%)



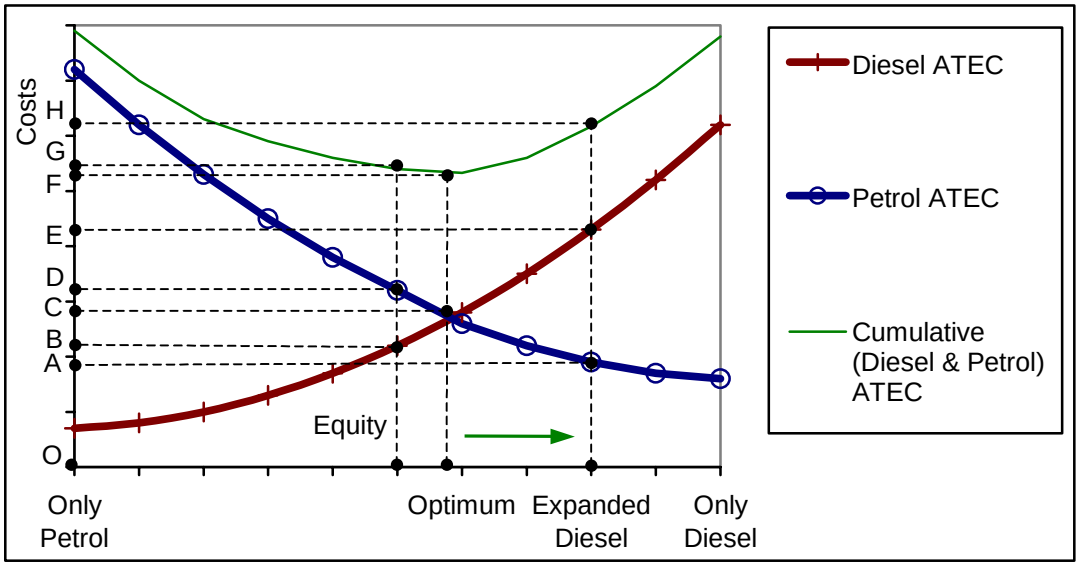
Source: Adapted from [44, 45]

However, there is an upper limit to the reasonable expansion of diesel fraction. The optimal refinery output breakdown by fractions, achieved at minimum energy losses and GHG emissions, is more or less technologically determined. It may vary within relatively narrow margins, depending on the specifications of the oil feedstock. The refinery output can be optimised towards enlarging a certain fraction, but only to a given extent. Beyond this extent, any further expansion of this fraction, at the expense of another one, results in higher energy and GHG costs.

Figure 6 presents a simplified example of optimised refinery breakdown. Only two refining fractions – diesel and petrol – are considered. The average total energy cost (ATEC) is applied as evaluation criterion, however GHG emissions can also be used. ATEC is presented as a function of the expansion of diesel fraction and the reduction of petrol fraction (petrol-to-diesel conversion). The thickness of diesel and petrol curves indicates the variations in ATEC, due to the differences in quality specifications of various crude oil brands. For simplicity, the cumulative ATEC for petrol and diesel is given on average, without taking into account the crude oil-specification variations. The “Equity” position on the diesel fraction axis marks the equal split between petrol and diesel yield. The “Optimum” position on the same axis marks the proportion between petrol and diesel, for which their cumulative ATEC reaches its minimum.

Figure 6 displays a refinery production that is optimised in favour of diesel. The cumulative “Equity” ATEC is higher than the cumulative “Optimum” ATEC (OG>OF on the cost axis). On the other hand, a further enhancement of diesel yield beyond the “Optimum”, e.g. to the

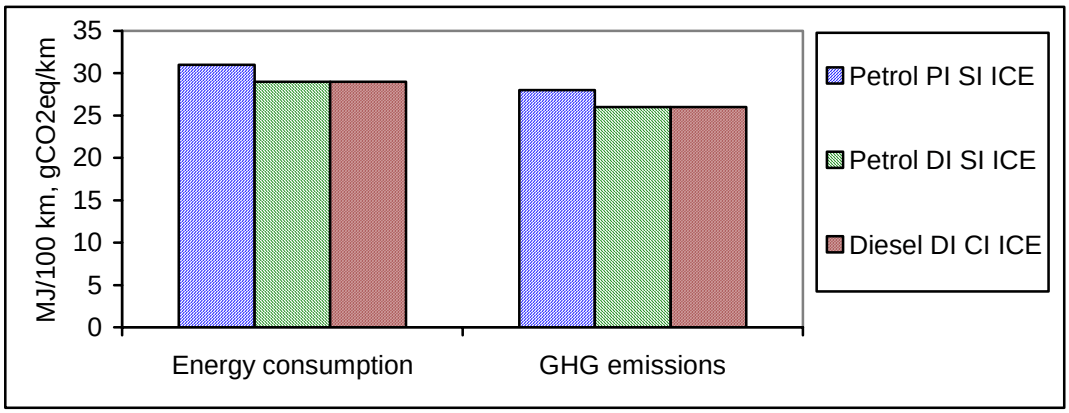
Figure 6
ATEC co-relation of petrol-to-diesel conversion and vice-versa[6], depending on the extent of diesel fraction



"Expanded Diesel" position on the diesel fraction axis, results in higher cumulative ATEC (OH>OF on the cost axis). Here, the marginal increase in diesel ATEC is larger than the marginal reduction in petrol ATEC (CE>AC on the cost axis), due to the decreasing marginal utility rule. Nevertheless, the increase in the cumulative ATEC at the refineries can be still fully offset in WTW by the much higher efficiency of diesel CI ICE, compared to petrol SI ICE[7].

Upon applying the co-relations from Figure 6 to the prevailing energy cost of producing petrol and diesel in the EU (Figure 7), it appears that the reasonable extent of this petrol-to-diesel conversion has been either already reached, or in the best case it is about to be achieved.→

Figure 7
Prevailing (2002) WTT energy requirements (MJ/100 km[8]) and GHG emissions (gCO2eq/km) for petrol (PI SI ICE and DI SI ICE) and diesel (DI CI ICE) in the EU



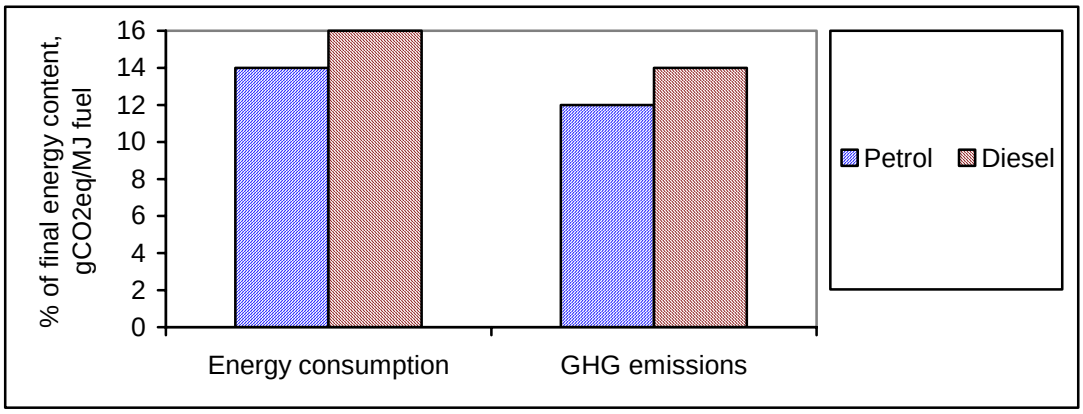
Sources: Adapted from [38]

[6] The curves are indicative, so they do not reflect any exact values for petrol and diesel costs in the EU.
[7] See Figure 1 and the explanatory footnote from its caption
[8] WTT figures about energy cost as a percentage of final energy content of the fuel are not available in [38].

Diesel fraction is obtained at energy cost and GHG emissions, which are only slightly lower or similar to those of petrol fraction. Referring back to Figure 6, this means that the breakdown between diesel and petrol yields is placed somewhere between “Equity” (since OB<OD on the cost axis) and “Optimum” (OC on the same axis).

Due to the continuously increasing demand for diesel, diesel yield is projected to expand, while petrol production to decline further by 2010 [38]. As a result, diesel will become clearly more energy and GHG-intensive than petrol (Figure 8).

Figure 8
Prospective (2010) WTT energy requirements (% of final energy content of fuels) and GHG emissions (gCO2eq/MJ fuel) for petrol and diesel production in the EU[9]



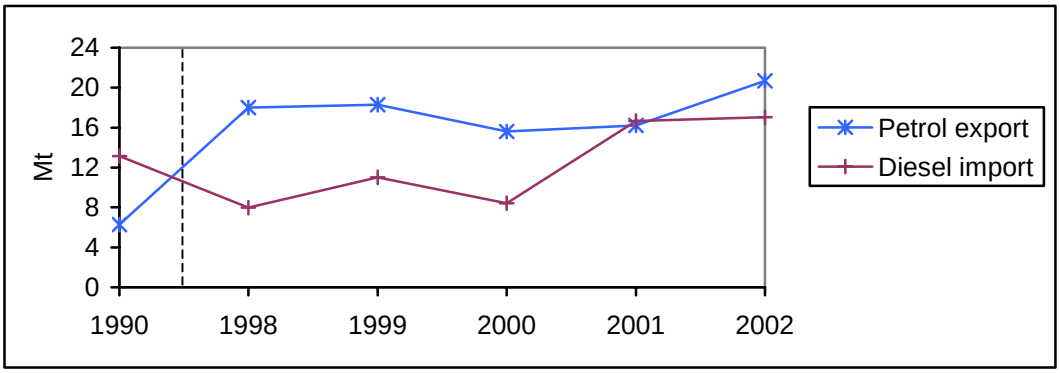
Sources: Adapted from [1, 38]

Back again to the co-relations from Figure 6, this means that definitely the proportion between diesel and petrol will move beyond the “Optimum” position versus the “Expanded Diesel” position, leading to increased cumulative ATEC.

However, even the recent additional growth in diesel refinery output appears insufficient to meet the still increasing automotive demand. Conversely, the reduced production of petrol still exceeds its automotive consumption. The expanding gaps between the automotive demand and supply by fuel brands are covered via diesel imports and petrol exports. As a result, the EU, which was already long in petrol and short in diesel before the recent growth in the sales of new diesel cars, just deepened its unbalance by types of automotive fuels (Figure 9). On top of that, the EU foreign exchange in petrol and diesel is not balanced by regions either. The EU exports petrol mainly to the USA, while it imports diesel predominantly from the FSU. This fuel-exchange schema still works, if on the world fuel markets there is enough demand for petrol and sufficient supply of diesel, whose specifications meet the EU fuel quality standards. The prospects look however slightly different, as discussed in the following paragraphs.

[9] The WTT differences between petrol and diesel are due exclusively to the refinery component, since the remaining WTT components, e.g. transportation, storage, etc., are basically the same for petrol and diesel [see 38].

Figure 9
Net export of petrol and net import of diesel from/to EU-15 in 1990 and within 1998-2002 (Mt)

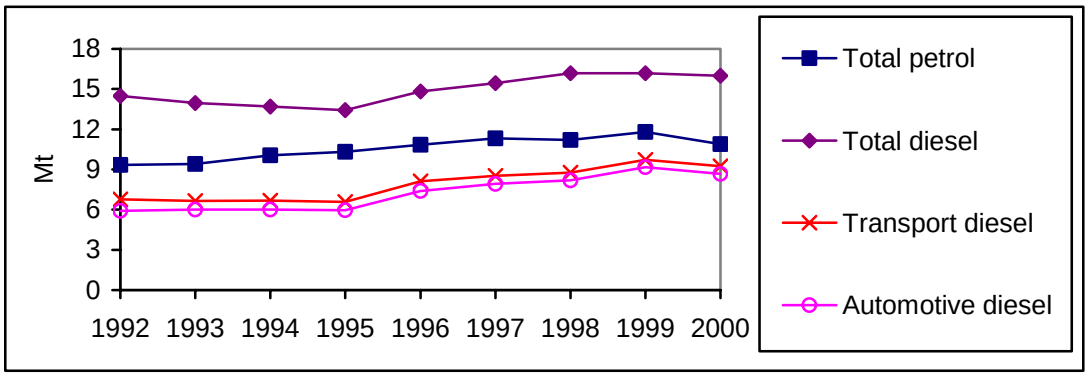


Source: Adapted from [40, 43]

NMS-10

The EU enlargement, that took place in May 2004, is not expected to improve the unbalance in diesel and petrol consumption, but rather to make it even worse. It is true that petrol automotive demand in NMS-10 is still larger than that of diesel. However, the gap between automotive diesel and petrol is getting more and more narrow – Figure 10.

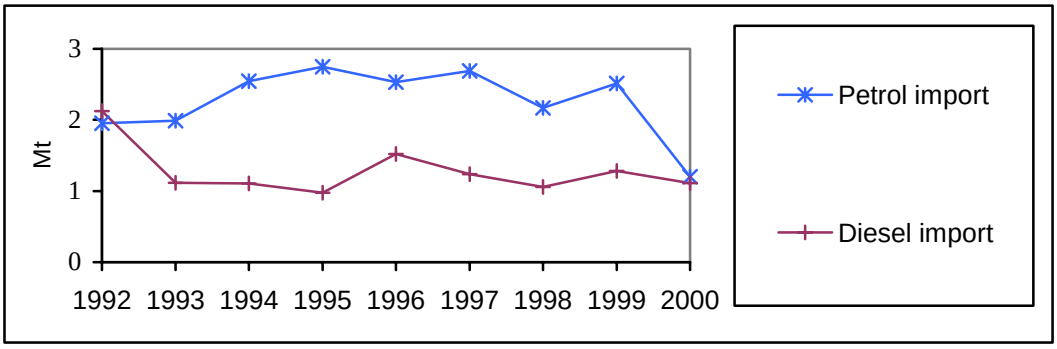
Figure 10
Total consumption of petrol and diesel, diesel consumption in transport and automotive diesel consumption in NMS-10 within 1992-2000, (Mt)



Source: Adapted from [15]

On the other hand, the consumption of petrol and diesel in NMS-10 represents only about 8% of petrol and 6% of diesel use of EU-15. Thus, the aggregate graph for petrol and diesel consumption in enlarged EU-25 (EU-15 plus NMS-10) would be basically the same as that for EU-15 (Figure 3). Finally, NMS-10 are even in a more complicated situation than EU-15, since they are forced to import both petrol and diesel (Figure 11). Hence, the EU-25 export availability of petrol most probably will be slightly reduced, but diesel imports will grow further.

Figure 11
Net import of petrol and diesel to NMS-10 within 1992-2000 (Mt)



Source: Adapted from [15]

OPTIONS TO INCREASE DIESEL SUPPLY IN THE EU

In the context of the above analysis, there are three options to increase diesel supply in the EU by 2010.

The first is qualitative increase of diesel supply via optimising the refinery output. As already stated, the reasonable upper limit of this optimisation appears as being already (almost) reached in the EU. Further expansion of diesel fraction is associated with higher energy costs and GHG emissions at the refineries.

The second alternative is quantitative increase of diesel supply via constructing new refining capacities. However, this option does not seem very appropriate either, because it would mean a parallel growth in petrol. In addition, the effect on the overall diesel availability will be in any case delayed, possibly beyond 2010, due the time needed to construct new refining facilities. An indirect proof for the low viability of this option is the negligible expansion in the EU refining capacities over the period 1990-2000 – 0.2% only [15] – despite the stable diesel imports.

The third option is diesel production from alternative feedstock. Several alternative ways of producing diesel are currently investigated – Gas-To-Liquid (GTL) processing of natural gas, coal or biomass [“Fischer-Tropsch” diesel] and oil extraction from oilseed (biodiesel). However, due to a number of techno-economic constraints, all these pathways do not appear able to provide substantial quantities of diesel at a reasonable cost by 2010 [49, 50].

Summarising the above, it seems that further growth in diesel demand in the EU will be met predominantly via additional imports. Considering the projections about the dynamics in the

automotive diesel consumption in the EU, the share of imported diesel in total diesel consumption might increase from the current level of 7% to about 20% by 2010[10].

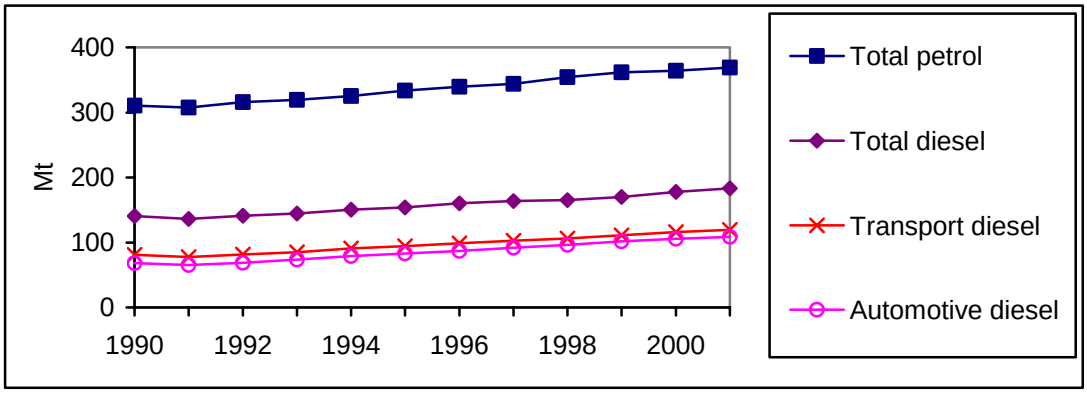
[10] Forecasts about total diesel consumption in [31] are not given, but projections about transport diesel consumption are available. The share of transport diesel consumption in total diesel consumption is about 60% – adopted from [43]. So, the probable amount of total diesel consumption in the EU is calculated via extrapolation. According to [15] and [43], no significant growth occurred over the past few years either in refining capacities, or in diesel production. Such a significant growth until 2010 is not foreseen either [51]. Thus, it is expected that the additional increase in diesel demand will be met mainly via imports. A 20% diesel import share comes out of the projections in [56] as well.

TRENDS IN PETROL AND DIESEL DEMAND IN THE USA, FSU AND WORLD-WIDE

USA

The USA, which are the main recipient of the petrol, exported by the EU, have the largest motorisation rate[11] in the world [31]. Unlike the EU, the US fleet of passenger cars consists mainly of petrol vehicles. For that reason, petrol demand in the USA exceeds by far diesel use (Figure 12), turning the country into the largest single petrol consumer in the world.

Figure 12
Total consumption of petrol and diesel, diesel consumption in transport and automotive diesel consumption in the USA within 1990-2001 (Mt)

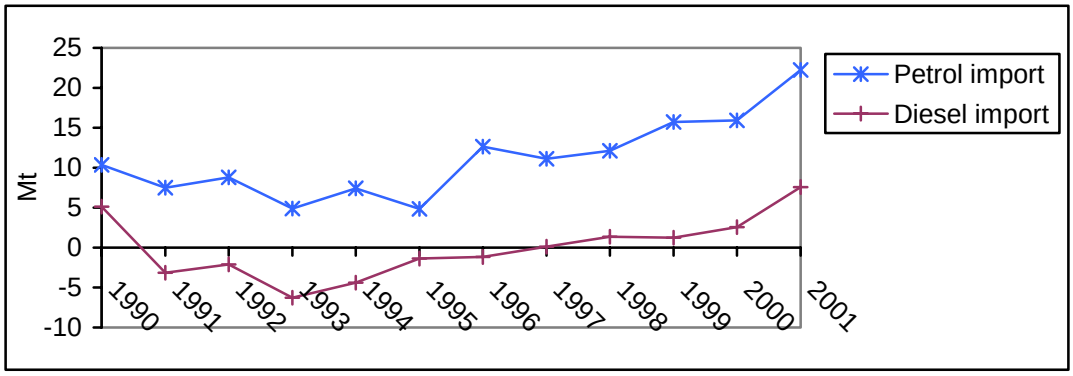


Source: Adapted from [15]

On the contrary, diesel power becomes more and more popular for light-duty vehicles (LDV) – small trucks, pick-ups, sport-utility vehicles, etc. – a segment that experiences a dramatic increase in new registrations. On the cumulative US market for passenger cars and LDV, only 1/3 of the new registrations were LDV in 1990, while in 2002 the number of the newly registered LDV already exceeded the number of the newly registered passenger cars [55]. Consequently, the growth in automotive diesel consumption is faster than the growth in petrol use. In parallel, diesel consumption recently exceeded diesel production. As a result, the USA started to import diesel fuel (Figure 13). The reserves to increase diesel production appear limited at least by 2010, since refining is already optimised versus petrol. An eventual re-design of refineries towards diesel will therefore not bring any benefits to the automotive fuel market. In such a case, replacing diesel imports by internal production will in parallel result in reduced internal petrol production and hence – higher petrol imports. Furthermore, there will be a large increase in production costs, due to the redesign of refineries. In addition, in fact there are no spare refining capacities available – their current utilisation rate is more than 97%. The overall process of building new facilities is time-consuming. The probability of getting large additional fuel supply by 2010 is therefore not very high. In brief, it seems that by 2010 there will be still a large import demand for petrol, but it is not unlikely for the USA to shift from a modest exporter to a large importer of diesel.

[11] Number of passenger cars per 1,000 persons

Figure 13
Net import of petrol and diesel to the USA within 1990-2001, (Mt)

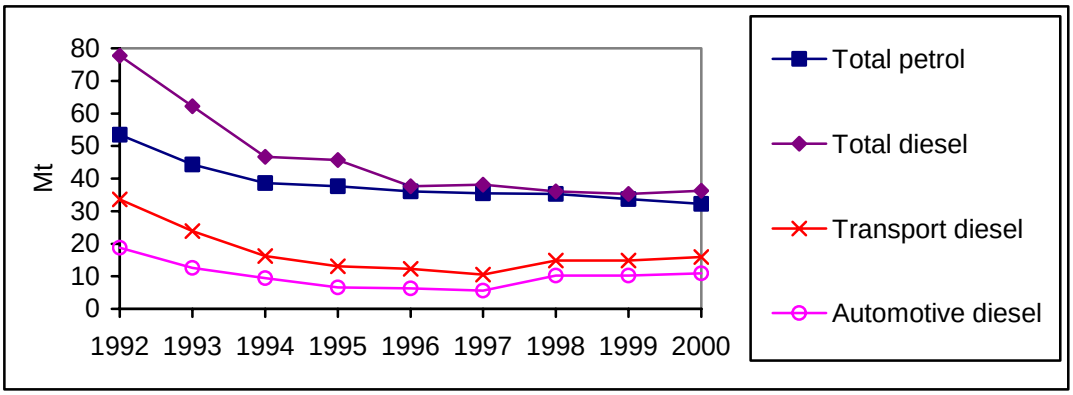


Source: Adapted from [15]

FSU

After the substantial political, economic and social changes in the FSU in the beginning of '90s, the internal consumption of petrol and diesel reduced significantly (Figure 14).

Figure 14
Total consumption of petrol and diesel, diesel consumption in transport and automotive diesel consumption in the Commonwealth of Independent States (CIS)[12] within 1992-2000, (Mt)



Source: Adapted from [15]

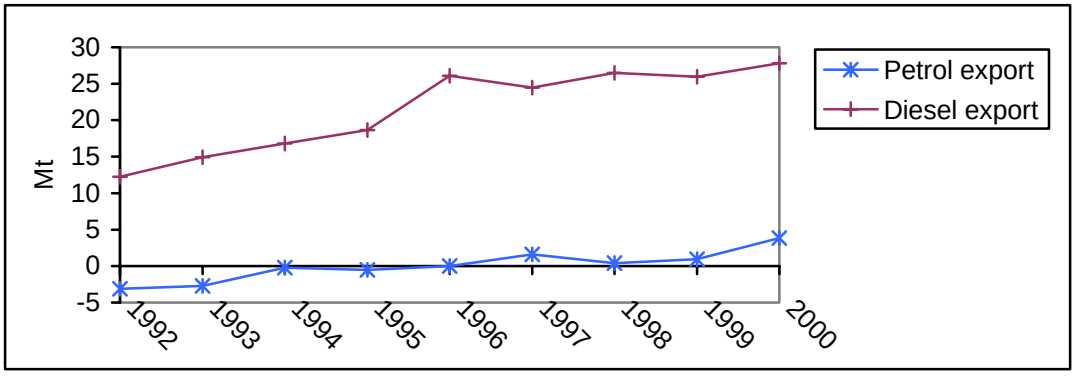
The relative reduction in total diesel consumption was larger than that in petrol but the absolute diesel use still exceeded that of petrol. With regard to road transport, petrol is still the preferred fuel, but a clear sign for increasing diesel application, at the expense of petrol, is observed – Figure 14. As a result, a reduction in diesel export availability (Figure 15) can occur. If the economy recovers to the level at the end of the '80s, diesel exports might be even cut.

Unlike the EU and the USA, the utilisation rate of the refining capacities is very low – about 46%. The efficiency of the FSU refineries is also assumed to be well below that e.g. in the EU [15, 42, 47]. The refinery output is optimised towards heavy fractions, which does not

[12] Different sources use different aggregations of the countries from the FSU. Where possible, the CIS, rather than the FSU aggregation is applied, since Estonia, Latvia and Lithuania (FSU republics) are amongst the NMS-10.

correspond to the world trends of maximising middle and light distillates fractions (diesel, gas oil, kerosene, jet fuel, petrol) – Figure 5 – driven by the market demand.

Figure 15
Net export of petrol and diesel from the CIS within 1992-2000, (Mt)



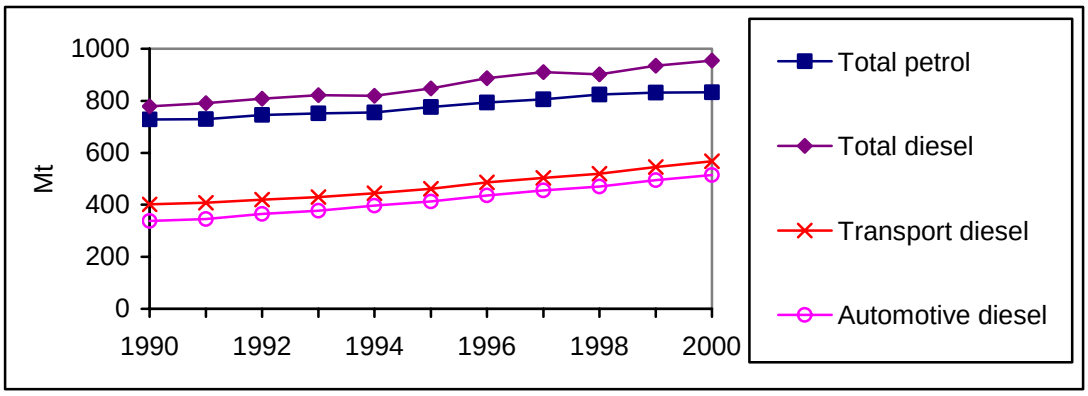
Source: Adapted from [15]

An eventual increase of the utilisation rate would therefore not bring much additional petrol and diesel to the aggregate supply, while the availability of heavy fractions with limited market realisation will be substantially expanded. Conversely, upgrading the refining capacities versus another fraction, e.g. diesel, appears to be quite expensive, since the refining process should be essentially re-designed [15, 42, 47]. The feasibility of such a re-design in real terms is questionable, at least by 2010, because of the time needed for construction and the uncertainties with the investment procurement.

WORLD

World consumption of both petrol and diesel increased recently, but the growth in diesel was larger than in petrol. Transport and especially – road transport was the key sector that contributed to this fast increase in diesel application (Figure 16).

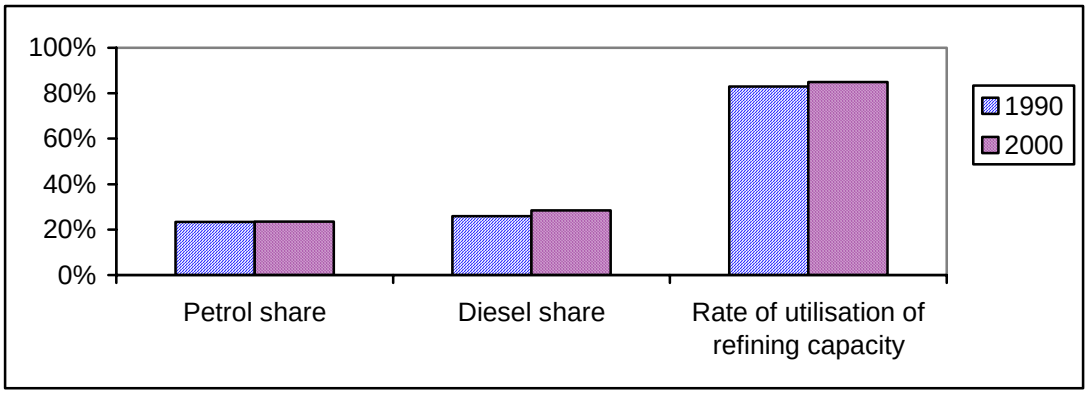
Figure 16
Total consumption of petrol and diesel, diesel consumption in transport and automotive diesel consumption in the world within 1990-2000 (Mt)



Source: Adapted from [15]

In order to meet the growth in diesel demand, world refinery output of diesel was gradually expanded (Figure 17). Combined with the improved utilisation rate of refining capacities, this led to an absolute increase in global diesel supply.

Figure 17
Petrol and diesel refining fractions as shares of gross refinery output, and rate of utilisation of refining capacities in the world in 1990 and 2000, (%)



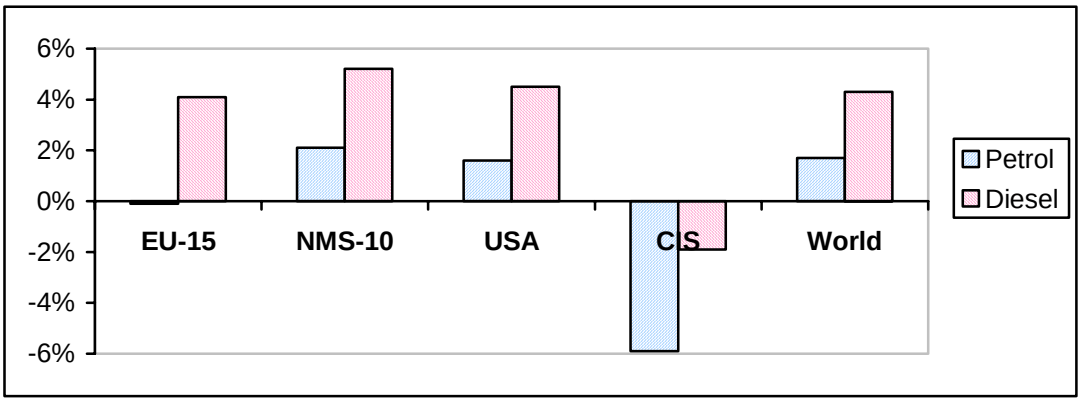
Source: Adapted from [15]

However, upon comparison with the EU, where the feasible upper limit of diesel fraction has been already (almost) reached, the reserves for further increase of world diesel output do not seem to be very large. Considering the extent of the reasonable petrol-to-diesel conversion in the EU and the internal proportions within the middle distillate fraction (jet fuel and kerosene plus gas and diesel oil), they appear to range within 3-4% at the maximum. Thus, if the growth in world diesel consumption continues at the same rate, there would be a risk from appearance of world diesel deficits by the end of the assessed period – 2010.

SUMMARY

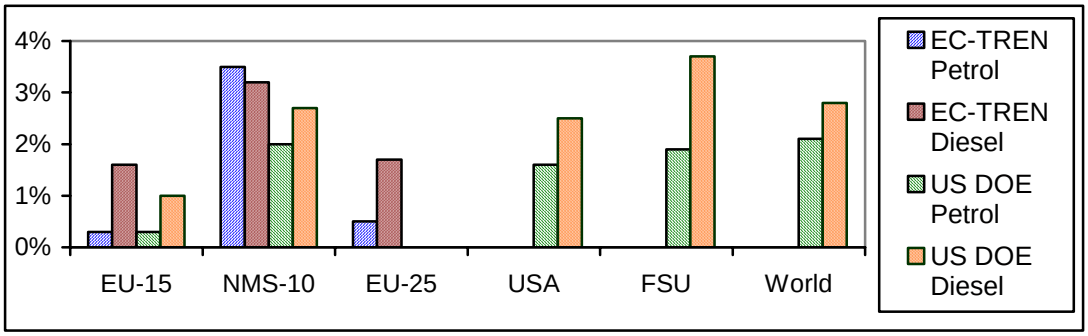
Figure 18 summarises the findings about the recent trends in the automotive demand for petrol and diesel in EU-15, NMS-10, USA, CIS and world-wide.

Figure 18
Average growth in the automotive petrol and diesel consumption in EU-15, NMS-10, USA, CIS and worldwide over the period 1990-2000 /the average figures for NMS-10 and CIS are for the period 1992-2000/, (% per year).



The obvious conclusion from Figure 18 is that all regions experienced larger growth in diesel than in petrol. The projections about consumption trends in diesel and petrol (Figure 19) basically do not differ from the recent evolution (Figure 18).

Figure 19
Projected trends in automotive petrol and diesel consumption in different regions for the period 2000-2020 (average % increase per year)

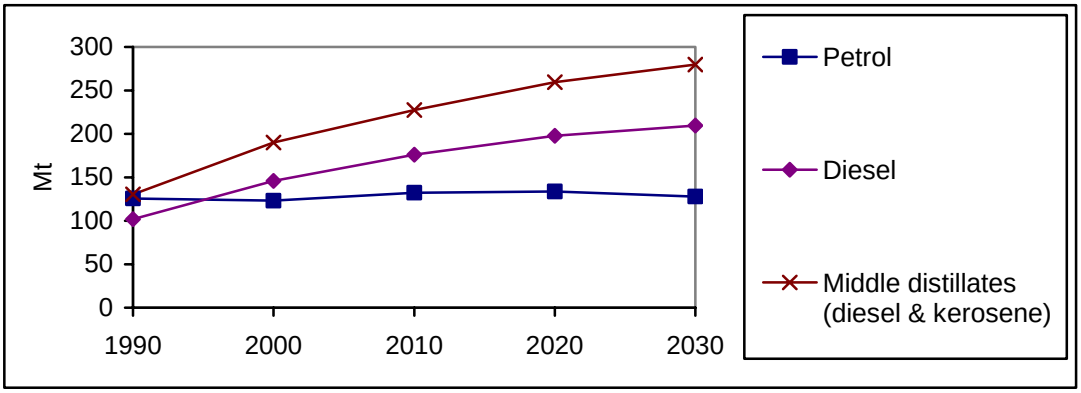


Source: Adapted from [31, 54]

With the exception of NMS-10, diesel demand is expected to grow faster than petrol use everywhere in the world. Within EU-25 the impact of the larger petrol growth in NMS-10 will be however fully offset by the much higher increase in diesel consumption in EU-15. Such a scenario means a further pressure on world diesel supply, i.e. on the refineries to provide sufficient quantities of diesel at reasonable cost. This could have negative impacts on the security of energy supply of the EU. With recent trends in world automotive fuel consumption, the diesel market will tend to become more a buyers' governed market, where the demand from the existing customers is likely to increase along with the appearance of new customers. On the contrary, the petrol market will tend to turn more into sellers' governed market, where the USA will be the major customer.

The pressure on diesel supply most probably will increase further, because of the projected boom in air traffic [23] and the respective large growth in kerosene demand – Figure 20.

Figure 20
Retrospective and projected consumption of petrol, diesel and middle distillates (diesel and kerosene) in the transport sector of EU-25 (Mt)



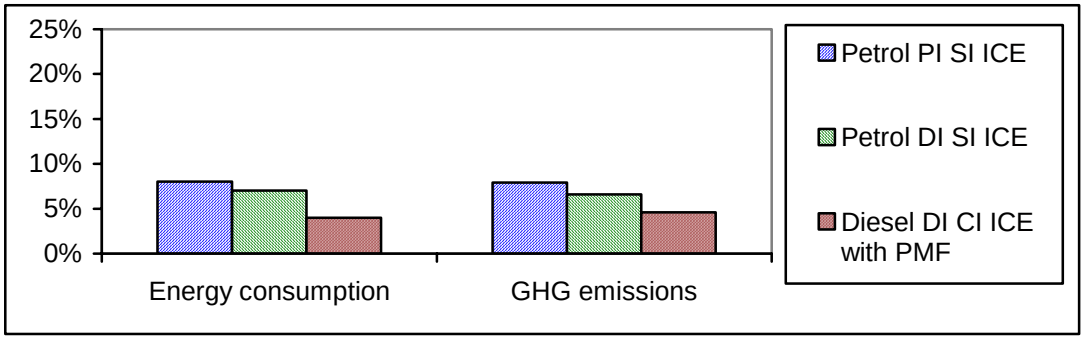
Source: Adapted from [31, 32]

Kerosene is the principal air transport fuel, since blends of different kerosene types (jet fuel) are used in aircraft turbines. Aviation gasoline, which has similar properties to automotive petrol, has a very limited application, only in piston engines [4]. Like diesel, kerosene is a middle distillate fraction from oil refining (Figure 5). Hence, the aggregate pressure on the middle distillate fraction appears to get even stronger than that on diesel solely.

ENERGY EFFICIENCY AND EMISSION PERFORMANCE

As indicated in Figure 1, at present diesel engines are more efficient than petrol engines, so they have lower energy consumption and GHG emissions. This situation is not expected to turn opposite in favour of petrol, but some changes are likely to occur. Over the past few years, car manufacturers were putting more efforts in developing diesel engine rather than petrol engine. As a result, a number of new technology improvements were introduced for the diesel power-train, e.g. direct injection, electronic injection, high-pressure injection (including the common rail system), turbo-charging, etc. Not all of these new technology solutions were applied to the petrol engine. As a result, diesel engine became relatively more advanced than petrol engine. Thus, most prevailing comparisons between diesel and petrol engines are done in fact on unequal terms, juxtaposing technologies at different stage of development. For the same reason, it is also considered that petrol engine has a larger potential for further improvement (10-15% by 2010) than diesel engine (only 2-6% by 2010), whose potential has been already to a large extent explored [2]. Consequently, the differences in energy consumption and in GHG emission per km. between petrol and diesel cars, when compared on equal footing (e.g. DI SI vice-versa DI CI) are projected to decrease to 6-7% only by 2010 – Figure 21.

Figure 21
Projected by 2010 relative excess of the WTW energy consumption and GHG emissions per km of petrol in PI SI ICE and DI SI ICE, and diesel in DI CI ICE with particulate matters filter (PMF), compared to diesel in DI CI ICE without PMF as a baseline (%)



Sources: Adapted from [38]

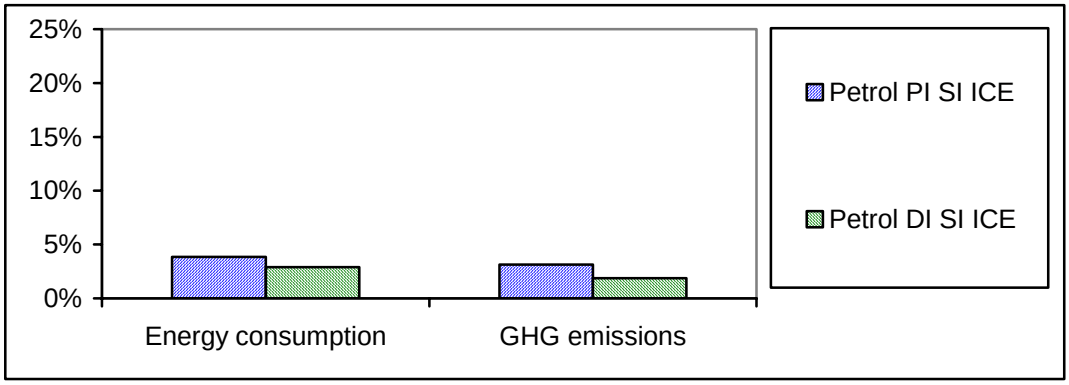
The projections in Figure 21 are for fuels, which are produced within the EU. Considering that more and more diesel will come from import, it is not unlikely that the actual WTW values will be slightly higher. The increase might come from a potential lower efficiency of the supplying foreign refineries, e.g. as it is assumed for the refineries in the FSU [15, 42, 47][13]. The additional energy and GHG costs, incurred along the transportation of the imported diesel, would represent another, but small [38] complement to the overall WTW balance.

[13] Unfortunately, representative data about WTT efficiencies, energy consumption and GHG emissions of the FSU refineries were not found. Anyhow, as it has been already stressed, GHG are not a regional, but a global issue. A reduction of GHG emissions in one part of the world at the expense of a larger increase of GHG emissions in another part of the world means a net increase of GHG, i.e. contribution to global warming and climate changes.

FUEL QUALITY STANDARDS

In addition to the measures for reducing GHG, the EU is aiming also at decreasing the emissions with impact on local air quality. In this context, the new emission standard EURO 4, replacing current EURO 3 standard in the beginning of 2005, will impose lower limits for a set of local pollutants in the EU – Annex 2. The reduction of nitrogen oxide (NOx) emissions from diesel engines is normally accompanied by an increase in particulate matters (PM) emissions and fuel consumption. Due to the NOx/PM trade-off, some after-treatment technologies might be needed – lean de-NOx catalysts or PMF. The automotive industry believes that the recent improvements in diesel technology will allow the new diesel passenger cars from the lowest class (1) from Annex 2 to meet simultaneously the EURO 4 limits for NOx and PM without additional equipment, e.g. PMF [6]. If this cannot be achieved in practice, the introduction of PMF will be necessary. In such a case, the energy consumption and GHG emissions per km. for diesel will be further increased and the gap with the comparable petrol option (DI SI ICE) will come down to a negligible 2-3%.

Figure 22
Projected by 2010 relative excess of the WTW energy consumption and GHG emissions per km of petrol in PI SI ICE and DI SI ICE, compared to diesel in DI CI ICE with PMF as a baseline (%)



Sources: Adapted from [38]

The introduction of tougher emission regulations takes place not only in Europe, but in other regions as well, e.g. the new TIER 2 standard in the USA. TIER 2 and EURO 4 are not directly comparable, as they look at slightly different pollutants, however the combined impact of both regulations will be an increase in the demand for cleaner fuels [13, 52, 53]. Meeting the stricter environmental regulations appears to be generally more difficult and more costly for diesel, rather than for petrol. This is partly due to the fact that the proper performance of a number of the new sophisticated improvements in the diesel technology requires cleaner fuel (especially with a low sulphur content[14]) with strictly determined and maintained specifications

[14] Currently in the EU the sulphur content limits are 350 ppm for diesel and 150 for petrol. As from 2005 they will get down to 50 ppm, while the application of only sulphur-free fuels (sulphur content below 10 ppm) as from 2009 has been imposed [37]. The new U.S. emissions limits for 2007-2010 are set up based on the assumption that exhaust after-treatment for NOx and PM will be available and that sulphur in diesel will be capped at 15 ppm starting middle of 2006, in order not to contaminate the exhaust treatment devices [13].

[13]. With growing global demand for diesel, the sufficient availability of such clean diesel can be questioned. Many refineries in the world will be forced to upgrade within relatively short period of time their facilities according to the new requirements. In case of such a large simultaneous modernisation, temporal price and supply disruptions in diesel may occur, due to potential equipment deficits and/or delays in deliveries [13, 56].

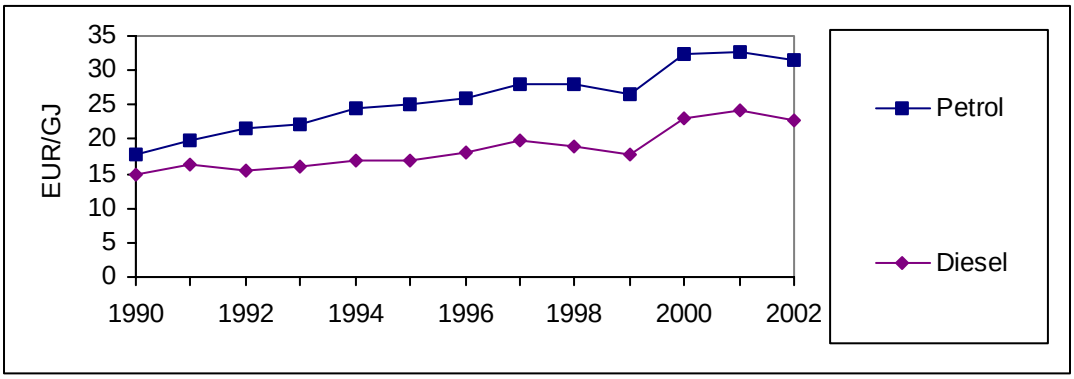
As Figure 7 indicates, recently the energy cost of producing diesel was equal to the energy cost of producing petrol. In parallel, the production costs of diesel and petrol are reported to be also equal – approximately EUR 0.24 per litre ([33], adopted also from [29]). As Figure 8 illustrates, diesel production in the EU will become more energy-intensive than petrol production. On equal terms, this would mean that the average diesel production costs should tend to get higher than the average petrol production costs, at least because of the additional processing at the refineries. The gap between diesel and petrol production costs is likely to widen further, because of the more expensive adjustments of diesel properties at the refineries to the new (as from 2005) fuel quality requirements, compared to petrol. For petrol, the cumulative cost of reducing sulphur content from 150 ppm to 50 ppm and aromatics from 42% v/v to 35% v/v is estimated to be around 6.5 billion EUR[15]. For diesel, only the cost of sulphur reduction from 350 ppm to 50 ppm is projected to amount to about 8 billion EUR[16] [7]. The cost of the additional reduction of sulphur content down to 10 ppm [22, 37] is expected to be 4.8 billion EUR for petrol and 6.7 billion EUR for diesel [8]. Hence, the average impact of the 10-ppm Sulphur on the fuel cost is foreseen to be 0.035 EUR per produced litre of petrol and 0.056 EUR per produced litre of diesel[17] [22]. Conversely, the relative WTW energy efficiency and GHG emissions gains per km. for petrol are estimated to be larger than those for diesel [33].

[15] If the reduction of aromatics comes first, otherwise the cost comes up to about 8 billion EUR [7].
[16] Net Present Values (NPV) by the time of the publication of the report – 1999.
[17] All figures are based on projections for EU-15 only, i.e. the NMS-10 are not considered.

COST ANALYSIS

Traditionally, the automotive application of diesel was promoted in Europe, unlike other regions, e.g. the USA. For this reason, diesel was and still is a cheaper automotive fuel than petrol (Figure 23), mainly due to a lower taxation[18].

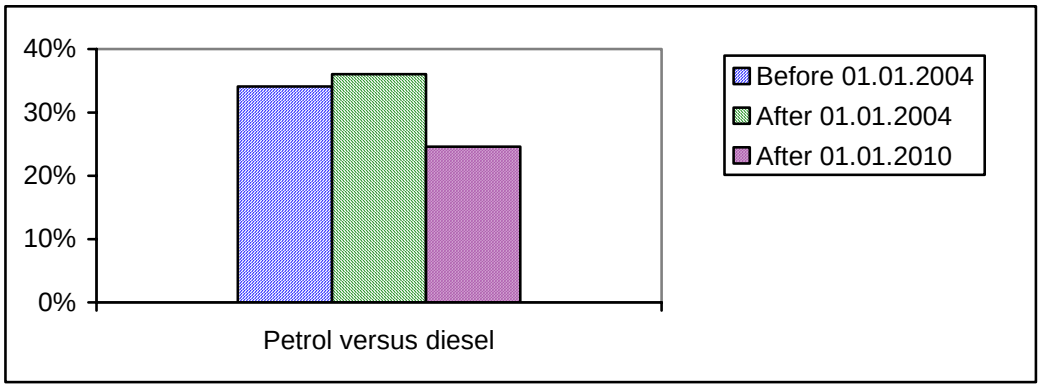
Figure 23
EU-15 – retail price of automotive petrol and diesel (EUR/GJ)



Source: Adapted from [32, 39]

This lower taxation of diesel in the EU is not likely to change in the future, rather to get even more favourable for diesel, at least by 2010[19] – Figure 24.

Figure 24
Relative minimal excise duty surcharge for petrol, compared to diesel (%)

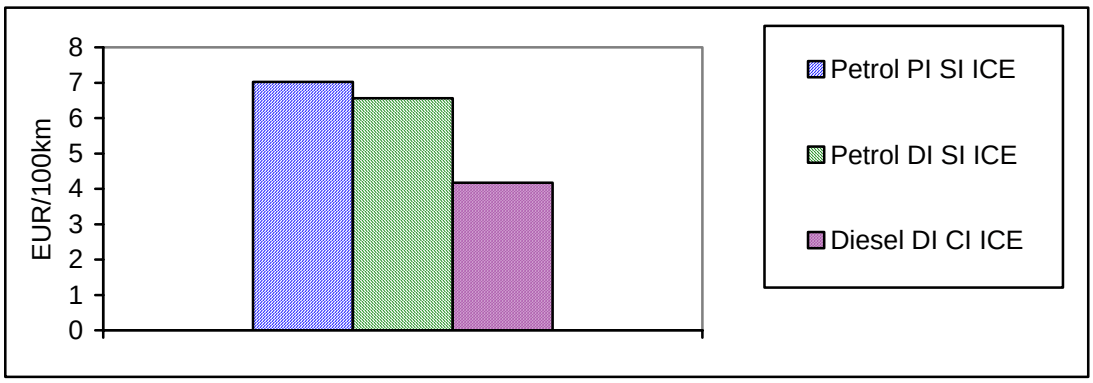


Source: Adapted from [12, 32]

This means that on equal terms driving a diesel car is associated with lower fuel costs per km., compared to driving a petrol car. The higher efficiency of CI ICE, leading to lower fuel consumption, allows further reduction in fuels costs per km. for diesel cars, compared to petrol cars. Consequently, on equal footing the aggregate fuel costs per km. for diesel are much lower than those for petrol – Figure 25.

[18] Since the production costs per litre are equal. However, due to the higher energy content of diesel – 35.7 MJ/l versus 31.2 MJ/l for petrol [39] – diesel production costs per energy unit are about 13% lower than those of petrol. In the USA, the retail price of petrol and diesel recently was equal – about USD 0.38 per litre of each fuel [30].
[19] The actual taxation advantages in favour of diesel over petrol will probably be even larger, since [12] foresees longer transition periods to adjust the national levels of taxation on diesel for a number of EU countries.

Figure 25
Prevailing (2002) fuel costs for petrol in PI SI ICE and in DI SI ICE, and for diesel in DI CI ICE (EUR/100km)



Source: Adapted from [38] and Figure 23

Taking the values from Figure 25, the fuel cost break-even point between diesel and petrol is reached at 38% higher energy consumption for diesel car, compared to petrol cars. The following most likely alternative impacts can be expected in this case:

- ✓ The drivers of diesel cars make the same mileage as the drivers of petrol cars, i.e. the drivers of diesel cars reduce their annual fuel costs. This means that diesel demand is not elastic at all, since it is not affected by any price changes. Diesel cars earn net overall energy and GHG savings over petrol cars, equal to the difference between the energy and GHG efficiency per km. of diesel and petrol cars.
- ✓ The drivers of diesel cars make higher annual mileage, but they still save money, compared to the divers of petrol cars. This means that the growth in annual mileage is lower than the price difference between diesel and petrol. Diesel cars earn net overall energy and GHG savings over petrol cars, if the increase in annual mileage is lower than the difference between the energy and GHG efficiencies per km. of diesel and petrol cars.
- ✓ The drivers of diesel cars make higher annual mileage, compared to the drivers of petrol cars, but they pay the same total fuel costs per year as the drivers of petrol cars. In this case diesel cars earn net overall energy and GHG penalties over petrol cars, as the price difference between diesel and petrol is larger than the difference between the energy and GHG efficiencies per km. of diesel and petrol cars.
- ✓ The drivers of diesel cars make much higher mileage per year than the drivers of petrol cars, actually increasing their annual fuel costs.

This slight paradox, occurring in the last 3 cases, can arise due to the specifics of the aggregate consumer's demand. Normally, the aggregate consumer's demand is relatively constant, defined by the prevailing and expected income. The breakdown amongst different items in the aggregate consumer's demand however tends to be flexible. The relative reduction in fuel costs (in EUR/km.) may result in an absolute increase in fuel costs (in EUR),

because of trade-offs with other items in the aggregate consumer's demand, which may include even not-market driven preferences. Typical examples of such trade-offs are:

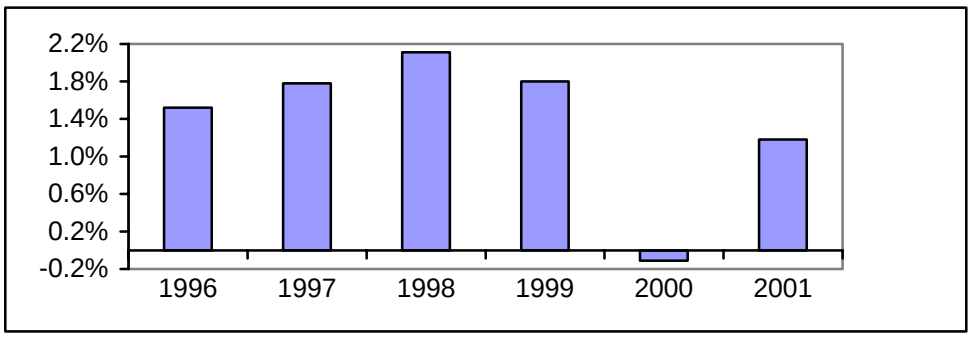
- Enjoying cheaper and more comfortable residence in the countryside, compared to the city alternative (trade-off between rent costs and fuel costs);
- Increased number and length of holiday trips over weekends (trade-off between fuel costs and the sense of freedom, having impact e.g. on the health expenditure);
- Increased number and length of business trips (trade-off between fuel costs and increased income, thanks to extended current or new business opportunities), etc.

At the end, the recent substantial development and improvement of road network in the EU gives customers additional incentives to increase their annual mileage. Hence, the drivers of diesel cars get additional incentives for further financial benefits, compared to the drivers of petrol cars.

It is challenging to identify exactly the potential impact of the fuel cost advantages of diesel on driver's behaviour. This is due to the fact that the structure of the statistical indicators, which may suggest such trends, e.g. overall energy consumption and GHG emissions, annual mileage, etc., is rather complex. For instance, the overall energy consumption and GHG emissions are in direct proportion of vehicle's weight, engine displacement and power, etc. – vehicle parameters, whose average values recently grew in the EU [17]. The average annual mileage also depends very much on the business cycles of the economic system. Last, but not least, the impacts of economic processes are usually peculiar with a certain time delay. So, at first the drivers of diesel cars most probably will just enjoy the lower fuel expenditure. Later on, they probably will adjust the breakdown amongst the items in their aggregate consumer's demand according to the relative priorities, which are flexible. The appearance of new items in their aggregate consumer's demand is not impossible either. All these reasons mean that making projections with a high extent of confidence is presently constrained by the lack of enough statistical proofs accumulated. Nevertheless, the latest available data about GHG emissions in the EU show that the positive impact of the enhanced application of diesel cars might not be so evident. Within 1999-2001 transport registered a new increase in its CO2 emissions – 0.9% per year on average, while the annual average growth in the automotive CO2 emissions was even larger – 1.3% [28, 30, 32]. The general upward trends in the annual mileage basically didn't change substantially either (Figure 26). Last, but not least, the relative reduction in person/kilometres[20] in 1999 and 2000 and the following new large increase in 2001 fits the assumption about the delay in consumer's response to the fuel cost benefits, ensuing from the lower fuel price and the higher engine efficiency of the diesel option, compared to the petrol option.

[20] Number of travelling persons multiplied by kilometres travelled

Figure 26
Annual growth/reduction in person/kilometres, performed by passenger cars in the EU within 1996-2001, (%, compared to the previous year)



Source: Adapted from [32]

It is even more challenging to predict the prospective changes in the aggregate consumer's demand of the drivers of diesel cars, due to the difference between diesel and petrol fuel costs, because of the uncertainties with the retail fuel prices. However, considering the recently increased difference between minimum excise duties of petrol and diesel (Figure 24), and the narrowing gap between SI ICE and CI ICE efficiencies (Figure 1, Figure 21 and Figure 22), currently it seems more likely for the gap between diesel and petrol fuel costs to get even larger. This would mean that the drivers of diesel cars would get stronger incentives to re-arrange the priority of items in their aggregate consumer's demand.

CONCLUSIONS

Based on the analysis, performed in the previous paragraphs, the following core conclusions about the probable impacts of the increasing automotive diesel demand, at the expense of petrol, in the EU by 2010 can be highlighted:

- ✓ Potential negatives for the security and diversity of energy supply, as more diesel should be imported and more petrol should be exported at the time of growing demand for diesel and declining demand for petrol in the world.
- ✓ Relative reduction of the WTW energy efficiency and poorer GHG performance per km., due to additional processing at the refineries, decreasing efficiency advantages of diesel cars over petrol cars and new fuel quality standards, whose meeting is associated with higher energy and GHG costs for diesel, compared to petrol.
- ✓ Potential increase of the overall energy consumption and GHG emissions of diesel cars, compared to petrol cars, due to fuel price differences, which strongly favour diesel usage over that petrol application.
- ✓ Increase of diesel production cost, because of exceeding the optimum upper limit of diesel fraction out of oil refining and new fuel quality standards, whose meeting is more costly for diesel, rather than for petrol.

For the above reasons, the EC already expressed its concerns about the continuous growth in diesel car fleet, respectively – in the automotive diesel consumption. The most feasible alternative, suggested by the EC, is further improvement of the petrol engine technology [26, 27]. Most recent engine novelties were elaborated for the diesel technology. Hence, petrol engine contains a larger unexplored potential for additional development than diesel engine [2]. By improving petrol engine and making it competitive to diesel engine in terms of energy consumption and GHG emissions, the balance in the automotive fuel supply by fuel brands and thus – on the automotive fuel market, can be re-established. In this context, the probable near-term and medium-term (by 2010) combined outcome from the feasible extent of improving petrol engine technology and the still increasing diesel demand are summarised in Figure 27.

Figure 27
Near-term and medium-term (by 2010) performance comparison between diesel and petrol cars, in case of continuing growth in diesel consumption and exploration of the technology reserves to improve petrol engine technology

Diesel versus Petrol	Security of energy supply	Energy efficiency (per km. / overall)	GHG emissions (per km. / overall)	Costs
Near-term	+ / O	+ / O	+ / O	O
Medium-term	O / –	O / –	O / –	–

Legend: (+) Moderate benefits; (O) Similar performance, no benefits; (–) Moderate penalties;

ANNEXES

ANNEX 1

CO2 reduction milestones for new passenger cars, sold in the EU, committed by ACEA, JAMA and KAMA

Milestones	ACEA	JAMA	KAMA
By 2000	120 g/km for individual cars	120 g/km for individual cars	120 g/km for individual cars
By 2003	165-170 g/km on average, evaluate the potential to reach 120 g/km on average in 2012	165-175 g/km on average, evaluate the potential to reach 120 g/km on average in 2012	-
By 2004	-	-	165-170 g/km on average, evaluate the potential to reach 120 g/km on average in 2012
By 2008	140 g/km on average	-	-
By 2009	-	140 g/km on average	140 g/km on average
By 2012 (?)	120 g/km on average	120 g/km on average	120 g/km on average

Source: [16, 19, 20]

ANNEX 2

EURO 3 and EURO 4 emission standards for passenger cars (PC) and LDV, (g/km)

	Vehicles / Pollutants	CO	THC	NOx	HC+NOx	PM
E	PC and LDV – petrol, (1)	2.30	0.20	0.15	-	-
U	PC and LDV – diesel, (1)	0.64	-	0.50	0.56	0.05
R	LDV – petrol, (2)	4.17	0.25	0.18	-	-
O	LDV – diesel, (2)	0.80	-	0.65	0.72	0.07
	LDV – petrol, (3)	5.22	0.29	0.21	-	-
3	LDV – diesel, (3)	0.95	-	0.78	0.86	0.10
E	PC and LDV – petrol, (1)	1.00	0.10	0.08	-	-
U	PC and LDV – diesel, (1)	0.50	-	0.25	0.30	0.025
R	LDV – petrol, (2)	1.81	0.13	0.10	-	-
O	LDV – diesel, (2)	0.63	-	0.33	0.39	0.040
	LDV – petrol, (3)	2.27	0.16	0.11	-	-
4	LDV – diesel, (3)	0.74	-	0.39	0.46	0.060

Legend: (1) – vehicle weight below 1,305 kg;
(2) – vehicle weight 1,305-1,760 kg;
(3) – vehicle weight more than 1,760 kg;
CO – carbon monoxide
THC – total hydrocarbons
NOx – nitrogen oxide
HC – hydrocarbons
PM – particulate matters
Source: Adapted from [25]

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