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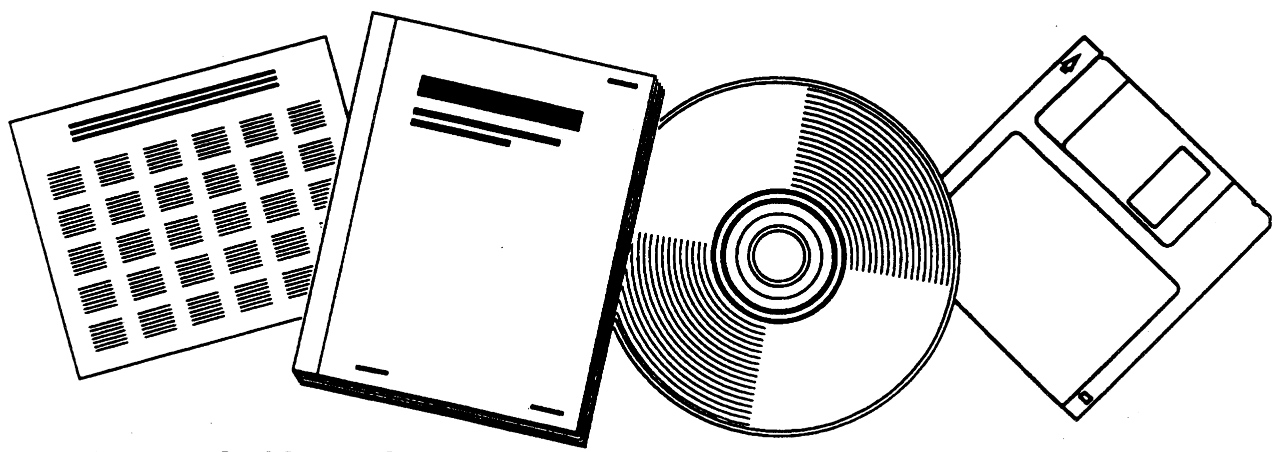

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Regional European Conference in celebration of the
10th anniversary of the
Danish Association for Energy Economics

TRANSPORT, ENERGY AND ENVIRONMENT

CONFERENCE PROCEEDINGS

Regional European Conference
3 - 4 October, 1996

Helsingør (Elsinore), Denmark

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PREFACE

Transportation demands a large and increasing share of total energy consumption in Europe. At the same time many European countries are facing difficult decisions in achieving their long term environmental goals. Therefore energy policy, environmental policy and transport policy should be seen and discussed in a common perspective. In particular the relative contribution from the transport sector and the energy sector involves a number of important and difficult issues.

The conference addressed economic and broader policy issues as well as technological perspectives. Further, focus was primarily on medium to long term aspects. The conference was primarily devoted to European issues, but papers were also addressing global aspects.

The aim of the conference was to bring together economists, scientists, manufactures, energy planners, transport planners, and decision makers in order to discuss the importance of the transport sector in relation to energy demand and long term environmental goals.

General conference sessions covered. Trends in Transport Energy Demand and Environmental constrains, Technological Development and New Transport Systems, Lifestyle Changes and the Transport Sector, Megacities: Solutions to the Transport and Air Pollution Problems, Effectiveness of Public Policies, Transport and Energy sector, and Methods, Models and Data.

The conference took place at Hotel Marienlyst, Helsingør, Denmark and attracted wide interest. The participants represented 14 different countries covering international organisations, ministries, universities, research centres, consulting firms, industry etc. The conference was organised in 6 sessions.

The conference concluded with a panel discussion addressing the important issue of national vs. international aspects of transport, energy and environment.

The conference was organised as a regional European conference in celebration of the 10th anniversary of the Danish Association for Energy Economics. The conference was organised jointly with the International Association for Energy Economics (IAEE) and European Foundation for Co-operation in Energy Economics (EFCEE).

Finally we would like to take this opportunity to thank all those who contributed to the success of the conference: The authors of the papers, the keynote speakers and the members of the committees.

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Conference Programme Committee

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Chairman:
Hans Jørgen Koch, IEA, Paris

TRANSPORT AND ENERGY POLICY - LOOKING TO THE FUTURE

By Timo Aaltonen, European Commission, Belgium

1 OBJECTIVES

In the quest of filling human needs, transport and energy do not appear to be the most exciting territories. They come in only later in the vast chain of commodities and services necessary in the smooth operation of a modern market economy. However, current concerns about pollution and the future of our planet have lifted these issues to the top of the agenda.

The objective of this paper is to give a glance at the complexity of possible futures facing us. Indeed, one of the main objectives is to show that there are different paths to be taken and we can influence our future. Furthermore, it will be shown that a key element in planning for different futures is the proper choice of energy policy objectives and instruments. An even bigger impact could be expected from the changing paradigms in transport demand patterns.

But, before leaping into the future, it will be useful to look at the energy policy guidelines that are being created. They are not only important at present, but they are also paving the way for the future by laying the foundation and stating the goals. These guidelines are in the Commission's White Paper on energy policy, published in January 1996, after the debate started by the Green Paper a year earlier.

In the process, four priorities were identified as the basis for energy policy. These are:

1) integration of the market. Building internal energy markets and a level playing field for everyone, as well as creating a favourable climate for investments in the energy sector, will work constructively not only for the energy sector but for the whole European economy;

2) managing external dependency. Given the geopolitical situation in oil markets, diversification and co-operation measures have an important role in policy-making. One of the aspects mentioned in relation to transport is the need for expanding the fuel mix;

3) sustainable development. Environmental aspects must be taken fully into account in energy business. Pollution abatement equipment, energy efficiency and renewables are some of the measures at hand;

4) changes in technology have contributed to significant changes in paradigms in the past. There is no reason to believe that this will not happen in the future, too. Therefore, research and technology are recognised as important elements in current and future policy-making.

These four cornerstones are designed to support energy policy-making. It is important that all Community instruments should be activated by common aims.

2 WHAT DOES THE FUTURE LOOK LIKE

Transport is the largest single energy consumer in OECD countries. However, it is only slightly larger than industry and domestic/tertiary sectors and without taking any liberties with numbers, it can be said that the three sectors are equally big and they all consume one-third of final energy demand. It is in the growth figures where the difference can be seen. IEA forecasts the industry to be the slowest growing sector (1.8 - 2.2 % p.a.), transport being the fastest one (2.2 - 2.6 % p.a.). This development is even more apparent outside the OECD area. Transport is still highly oil-dependent, but in the other sectors the importance of oil has clearly diminished. On balance we can expect that geopolitics involved in oil production will continue to be an important issue in the future.

The continuing use of oil in the transport sector is one of the reasons that transport is a crucial factor in climate change discussions. At the European level, it will be the biggest source of new CO_2 emissions and the major contributor to increase in energy use with a growth rate between 0.8 and 1.4 % till 2020.

Transport energy intensity is improving, but behavioural factors will have an adverse effect. People are changing to bigger and more powerful cars. The result of all this is that private transport energy use will not decline in pace with improvements in motor and car technology.

Renewables are gaining importance in European policy-making. They seem to have many preferable features. They are CO2 neutral, they can increase local employment and they add to the security of energy supply. Therefore, biofuels could meet some 10 % of the transport fuel mix by 2020. This figure is, however, highly policy dependent.

3 WILL POLICY MAKE ANY DIFFERENCE

Figure 1 shows scenarios on transport energy demand in Europe. Each of the four lines on the graph corresponds to one feasible outcome given the underlying policy approach. Conventional wisdom (CW) is almost like business as usual, but it incorporates the idea of technological advancement. Forum (FO) is about public action and efficient institutional approach to complex shared problems. In Battlefield (BF), contradictions and instabilities result into fragmentation and blocs. Hypermarket (HM) is a scenario of global economic integration and high level of liberalisation.

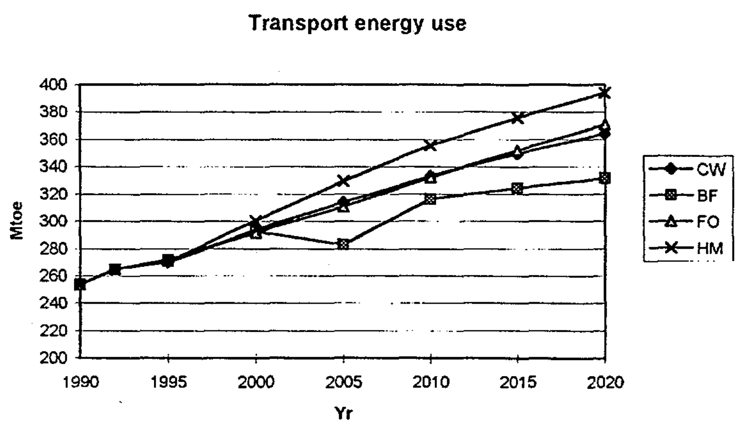

Figure 1. Transport energy scenarios (source: European Energy to 2020).

What is the message of the scenarios? Energy demand grows in all of them, and it would take a draconian policy to reverse the trend. At this point it should be noted that all policies in these scenarios are mainly working on the supply side of transport, although everything is finally interdependent in an economy.

But, these supply-side policies can make a difference. The highest scenario has 16 % more transport energy demand than the lowest one. To conclude, while supply-side oriented policies can make a difference they require support from complementary demand side actions.

4 EUROPEAN UNION RESPONSE

The political pressure on environmental matters is constantly growing. One need only mention the Berlin Mandate and the following Conference of Parties meetings, which show the global concern of climate change and environmental issues.

The Fifth Environmental Action Programme and the White Paper are both key concepts in creating Community environmental and energy policy. The main theme in the fifth environmental action programme is sustainability. The Report of the World Commission on Environment and Development defines sustainable development as 'development which meets the needs of the present without compromising the ability of future generations to meet their own needs'. The Fifth Environmental Action Programme is trying to tackle the problem by breaking the current trends. The programme should be seen as an important step in a longer-term campaign to safeguard the environment and the quality of life.

One of the most important concepts in the programme and in the White Paper on energy policy is internalisation of external costs, which means that environmental policy is not going to work against market mechanisms, but rather with them and using them. In practice this means that externalities have to be reflected in appropriate prices, and the final decision on changing behavioural patterns is left to individual consumers and companies.

The Commission, auto and oil industries have collaborated for three years in a programme called "Auto Oil" aiming towards new car emission standards for the beginning of next millennium. The related legislation package aims at a reduction of 60 - 70 % in road transport emissions by 2010. This significant improvement is achieved by a concerted action on fuel quality improvement and reduction of car emissions. The legislation will come into force by 1st January, 2000. The importance of these measures is evident. The low quality of air in European cities has been shown to contribute clearly to public health.

The Auto-Oil measures do not include car CO_2 emissions, which are dealt with in a different framework. In their meeting in Luxembourg at the end of June 1996, the

Environmental Ministers of the European Union urged the Commission to negotiate a deal with the European auto industry to reach a CO_2 emission level of 120 grams per kilometer driven for private cars. New cars should reach this level by 2005. In fuel consumption terms it means 5 litres of petrol or 4.5 litres of diesel per 100 kilometres. It is foreseen that the growth in car CO_2 emissions presently jeopardises the Community's objectives.

5 CHANGING DEMAND PARADIGMS

Most of transport and energy use is derived demand. The current paradigms of land-use, service and commodity supply, communication and transport are deeply rooted in the current Western culture, even though new patterns of communication are starting to emerge. Fundamentally different alternatives for current behavioural patterns have been proposed and they could affect essentially the structure and magnitude of transport demand.

In section 3 above, it was demonstrated that supply-side policies can make a difference in degree. It seems a reasonable assumption that profound changes in the demand side could completely turn the trend. In the long, run continuing energy use growth cannot be in line with sustainable development, therefore demand side changes and the policies affecting demand should gain increasing importance.

There are different scenarios about future patterns of working, shopping and commuting. To some of us they sound like impractical science-fiction stories, others take them seriously down to the last word. However, the world is not black or white. The so-called information society may come gradually. For example, let us consider a system in which people work once a week at home. That does not seem too controversial. But, the people in the system would reduce their commuting by 20 %, which is an impressive saving. This is just a single example among different transport demand scenarios, and there can be other even more feasible ones.

Internet has given rise to a lot of discussion about "net" shopping and other ways of using the "net" for new services. The flow of goods and people would alter greatly if goods were delivered straight to customers from factories or from some intermediate storage facilities. Nowadays, supermarkets and shopping centres are the nodal points for goods and customers coming in and out. This nodal status could disappear or at least diminish, resulting in clearly different traffic flows.

6 FUTURE POTENTIAL FOR TRANSPORT AND ENERGY POLICY

Transport is an important sector in the economy and it influences all walks of life. Transport, energy and environmental policies have to work in accordance with land use planning, urban area management, industrial production and commercial policy. If the transport demand changes drastically it means that all the decisions and investments made under the old paradigm will become more or less useless. This is a scary prospect - there is a possibility that resources invested for the future will not meet their designed demand.

The complexity of policy-making and the importance of the transport sector in the general picture of energy policy is evident. Nonetheless, however complex the future may be, it must not be seen as a threat, but as a great possibility.

RELATED LITERATURE

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KEY ISSUES FACING THE TRANSPORT SECTOR IN SUB-SAHARAN AFRICA

By John Turkson, Gordon Mackenzie, Jørgen Fenhann, Risø, Denmark

1 INTRODUCTION

Road transport is an important sector of economic activity, especially in developing countries, where it plays an essential role in marketing agricultural products and providing access to health, education and agricultural inputs and extension services. Conversely, lack of accessibility and poor road conditions are barriers to agriculture, industry and trade, and may hinder the entire development efforts of developing countries. The transport sector is a major input to the development process of the countries in Sub-Saharan Africa (SSA). It influences, to a large extent, patterns of population distribution and settlement, location of economic activities and facilitates the mobility of people and goods.

In recent times the issue of environmental impact of transport system, particularly road transport has been gaining currency in the public policy arena of most developing countries. Governments in developing countries are confronted with the twin problems of improving their transport systems, particular road transport and dealing with the environmental problems associated with it.

This paper presents discussions on the key issues facing the transport sector in Sub-Saharan Africa as they relate to development and environmental aspects of the sector. Examination of these issues is an important input to the public policy making process in the transport and environment sectors of the national economies in the region because the livelihoods of a vast majority of people in SSA depend directly on the productivity of the land, forest, oceans, rivers and lakes. The COPERT model (CORINAIR, 1990) has been used to analyse emissions of air pollutants from road transport and thus provide insights into how the environmental impacts of road transport relate to fuel efficiency and quality of roads, to mention a few.

2 ROAD TRANSPORT INFRASTRUCTURE IN SSA

Road Transport grew rapidly after the Second World War and is the dominant form of transport in SSA. It carries about 80-90 percent of the region's passenger and freight transport and provides the only form of access to most rural communities.

The gradual replacement of traditional forms of transport - animal carts and walking - by motorised vehicles has led to a multipurpose use of roads. This came with increased expectations of ease of mobility and accessibility, time saving and cost reduction. The extension of road networks to rural areas and farming communities and availability of motorised vehicles spurred farmers to expand the area under cultivation with the expectation that it would be relatively easy to transport their produce to market centres. The experience of most farmers in SSA is that most roads linking producing centres to marketing centres are not motorable all year round. Agricultural products often rot on the farms or in trucks because markets are not accessible due to bad roads, or because vehicles break down in the course of transporting products. This leads to a substantial cost to farmers (Singh, 1986).

Table 1 Road density and road quality in some selected countries

Country/Region	Density of Total Road Network (km/km^2)	Percentage of Road Paved
Mauritius	0.98	93.0
USA	0.64	58.2
India	0.61	-
Brazil	0.20	8.6
South Africa	0.17	29.8
Argentina	0.08	28.5
Nigeria	0.034	81
Zaire	0.006	0.002
Sub-Saharan Africa (average)	0.19	n.a.

Source: World Road Statistics, 1990-1994

While motorization of SSA has led to growth in the fleet of motor vehicles, the vast majority of which run on petroleum products, with the exception of Zimbabwe where ethanol blend is used, rural accessibility and mobility still leave much to be desired. By the end of 1980s, there were nearly 2 million km of roads in SSA, including about 730,000 km of main roads. In spite of the importance of road transport infrastructure in the economic development of the region the spatial density of the road network is quite low. Table 1 shows that the spatial road density ranges from as low as 0.006 km/km^2 in Zaire to as high as 0.98 km/km^2 in Mauritius in 1990 (World Road Statistics 1990-1994), with an average of 0.19 km/km^2 for SSA.

The road density in Mauritius compares favourably with those of industrialised countries, but Mauritius is an exception in SSA. Most of the countries in the region have spatial road densities between 0.006 and 0.23. The insight one gets from this information is that villages, towns and cities in the countries in the region are not well linked by roads. The implication of this is that most part of the region are not accessible by road, and consequently economic development of the region is hampered.

Nevertheless the road networks are some of the region's largest assets. Their replacement costs have been estimated to be about $170 billion and required annual expenditures on routine and periodic maintenance to keep them in a stable long-term condition are between $1.2 billion to $2 billion (Africa Road Maintenance Initiative, 1996). In spite of their importance, however, most of the roads in SSA are poorly managed and badly maintained. It has been estimated that it may take about $50 billion to fully restore all roads requiring immediate rehabilitation or reconstruction. Countries in the region have spent far too little on periodic and routine maintenance during the past 20 years and as a result, nearly a third of the $170 billion invested in roads have been eroded through lack of maintenance. Most of the roads in the region are unpaved. Over 50 percent of the countries in SSA have less than 20 percent of their road network paved, and only about a third of the countries in the region has 20 percent or more of their road network paved (World Road Statistics, 1994). While data are not readily available, it can be assumed that most of the paved roads are concentrated in the few urban centres in the region.

3 THE ROAD TRANSPORT SYSTEM AND DEVELOPMENT

The crucial role of transport in improving a country's economic performance and the well-being of its population cannot be over-emphasised. Restriction of accessibility hinders efficient mobility of factors of production, and defers the transfer of human and material resources to places where they can be employed most productively. Conversely, improving the existing and expanding transport infrastructure in the region is essential to the region's economic development in terms of distribution of population, industry and income.

Countries in the region with low standards of living are characteristically those with inadequate methods of moving people and goods largely because of poor access between villages and markets, schools, medical, economic, administrative and social services which affect the daily lives of the population especially those in rural areas (Riverson & Carapetis, 1991). An effective road network can hasten progress in agricultural and rural development in the countries in the region, industry and trade, viability of urban centres and the expansion of jobs, education and personal opportunities (World Highways, 1990).

There are research studies that support the notion that road infrastructure is a necessary element in the development process of countries.** In one of such studies by Queiroz and Gautan (1992), they concluded that there is statistically significant relationship between road infrastructure and economic development on a world-wide basis. Using a cross-section analysis of data from 98 countries and a time-series analysis of US data between 1950 and 1988, they show that there exists a significant relationship between per capita gross national product and road density (km per million inhabitants).

Using statistical data (Queiroz and Gautan, 1992), it can be shown that the supply of road infrastructure in high-income countries is higher than in middle-income and low-income countries. Available statistical data suggest that a correlation exists between economic development and the density of paved roads, as portrayed in Figures 1 and 2. In the particular case of Sub-Saharan Africa, there is a similar trend between low-income and middle-income countries as portrayed in Figure 2.

The poor state of the road network is reflected in the large backlog of deferred maintenance. The economic costs of lack of maintenance are enormous for the region and are borne primarily by road users. This is because road transport impacts on an economy in two basic ways. First, it gives consumers access to places where they can engage in income-generating activities, consume other goods and services (including education and health care). The 1995 Ghana Extended Poverty Study covering the period 1988 to 1992 revealed that improvements in transport infrastructure were a principal factor contributing to the reduction in rural poverty from 42 percent to 32 percent. The study concluded that the reduction was primarily due to growth in non-farm self-employment activities. Second, transport enters the economy as an intermediate input into the production process, either directly or as a complement to other factors of production (for instance, securing inputs or getting output to market). At the national level, the low road density coupled with its low quality reduce trade which in turn leads to a reduction in productive efficiency, putting upward pressure on consumer prices and increasing seasonal fluctuations in prices.

** Some of these studies are by Binswanger (1990), Hirschman (1958), Aschauer (1989), Israel (1991)

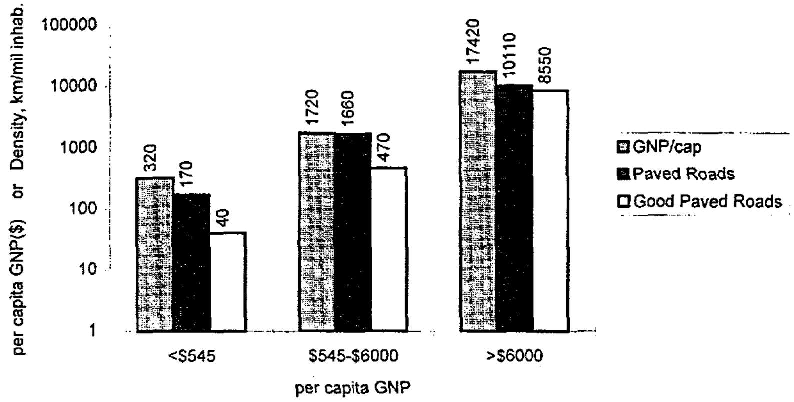

Figure 1 Average road density in low, middle and high income economies

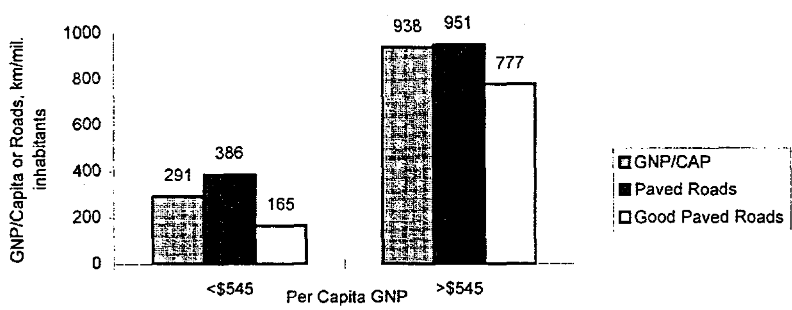

Figure 2 GNP and road density in low and middle income economies in Sub-Saharan Africa

In the rural areas, where roads often become impassable during the rainy season, poor road maintenance has a profound effect on agricultural output. When a road is not maintained and is allowed to deteriorate from good to poor condition, each dollar saved on road maintenance increases vehicle operating costs by $2 to $3. This increase in cost is passed on to passengers in the form of higher fares. Thus, cutting back on road maintenance increases the costs of road transport and raises the net costs to the whole economy. It has been estimated that extra costs of insufficient road maintenance in SSA amount to about $1.2 billion, that is about 0.85 percent of the region's GDP(Africa Road Maintenance Initiative, 1996.) Statistical data available suggest that countries which were able to improve their road network had increases in real per capita income. Ghana is a good example: From 1984 to 1989, its per capita GNP increased by 11 percent - from $350 annually to $390; in the same period, the density of paved roads in good condition expanded by 102 percent from 56 to 113 km per million inhabitants. Figure 3 presents the relationship between growth/decline in GNP per capita and growth/decline in good paved roads

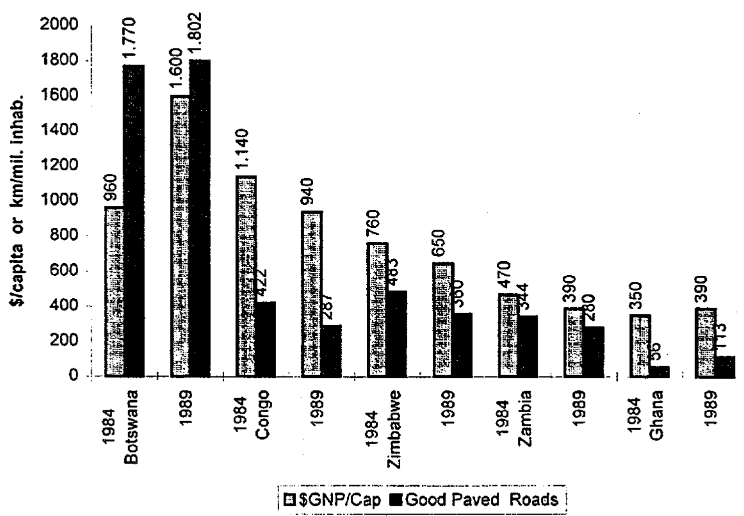

Figure 3 Comparison between real GNP and length of good paved roads per million inhabitants (1984 and 1989)

4 ROAD TRANSPORT AND ENVIRONMENTAL IMPACT

The improvement and expansion of the road transport system imply increased motorization of the transport infrastructure which in turn affect fuel consumption and hence the environmental impact. It is also true that poor quality roads and the use of old and inefficient vehicles increase fuel consumption and lead to environmental impact. This section discusses the environmental impact of the road transport system.

The replacement of traditional forms of transport by motorised vehicles led to the increase in fuel consumption. In a survey of how people travel in three SSA cities, i.e. Abidjan, Dakar and Nairobi, it was found that between 15-50 percent travel by non-motorised means, the highest is 50 percent in Dakar and the lowest, 15 percent in Nairobi; 12-25 percent by private motorised means and 32 -51 percent by public transport or taxi (Davidson, 1993). With this trend in motorisation of the transportation system, energy use in Sub-Saharan Africa has risen more than threefold over the past three decades and is expected to continue increasing rapidly in the future. The increase in the services that energy provides is necessary and desirable, since energy services are essential to economic growth and development, improved living standards, and to provide for an increased human population.

Fuel Efficiency of Vehicles

Emissions from transport depend mainly on energy use, which is the product of energy intensity (energy use per passenger-km or tonne-km) and the level of activity (passenger-km or tonne-km). Energy use is influenced by a variety of inter-linked factors such as age and design of vehicles, quality of maintenance and level of traffic congestion. While data on age of vehicles in countries in SSA are not readily available, it can be assumed that about 50 percent or more of the newly registered vehicles are second-hand vehicles imported from OECD countries. In 1991, a survey on the transport sector in Ghana, for example, revealed that over 30 percent of all vehicles operating in the country are more than 10 years old (Ministry of Mines & Energy, 1994).

Table 2 Passenger transport energy intensity - estimated national averages

	Light - Duty pass.		Vehicles		Mopeds	Buses	
Country/ Date of Estimate	Fuel Economy l/100km	Load Factor (# people)	Energy Intensity (MJ/pass-km)	Load Factor (#people)	Energy Intensity (MJ/pass-km)	Load Factor (#people)	Energy Intensity (MJ/pass-km)
Sub-Saharan Africa							
1985	20-24	2	3.2-3.8			35-60	0.2-0.33
China. India & Thailand							
1990	11-14	2	1.8-2	1-1.6	0.5-0.8	35	0.35
Singapore							
1992	9	1.7	1.7	1.2	0.7		0.6
Japan & Korea							
1991	10-11	1.4	1.5-1.6	1	0.7- 0.8	20	0.65
United States							
1991	13-14	1.5	2.6			14	0.9
Western Europe							
1991	8-11	1.5-1.8	1.2-1.96	1	0.7-0.8	10-25	0.49-1.32
Poland							
1991	9	2	1.3	1	0.73	35	0.33
Former USSR							
1988	12	2	2			20	0.6

Source: IPCC Climate Change 1995, Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses, UNEP & WMO.

Table 2 shows that the fuel economy for light-duty passenger vehicles is lower in SSA. It averages between 20 and 24 litres per 100km as compared to 9 litre per 100km in Singapore and 10-11 litres per 100km for Japan and Korea. All the indicators presented in table 2 except energy intensity for buses show that the SSA transport system is fuel inefficient. The apparent relatively low energy intensity for buses for SSA is due to frequent overloading of buses in the countries in the region.

Lack of data on different aspects of the transport sector in the countries in SSA makes any bottom-up analysis next to impossible. With the existing aggregate data for the countries in the region together with a few country-specific studies on the transport sector, we have attempted to investigate the environmental effects of the road transport system in SSA, by using the COPERT[1] model to estimate the levels of emission of

[1]COPERT - COmputer Programme to calculate Emissions from Road Traffic. For more detailed information on this programming model, one may consult CORINAIR Working Group's document : Methodology and Emission Factors. Vol.1, 1993.

different gases. This model was originally developed to study emissions from road traffic in the European Union. It has been used for similar studies in some East European countries to study emissions from road traffic.

The aim of the calculation is to estimate the 1993 emissions of gases such as CO_2, CO, NO_x and CH_4 from road traffic in Sub-Saharan Africa and to compare them to a scenario in which improvements are made, for instance, to quality of roads and fuel efficiency. The baseline methodology takes into account the knowledge and statistical data available in SSA. The application of this model requires certain input data. The major ones are summarised in Table 3 following the format of the COPERT model.

Data Sources and Underlying Assumptions

The available sources of data are in general not broken down into vehicle type, capacity and fuel type. The figures in bold were those we extracted from statistical sources mentioned below table 3. Percentages used to estimate the number of vehicles for each capacity and fuel type were assumed on the basis of studies of the transport sector in Ghana and countries in the East and Southern Africa (see Transportation Sector Energy Audits, 1994; Development of an Efficient Transport Sector in East and Southern Africa, 1995).

Another difficulty we faced was obtaining estimates for total mileage for each vehicle category as indicated in table 3 and the average speeds for vehicles on urban, rural and highway roads. Based on data from World Road Statistics which give figures for annual distance travelled by cars, buses and goods vehicles and the country studies, estimates were made for the total annual mileage for each category and capacity. These are presented in column 4. Similarly, estimates of the speeds for the different road categories are presented in columns 5-7.

Table 3 Summary of Input Data (1993)

Vehicle	%	Number[1] of Vehicles	Total Annual Mileage per Vehicle (km)	Speed (km/hr) Average Urban	Rural	Highway
Total Passenger Cars		**6,000,000**				
Gasoline		5,280,000				
<1.4L	50	3,000,000	27,000	20 (70)*	45 (25)	90 (5)
1.4L - 2.0L	30	1,800,000	27,000	20 (70)	45 (25)	90 (5)
>2.0L	8	480,000	27,000	20 (70)	45 (25)	90 (5)
Diesel		720,000				
<2.0L	5	600,000	13,000	20 (70)	45 (25)	90 (5)
>2.0L	1	120,000	14,000	20 (70)	45 (25)	90 (5)
Light Duty Vehicles		**1,260,000**				
Gasoline	4	120,000	15,000	(75)	(20)	(5)
Diesel	38	1,140,000	15,000	(75)	(20)	(5)
Heavy Duty Vehicles		**1,540,000**				
Gasoline	0	0				
Diesel						
3.5t - 16t	50	1,300,000	20,000	(25)	(70)	(5)
>16t	8	240,000	30,000	(25)	(70)	(5)
Two Wheelers		800,000				
Mopeds		**720,000**	3,000	(90)	(10)	
Motorcycles		**80,000**	14,000	(90)	(10)	
Tot. Gas. Cons.[2] (kt)	**15,054**					
Tot. Diesel Cons.[2] (kt)	**9,948**					

**Figures in parentheses are mileage distributions in percentages for each road category. 1.Source: World Road Statistics (1990-1994); 2.Sources: World Road Statistics (1990-1994), United Nations Energy statistics Yearbook (1993), OECD, Energy Statistics & Balances of Non-OECD Countries, 1992-1993 3. Climate Change Mitigation in Southern Africa (1995).*

Emission factors and fuel properties follow the default values presented by IPCC (1995). For climatic conditions we assume the average minimum and maximum monthly temperatures to be 26°C and 30°C respectively.

5 RESULTS AND ANALYSIS

We have used the COPERT model to estimate the level of emissions of air pollutants associated with road transport in Sub-Sahara Africa under two scenarios. The first scenario, for the reference year 1992/3, assumed pre-EC vehicle specifications, that is vehicles before 1969. The calculations of the levels of emissions for this scenario are presented in table 4.

Table 4 Total emissions for 1992/3

	NO_X	CO	NM VOC	CH_4	TPM
Passenger Cars	269.061	5,518.840	665.071	19.625	2.291
Light Duty Vehicles	30.750	78.414	13.735	0.305	3.891
Heavy Duty Vehicles.	307.642	332.664	55.046	1.741	32.343
Mopeds	0.108	21.600	13.710	0.216	
Motorcycles	0.090	24.640	17.311	0.168	
Total	**607.651**	**5,976.158**	**764.873**	**22.054**	**38.525**
Total Emissions (kt).	N_2O	NH_3	lead	CO_2	SO_2
Passenger Cars	0.808	0.295	2.220	46,718.467	154.862
Light Duty Vehicles	0.302	0.021	0.031	5,862.552	18.904
Heavy Duty Vehicles	0.996	0.100	0.000	23,324.256	75.513
Mopeds	0.002	0.002	0.006	123.768	0.397
Motorcycles	0.002	0.002	0.005	106.960	0.343
Total	**2.109**	**0.419**	**2.261**	**76,136.005**	**250.020**

The results show that road transport produced over 76 million tonnes of CO_2 and close to 6 million tonnes of CO in 1993 whilst the values for NO_X and SO_2 are 608,000 tonnes and about 250,000 tonnes respectively. Comparing CO_2 emissions from our calculations with the world's CO_2 emissions from road transport of 1.6 billion tonnes in 1995, Sub-Sahara Africa accounts for about 4.8 percent. In a background study for the Office of Technology Assessment Global Warming Report (Parson, 1989), Africa's share of the world's transport CO_2 was estimated to be 3.5 percent.

While the impact of these emissions as represented by these figures may look small and insignificant within the global context, the prime concern in the countries is the local air pollution associated with these emissions. Vehicle emissions of carbon monoxide (CO), NO_X and others can cause or contribute to serious human health effects, in addition to harming terrestrial and aquatic ecosystems, causing crop damage and impairing visibility. Most of the vehicles in SSA are concentrated in the urban centres. In Ghana, for instance, close to 60 percent of vehicle fleet is concentrated in the twin city of Accra-Tema. It can be inferred that most of these pollutants are concentrated there.

Closely related to this, is the problem of traffic congestion which is fast becoming a major problem in some cities in the region. In cities like Accra and Lagos, vehicular speed during rush hours averages 15-20 km/hr or less. In addition, the quality of roads, the age of vehicles (on the average 10 years) and lack of routine maintenance of vehicles in the region contribute to the level of emissions as shown in table 4. If the present situation in the road transport sub-sector continues, cities in SSA are likely to face problems similar to those in the Asian and Latin American "megacities".

Vehicle emissions of carbon monoxide (CO), NO_X and others can cause or contribute to serious human health effects, in addition to harming terrestrial and aquatic ecosystems, causing crop damage and impairing visibility.

6 IMPACT OF PUBLIC POLICY OPTIONS ON EMISSIONS

We evaluate the potential impact which different public policy options could have on the emission level from road transport. This is the second scenario. We looked at public policies that could affect fuel efficiency of vehicles, age of vehicles imported, quality of roads and traffic congestion to the extent that they affect the levels of emissions in the region. We assume that improving the quality of roads and easing congestion will affect the speed of vehicles and the mileage distribution among urban, rural and highway roads. We therefore increased the vehicular speed and changed the mileage distribution for the different categories of roads. These changes represent a proxy for improvements in road conditions and traffic flow.

The speeds assumed in the second scenario were: urban - 30 km/h; rural - 55 km/h and highway - 100 km/h. For passenger cars the mileage distribution was changed as follows: urban - 60%; rural - 35% and highway - 5%; for light duty vehicles: urban - 65%; rural - 30% and highway - 5%; and for heavy duty vehicles: urban - 20%; rural - 75% and highway - 5%. Similarly, for fuel efficiency, we assumed a certain fuel efficiency level for the different vehicle categories as used in the European Commission studies i.e. for the period 1981-1985. We further assume that countries would have introduced unleaded fuel by 2006 assuming the same number of vehicles and mileage. The new emission levels are presented in table 5.

Table 5 Total emissions for 2006 in kilotonnes

Vehicle category	NO_X	CO	NM VOC	CH_4	TPM
Passenger cars	284.269	2,560.086	472.669	13.699	1.809
Light Duty Vehicles	30.012	73.662	13.156	0.285	3.891
Heavy Duty Vehicles	305.448	313.574	51.416	1.626	32.102
Mopeds	0.108	21.600	13.710	0.216	
Motorcycles	0.090	24.640	17.311	0.168	
Total	**619.927**	**2,993.562**	**568,263**	**15.993**	**37.803**
Vehicle category	N_2O	NH_3	lead	CO_2	SO_2
Passenger Cars	0.808	0.295	0.000	30,055.737	42.418
Light Duty Vehicles	0.302	0.021	0.000	5,629.150	16.923
Heavy duty Vehicles	0.996	0.100	0.000	23,138.214	74.649
Mopeds	0.002	0.002	0.000	123.768	0.156
Motorcycles	0.002	0.002	0.000	106.960	0.134
Total	**2.110**	**0.419**	**0.000**	**59,053.830**	**134.280**

Comparison of the two scenarios

A comparison of the two scenarios shows that there is a reduction in emissions from road transport. Table 6 presents a summary of the comparison of some emissions. All the major greenhouse gases (GHGs) experienced 20 percent or more reduction in their emission levels with the exception of NO_X and N_2O which showed very small increases. This is due to the assumed increase in the average speeds in towns and rural areas in the second scenario.

Table 6 Comparison of 1992/3 and 2006 Emission Levels

	NO_X	CO	CO_2	SO_2	NMVOC
1992/3	607.651	5,976.158	76,136.01	250.02	764.873
2006	619.927	2,993.562	59,053.83	134.28	568.263
Diff. (%)	2	-50	-22.4	-49.3	-26

The statistical figure for gasoline and diesel consumption for the reference year were 15,054 kt and 9,948 kt respectively. The fuel consumption calculated by the model are 14,733.9 kt and 9,918.7 kt for gasoline and diesel respectively. This shows an acceptable difference of 2.1 and 0.3 percent for gasoline and diesel. With the introduction of policy changes as described above, gasoline consumption fell by about 37 percent and diesel by about 2.9 percent.

7 CONCLUSIONS

Within the constraints of data availability, we have tried to estimate the levels of emissions of GHGs associated with road transport sub-sector in SSA. In this context we have also shown that consistent and rational investments in road transport infrastructure could have a significant impact on economic development and reduction in emission of both local air pollutants and greenhouse gases in the region. Motor vehicle emissions can be seen as major sources of climate modification as well as adverse health and environmental effects from ground-level pollution. To deal with these problems in a co-ordinated fashion requires the minimisation of all these emissions. The emissions of these pollutants depend on the number of vehicles and their emission rates. In turn, their actual emissions rates depend on their fuel efficiency and their use of available control technologies.

To improve fuel efficiency requires the use of fuel efficient vehicles. While governments in the region cannot force their citizens to buy new cars instead of used ones from Europe or the USA because of low income levels, policies that would encourage vehicle owners to undertake routine maintenance could help improve fuel efficiency of vehicles.

Understanding the correlation and causality between the supply and quality of road infrastructure and economic performance of countries in the region is an important area for future research. Undertaking this study has been revealing and rewarding. It reveals the paucity of data and lack of studies and research on this subject in the region. It has been rewarding for us as we grapple with the problem and opens a whole new pror .ising area for research in the region. It has also highlighted the need for an inter-disciplinary approach to the study of the issues. There is a need for co-ordination between transportation planners and energy/environmental economists in this area of research.

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WHY DOES THE ENERGY INTENSITY OF FREIGHT TRANSPORT RISE?

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1. INTRODUCTION

In advanced economies it is normal to observe declining energy intensities. Both improvements in conversion efficiency and in organisational efficiency of energy use cause energy demand to grow at a slower pace than the economy. In addition the structural change of the economy also causes energy intensities to decline. It is quite relevant to monitor the development of energy intensities as they indicate to what level energy demand may rise in an ever expanding global economy. The very scale of energy demand in the next century is quite likely to pose the global community for huge challenges.

In this context it is somewhat particular that in the vital sector of freight transport the energy intensity does not decline, but instead increases. The energy demand of this sector only takes a small share of the total energy demand. According to the World Energy Council the transport sector takes 30 percent of world energy demand and freight transport again takes 30 percent of the transport sector share, maritime transport excluded. Despite this small share some explanation is needed why the increase in energy demand from the volume growth of freight demand is not at least partly countered by a decline in the energy intensity. The purpose of this paper is to review some of the explanations that are given in the literature and to support these explanations with empirical evidence.

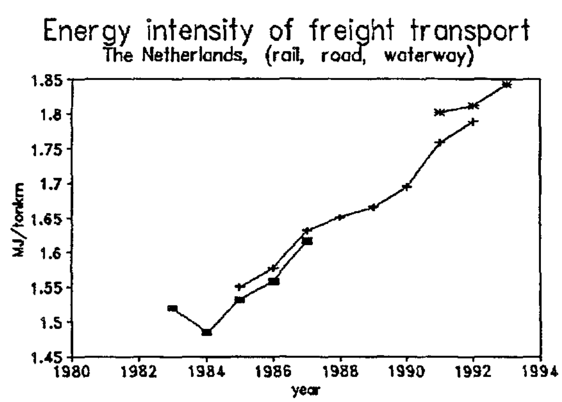
In the next section it will be shown for the case of the Netherlands that the energy intensity of aggregate freight transport is indeed increasing. As could be expected it shows that a shift in the modal split is the main factor responsible for this increase. The subsequent section analyses the causes for the shift in the modal split. And, in the last section some implications for energy policy are reviewed.

2. THE RISING ENERGY INTENSITY OF FREIGHT TRANSPORT

Of all sectors within the economy the transport sector shows the largest growth of energy demand. There still remains a considerable demand potential for personal mobility unsatisfied that is perhaps the most important factor for the rise of energy use within the transport sector. Another factor behind this growth in energy use is the development of freight transport. It is remarkable that energy demand for freight transport not only rises because of the growth in the volume of freight transport, but also because the energy intensity of the freight transport system rises. This is in sharp contrast to the declining trend in energy intensity that prevails for aggregate energy demand in all industrialized economies.

The rise in the energy intensity of freight transport is shown for the case of the Netherlands. Energy intensity is defined in terms of direct energy use divided by the volume of freight transport as measured in MJoule per tonnekm. In many countries a good part of the freight transport has a foreign destination. This is certainly the case for freight transport in the Netherlands that is situated close to the center of economic gravity of northwestern Europe at the delta of the intensively navigated river Rhine. In the picture that is offered the volume of freight transport concerns both domestic and international traffic, but only for that part that takes place within the national borders. All three transport modes, road, rail and internal waterways are included, but pipeline transport is excluded because of lack of data. Energy use concerns figures from primary statistical sources, except for the case of freight transport by rail, where use is made of secondary sources.

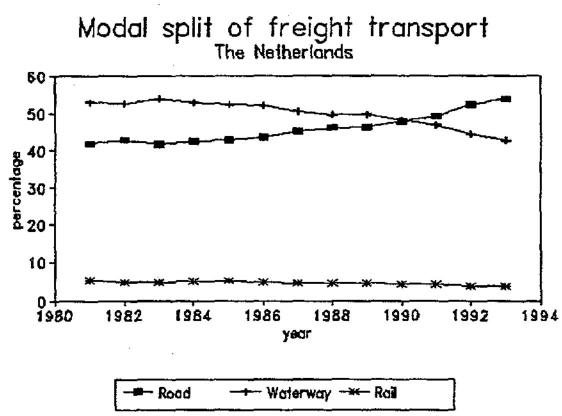
Figure 1.



Source: Central Bureau of Statistics, *Maandstatistiek Verkeer en Vervoer.*

From the early 1980's on, when the Central Bureau of Statistics first started its survey of energy use for freight transport, the energy intensity of the freight transport system has been increasing. The two discontinuities arise from improvements in the statistical procedures. The main reason behind the rise in energy intensity is the shift in the modal split. The share of freight transport by road has risen considerably. In fact, road transport has been responsible for the growth in freight transport and to some extent road transport has substituted for the other modes. Total freight transport has risen by 1.9 percent per year over the period 1981 to 1993, while freight transport by road has risen by 4.0 percent per year over the same period. As the energy intensity of freight transport by road is much higher than those by rail or by internal waterways, the aggregate intensity of the transport system has risen as a result.

Figure 2.



Source: Central Bureau of Statistics, *Maandstatistiek Verkeer en Vervoer.*

But, international freight transport also takes place by means of other transport modes than the three already mentioned, notably by air and by sea. In the national statistics the volume of freight transport by maritime and by air transport is for practical reasons only counted in terms of weight and not in terms of the distance covered by weight. Thus, allthough for both maritime and air transport the fuel intake is reasonably well known, since by nature the necessary fuel is bunkered at the point of departure, this fuel intake cannot be related to the actual transport volume. Still, whatever the freight distance covered by both modes, the gap between the ratios of fuel bunkers to the weight transported is so large that again it must be concluded that the energy intensity of the transport system is actually increasing. A close look at the growth rates of freight tonnages supports this conclusion.

Table 1. Freight transport and demand for energy, the Netherlands

	1983		1993	
Transport mode	mln tonne-km	PJ	mln tonne-km	PJ
waterway	32297	19.5	32096	20.7
rail	2737	1.6	2640	1.6
road	25071	73.8	40309	116.0
	mln ton	PJ (bunker)	mln ton	PJ (bunker)
maritime	284.4	259	326.9	411
air	0.3	10	0.7	22

Source: Central Bureau of Statistics, *Maandstatistiek Verkeer en Vervoer;* and *Maandtatistiek van de Buitenlandse Handel.*

In the table above, the bunkering of heavy fuel oil is attributed to maritime freight transport. The bunkering of jet fuels is attributed to air cargo in accordance with the share of air cargo in the total weight carried, passenger transport included. Considering the importance of Rotterdam harbour to the Dutch economy is is not surprising to find that energy demand for maritime bunkers is so dominant. The tonnage of maritime transport follows a cyclical pattern with a clear downturn in 1983. The growth trend of maritime freight tonnage has been around 0.2 percent since the first oil crisis. The growth in the freight tonnage by air has been much more pronounced at 6.8 percent per year over the period 1980 to 1993. This sharp growth combined with the high specific energy intensity of air freight supports the claim of an increasing energy intensity of the transport system.

The conclusion that the energy intensity of the transport system is increasing is by no means particular to the case of the Netherlands. The same factors that are responsible for this development can be found in other countries. In all European countries freight transport by road has taken the lead of the other transport modes. And the growth in freight transport by air in the Netherlands also compares to aggregate international growth. According to IATA, tonne-kilometers performed on international flights grew by 7 percent per year over the period from 1983 to 1993.

Table 2. Modal split of European freight transport measured in tonne-km (%)

	1970	1975	1980	1985	1990
Rail	31.3	25.3	23.2	21.2	17.4
Road	55.2	62.9	65.9	69.3	74.2
Water	13.5	11.8	10.9	9.5	8.4

Source: European Conference of Ministers of Transport, 1993.

Of course, the fuel efficiencies of the various transport modes have improved in the course of time. But, this has not been enough to offset the effects of the shift in the modal split. Generally improvements of fuel efficiency in trucks, trains and vessels amount to less than 1 percent on a yearly basis[1]. The rate of improvement of energy efficiency in aircraft has been somewhat higher, in the range of 1 percent, due to the fact that the aircraft industry is still relative young. Also, improvements in energy efficiency may be expected from the replacement of older aircraft and the optimalisation of the operations of carriers. Together the improvement in energy efficiency of air transport could amount to 2 percent per year[2].

3. WHICH FACTORS HAVE DETERMINED THE SHIFT IN THE MODAL SPLIT?

A gradual shift towards more energy intensive modes of transport has been identified as the main factor behind the upward trend in the energy intensity of the freight transport system. A similar conclusion has also been reached by others[3]. In this section the question is raised why such a shift in the modal split has occurred.

The choice of a transport mode for freight transport is motivated by a range of factors. On the one hand there is the functionality of the particular transport mode to the freight that is offered for transport. On the other hand the choice of a transport mode is very much determined by long lived traditions that have become embodied in the transport infrastructure.

Gruebler and Nakicenovic offer an interesting historical perspective on the evolution of transport systems[4]. Long term technological transformations render older modes of transport, that have been in existence for a long time already and cover a large part of the market, to newer ones that have been developed more recently and whose infrastructure is spreading rapidly. They start their analysis at what they call the canal era which they locate in time at the turn of the 18th century and that is characterised by the construction of dense networks of internal waterways (rivers and canals) and a dominant position of transport by water. A new era starts in the second part of the 19th century with the construction of the railway systems. They show that from that time on the emergence of rail infrastructure gives an unprecedented impetus to the volume of freight transport, that soon fades away the large market share that was formerly held by transport over water. It is only in the middle of the 20th century that progress in truck transport technology and the expansion of the highway system led freight transport by road to make inroads on the market shares of transport by rail and by waterways. Only recently freight transport by air is gaining some ground.

It has been the characteristic of each new phase in the development of the transport modes that advantages were offered in terms of speed and flexibility. But, all of these improvements came at a cost. The more speed or flexibility a transport mode could offer, the higher the costs of transport were.

Table 3. Indicative transport costs (Dfl per tonne over 1000 km)

	maritime	rail or waterway	road	air
Cost	20	80	150	800

Source: A. Kusters, B. Minne, *Technologie, marktstrutuur en internationalisatie*, Onderzoeksmemorandum no. 99, Centraal Planbureau, 1992.

The cost differentials have of course resulted in a specialization of the various modes of transport for certain categories of goods. Most of all it are the goods with a high value to weight ratio that are transported by the more speedy and flexible modes. Below imports and exports together are tabulated according to their mode of transport. A low weight share and a high value share indicates that on average goods with a high value to weight share are transported by that particular transport mode.

Table 4. Value and weight shares of transport modes in the Netherlands, 1991

Transport mode:	weight share %	value share %
Sea	43.4	21.8
Waterway	22.8	4.1
Rail	1.9	1.8
Road	31.8	67.4
Air	0.1	4.9

Bron: Central Bureau of Statistics, *Maandstatistiek Verkeer en Vervoer*, 56 (8), 1993.

In many cases also, the speed of transport adds to the export value of the products. Certain categories of products could never be transported over the distances, that are now routinely covered, without the speed developed by their means of transport. This is for example the case with perishable goods, such as flowers, or with live animals.

But, in the modern economy speed, or more generally responsiveness to the market, has a more general significance.

One of the most remarkable changes in the present business environment is the increasing volatility of markets. There is a shift in the ways that enterprises compete each other. While efficiency, more specifically the control of costs, and quality, which increasingly includes the delivery of services, still are necessary conditions to stay in the market, other factors of competition, such as flexibility and market responsiveness have in addition gained in importance. In a dynamic market it is essential to identify changes in customer preferences timely. Under a regime of sharp competition - as it is partly caused by industrial development in low-wage countries - profits must often be raised in niche markets, even if these are short lived.

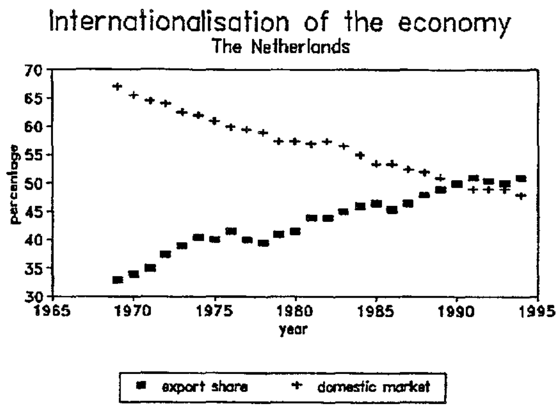
Lean production strategies can in particular be understood in the context of these additional factors of competition[5]. The aim is to reduce organizational inertia by diminishing the work flow that is in the pipeline. Short production cycles, just-in-time delivery and flexible production facilities help to increase the responsiveness of the organization and to reduce buffer stocks, thereby saving on capital tied up in the production chain[6]. The effect on freight transport is likely to be a preference for increased speed and flexibility which is most of all met by road and by air transport. Also, containerisation has greatly increased the flexibility of freight transport. In many cases the importance of speed in the performance of business operations diminishes the weight attached to transport costs.

Several authors mention the effect of for example just-in-time delivery systems on the shift in the modal split. However, the present effects of such lean production strategies must not be exaggerated. It is still very hard to find empirical evidence of it. Possibly much organizational change in this direction has still to come. The need for such organizational change has been felt only recently - i.e. in the late 1980's - under the pressure of foreign competition, especially from Japanese firms. In fact, much of the common knowledge on this subject is based on the experiences of a few pioneering firms.

Apart from the progress in transport technology there have also been some marked developments in the volume and the composition of the goods to be transported. The internationalisation of the economy has a clear impact on the demand for transport. But, this impact is much more pronounced on the composition than on the volume of goods.

The internationalisation of the economy is clear from the increase in the export share of Dutch manufacturing and the decrease of its share in the domestic market. The export share has increased from one third in the early 1970's to one half in the early 1990's. In the same period the share in the domestic market has decreased from two thirds to one half.

Figure 3.



Source: Centraal Planbureau, *Centraal Economisch Plan 1993*; Den Haag, 1993.

The internationalisation of the Dutch economy is illustrated for manufacturing products. In fact, international trade in manufacturing products has been growing much faster than the trade for all products together, even if counted in terms of weight. In the period from 1978 to 1994 the growth rate of manufacturing products (NSTR chapters 5, 8 and 9) has been twice as high as the growth rate of all products together. Still the major part of freight transport consists of goods with a low value to weight ratio that are transported in bulk. The smaller part of it consists of goods with a high value to weight ratio. The growth rate of high value to weight goods is above average, while the growth rate of most low value to weight goods is below average. The value to weight ratios of 10 chapters of the NSTR classification are given below. Imports and exports are lumped together.

Table 5. Changes in freight composition in the Netherlands

	value to weight Dfl/kg	share in 1992 %	growth 1978-1992 %
0 Agricultural products	0.21	4.8	0.7
1 Feedingstuffs and fodder	0.59	11.0	3.5
2 Solid fuels	0.04	7.0	5.2
3 Crude oil and refinery products	0.15	34.4	0.7
4 Ores and scrap	0.04	12.3	1.1
5 Metals and metal parts	0.61	3.8	2.5
6 Raw materials and building materials	0.07	10.4	0.8
7 Fertilizers	0.17	1.8	0.3
8 Chemical products	0.58	8.9	4.9
9 Other goods and finished products	0.55	5.5	4.6

Source: Central Bureau of Statistics, *Statistiek van de aan-, af- en doorvoer.*

The composition of international trade is changing. The share of the higher value to weight goods has increased. As we have seen, exactly these high value to weight goods are most likely to be transported by the faster and the more flexible transport modes. So, the fact that the internationalisation of the economy most of all concerns manufacturing products is another factor that causes a shift in the modal split of freight transport towards transport by road and transport by air.

4. EVALUATION

An important objective of energy policy in many European countries is to improve on energy efficiency. To a large extent the motivation for this objective is nowadays related to climate policy. Internationally the political conviction has grown that at least a stablisation of the emission of greenhouse gasses is desired as an answer to the risk that is posed by the greenhouse effect. Recently the Dutch government has formulated the objective to improve on energy efficiency by one third and to increase the share of renewable energy to 10 percent, all to be reached in the next 25 years[7]. In the freight transport sector an initiative has been launched to achieve reductions of CO_2-emissions of 30 percent in the year 2010 as compared to the level of emissions that would arise without any policy.

In the many energy scenario studies that are generally used to formulate such policy objectives much more attention is paid to the impact of technological progress on transport energy efficiency than to new concepts of freight transport. For single transport modes it is of course essential to identify the progress in motor concepts or the emergence of alternative fuels. But, the improvement of the energy efficiency of a certain transport mode is no more than a secondary level policy objective. The primary level policy objective is to improve on the energy efficiency of the freight transport demand. A substantial part of the freight supply can be transported by more than one transport mode and the shift in the modal split has been identified as the main facto. behind the increase in the energy efficiency of freight transport. To improve on this primary level policy objective it is perhaps much more effective to exert influence on the shift in the modal split than to concentrate on sheer technology.

Of course it may be technically feasible that freight is transported by less energy intensive transport modes, but we also have seen that the shift in the modal split is deeply rooted in the functioning of the economic system. Therefore it may be very difficult to influence the modal split. But, energy policy is by far not the only policy field that is concerned with this shift in the modal split. For example, truck transport is growing so fast that serious congestion has resulted. The answer, as formulated by transport policy makers lies partly in the extension of the infrastructure. But, the overburdening of the existing infrastructure also leads to a process of rethinking the very concepts of freight transport. In many cases it is for example less important that transport is fast than to know when the freight will arrive. The development of logistics is closely linked to this process and energy policy may benefit from it.

So, energy policy on freight transport energy demand has no strong links with transport policy directed at a selective use of the transport infrastructure. Such transport policy is even not very elaborated in the case of those transport modes that that are strongly oriented towards international transport, notably maritime transport and air transport. The obvious reason is that both modes are seen as extremely vital to the national economy. As air transport is highly energy intensive the economic incentive to improve on efficiency is strong and bears clear results. The improvements in energy efficiency may even exceed 30 percent in the next 25 years. But on the other hand the growth in freight transport by air is so strong that in the same time the energy demand from air transport may almost double. Depending on the kind of energy policy that one would adhere this might be seen as a less desirable development.

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THE ROLE OF TRANSPORT SECTOR WITHIN THE GERMAN ENERGY SYSTEM UNDER GREENHOUSE GAS REDUCTION CONSTRAINTS AND EFFECTS ON OTHER EXHAUST GASES

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1. INTRODUCTION

The German Federal Government pledged itself to make a 25% reduction in national CO_2 emissions by 2005 on the basis of 1990 CO_2 emissions. This reduction target is valid for the entire Federal Republic. Within that context the Federal Ministry of Education, Science, Research and Technology initiated the IKARUS project (Instruments for Greenhouse Gas Reduction Strategies) in 1990. The aim of the project is to provide tools for developing strategies to reduce energy-related emissions of greenhouse gases in Germany. A range of instruments has been developed consisting of models, a data base and various tools with the aid of which different action sequences can be simulated and evaluated until the year 2020.
By using the database and mainly one of the models of the project a scenario in terms of energy and carbon dioxide emissions will be shown as it could be expected for the year 2005. For this scenario as base two different strategies that hit the 25% reduction target will be discussed. Special attention is given to the transport sector.

2. MODEL DESCRIPTION

One element of the IKARUS instruments is a classical bottom-up energy optimization model (IKARUS-LP) describing the energy system on a national level. This model has been developed by the Programme Group Systems Analysis and Technology Evaluation (STE) of the Research Centre Juelich. IKARUS-LP statically represents the linearized energy system of Germany for the years 1989, 2005, and 2020. It covers the energy flow from the primary energy sector to the energy end-use sectors industry, households, small-scale consumers, and transport. Links are given as energy sources, conversion and transport of energy, and energy sinks. Conversion and transport-losses arise throughout, starting from the provision of primary energy until the demand for useful energy or energy services have been satisfied. Interlinkages between the energy flows are achieved by the techniques used, which are described by specific inputs per unit outputs. Cost and emission flows are modelled simultaneously. Driven by the exogenously given demands as useful energy or energy services demand, the model offers a cost-minimizing solution for the energy system fulfilling this demand. This includes the optimal technique structure as well as the optimal energy carrier mix. Restrictions, i.e. the maximum permissible carbon dioxide emissions, can be determined exogenously.

In addition it is possible to check the macroeconomic consistency of the IKARUS-LP calculations by using a macroeconomic simulation model that has been developed by AGEP (Working Group Energy and Systems Modelling, Oldenburg University) within the framework of cooperation with STE.

3. BASIC ASSUMPTIONS

Basic assumptions that lead to the formulation of a scenario comprise economic and demographic developments, and energy-related political decisions. This includes the expected development of macroeconomic variables like gross domestic product (GDP) and prices of imported energy, the resulting determinants generating energy demand, as well as political legislation and measures restricting the use of primary energy carriers and conversion techniques.

Based on the predicted economic development (e.g. by PROGNOS), detailed sectorial analysis, and own estimations, AGEP and STE expect GDP to increase in real terms from 2.1 billion DM_{1989} to 3.6 billion DM_{1989} in 2005 for the western part of Germany, in the east the GDP should grow to 0.6 DM_{1989}. The prices of the imported energy carriers develop differently. They are estimated for 2005: Coal price is stable at 3,65 DM_{89}/GJ, crude oil increases moderately to 7,18 DM_{89}/GJ, and natural gas price increases smoothly, too, with a rate of 1.5 %/year to 4,61 DM_{89}/GJ. This price is valid for imports up to 2000 PJ. Additional gas imports are more expensive (5,76 DM_{89}/GJ). In west Germany population increases from 61.7 million in 1989 to 65.0 million in 2005, in the eastern part population decreases from 16,7 million to 15.2 million.

The development of the economic and demographic variables result in new energy generating demands: These are for the industry the net production, for households the square metre of living space (space heat) and household members (hot water, light/communication), for the small-scale consumers the number of employees, and for the transport sector the person-kilometres (pkm) respectively the ton-kilometres (tkm). For the year 2005 important demand numbers are given in table 1, together with their decrease in percent opposite 1989.

West	2005	Increase
space heat	2586 bill.squ.m	17,70%
industry	802 bill.DM	35,50%
small-scale consumer	24,1 mill. empl.	9,00%
transport sector :		
-> passenger	850 bill. pkm	23,20%
-> goods	415 bill. tkm	47,70%
East	**2005**	**Increase**
space heat	480 bill.squ.m	14,60%
industry	135 bill.DM	n.n
small-scale consumer	6 mill. empl.	31,00%
transport sector :		
-> passenger	213,5 bill. pkm	51,10%
-> goods	137,9 bill. tkm	83,60%

Table 1: Important Demand Numbers for end-use sectors

Due to energy policy and country specific energy market structures in Germany, several assumptions have to be formulated to specify the technical options for the year 2005. The main assumptions are:

- at least 1250 PJ domestic hard coal have to be used in west Germany (750 PJ for electricity production)
- at least 750 PJ of domestic lignite must be used by power stations
- nuclear capacity of power stations (22.6 GW) is not allowed to increase

Moreover, due to the short time period up to 2005, several specific limits on dynamics for the implementation of fossil power plants in the conversion sector and limits concerning the substitution of energy carriers and technological changes have been set. This comprises for example upper limits on industrial efficiency gains and on changes in modal split in the transport sector, and upper and lower limits on changes in heating systems and energy conservation for households and small-scale consumers according to building stocks and standards.

4. RESULTS

With regard to the described basic assumptions one gets a scenario for the year 2005 that is the consequence of a normal development. This development is characterised by a stable progress in the economy of western Germany and in contrast by the economical break down in the eastern part after 1989 and the following new orientation in industry and economy. The results of the IKARUS-LP calculations are shown in the cases called "west 05" resp. "east 05" in the following figures. To have a basis of comparison the situation of the year 1989 (cases called "west 89" and "east 89") was calculated, too. Figure 1 shows the results of the calculations for the energy demand of the different energy sectors. Comparing the years 1989 and 2005 and taking into regard that the demands of all sectors have increased (Table 1) it is surprising that the energy demand in western Germany has not grown significantly. This can be explained by an increase in conversion efficiency (electricity and process heat facilities) and by structural changes in the end-use sectors.

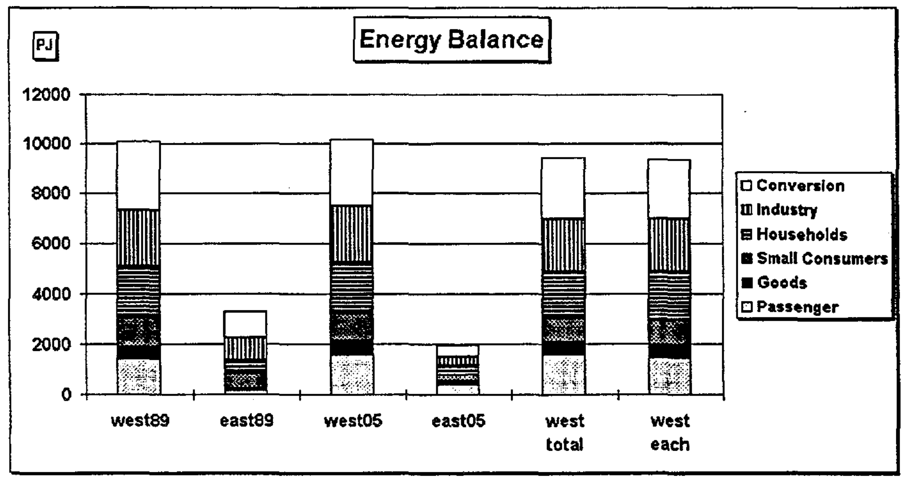

Figure 1: Sectorial energy demands for different cases

In eastern Germany the structural changes are stronger, the effect of modernising the technical structure and the substitution of lignite -allowing higher efficiencies- lead to a notable decrease in energy. In both parts only the transport sector has growing energy needs.

From the shown energy situation one can simply derive that the target of 25 % less carbon dioxide emissions will not be reached in the west. Therefore two other cases were calculated:

Without any change of the basic assumptions the CO_2 emissions were limited to 75 % of the emissions of the year 1990. The philosophy for defining these two cases can be demonstrated with the help of figure 2. Figure 2 shows the carbon dioxide emissions corresponding to the energy situation in figure 1.

Whereas the energy in the case "west 05" is with 10162 PJ about 85 PJ higher than 1989, the CO_2 emissions are about 3 % lower. This can be explained by the shift from coal to natural gas whose emission factor is lower. In the eastern part energy decreases by 41 % and CO_2 emissions by 53 %. This great difference in the decreasing rates can be explained with the energy policy of the former DDR which made lignite dominant in

energy supply (nearly 70 %), and this was the starting point of calculation in 1989. Thus the change to natural gas and oil having a 60 % share in 2005 had a large effect on decreasing the emissions. In contrast to the western part the east has fulfilled the CO_2 obligation more than twice.
Taking account of the bonus of the east, the emissions in western Germany have to be less than 581.5 mil tons of carbon dioxide. This is compared to the 1990 emission about 18 % less and 13 % less in comparison with the case "west 05".

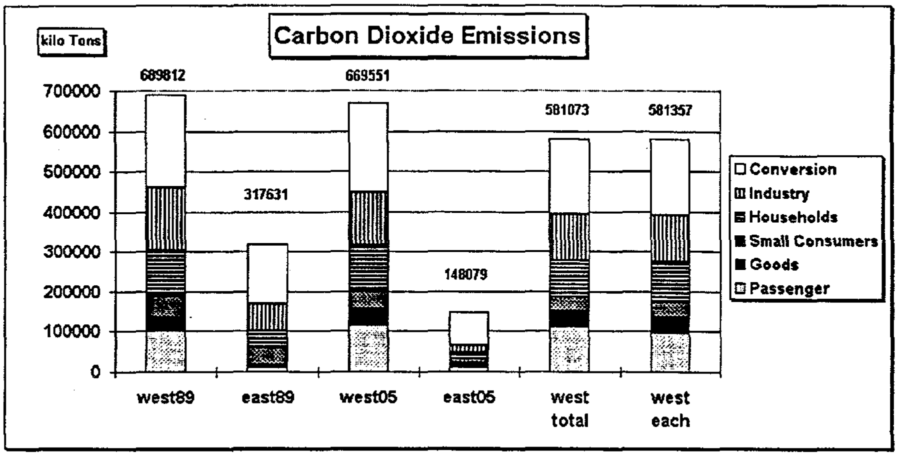

Figure 2: CO_2 emissions in Germany 1989 and 2005 with two reduction strategies

Thus a reduction strategy called "west total" was calculated with an upper limit (-18 % in the west, compared to 1990) on the sum of all carbon dioxide emissions. Regarding this case in figure 2 one can see that there are notable reductions in some sectors, especially in the conversion sector, but also in the industry sector, and households. On the other side there is no reaction by the passenger traffic.
There are discussions in politics and in the public if it would be fair that each energy sector should add almost the same relative reduction amount to the reduction target. Therefore another strategy was calculated -called "west each" - in which each sector has to reduce its emission at the same relative rate. Based on the emission structure of the year 1990 this means: about minus 18 % CO_2 emission per sector for the year 2005.
In both cases it is of interest what is going on in the transport sector. Is there no reaction or cannot we see it ?
At first the development from 1989 to 2005 will be analysed. There is different behaviour in the eastern and in the western part.
The demand in the passenger traffic sector is growing much more in the east as in the west: 51.1 % versus 23.2 % between 1989 and 2005 (Table 1). This is accompanied by an increase in CO_2 emission of 134 % in the east and only 12 % in the west.

The key date that connects demand and carbon dioxide emission is the specific CO_2 emission per person-kilometre (in kg/100pkm). This date is influenced by many facts. First it is influenced by the modus of moving: taking a bus or train or moving in a car, second by the number of people (occupation number) using the same vehicle, and third by the technical dates of the vehicle (fuel consumption, exhaust gas dates). These are the most important facts, there are other ones like the drivers behaviour or the kind of road that have not so much influence.

Figure 3 shows the specific CO_2 emission per 100 pkm for the calculated cases.

"east 89" has a very low value. This is due to the fact that the share of individual passenger transport (modal split) was very low (59 %) and that on average the private cars were well occupied by 2.0 persons. The fuel consumption was lower than in the west.

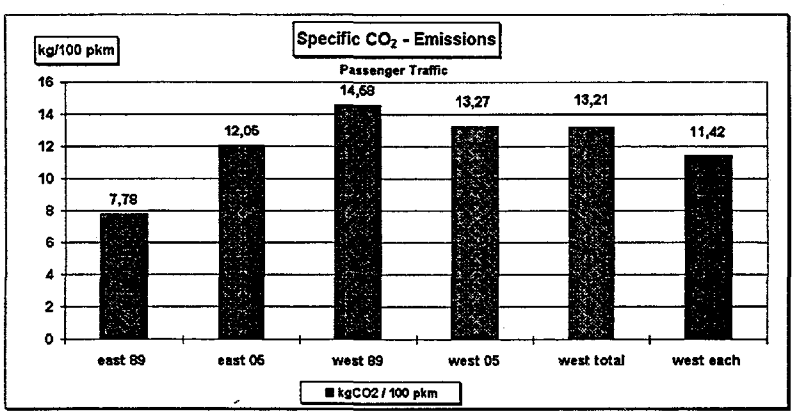

Figure 3: Specific CO_2 emission per 100 pkm from the calculated cases

In the year 2005 almost all of these facts change into the direction of more emissions: the modal split increases to 75% individual pkm-transport, the occupation number (person per car) sinks to 1.3, the same happens with the public passenger services where the occupation number decreases about 20%, only the fuel consumption becomes better (-7.2 %).

The behaviour in the west is another one: only a slight increase of the modal split for individual transport (from 86.6 % in 1989 to 87.4 % in 2005) is to be seen, the occupation number (person per car: 1.3) remains constant but the public passenger service has an occupation number 10 % higher than in 1989 and the fuel consumption per car is more than 9% less. Therefore the specific CO_2 emission per 100 pkm decreases about 9 %. This is not enough to compensate the higher demand but helps to halve the emission consequences.

Before discussing the reduction cases the development in the goods transport sector will

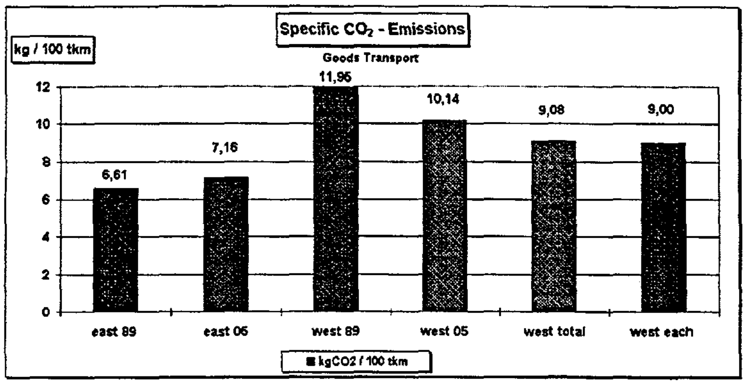

Figure 4: Specific CO_2 emission per 100 tkm from the calculated cases

be shown. Figure 4 demonstrates by analogy with the passenger sector the situation by giving the specific CO_2 emission per 100 tkm.

The situation in the eastern part of Germany seems similar to the passenger sector. However in this case the load numbers (tons per truck or goods train, freight ship or aeroplane) go up from 1989 to 2005 (as well for road traffic as well as for the other traffic modes), the fuel consumption is less than in 1989. These facts lead to lower emissions. Only the modal split changes significantly from 20 % to 36 % road traffic. Nevertheless this change dominates the situation and makes the specific emission per tkm higher.

In the western part the share of road traffic decreases from 60 % to 53 %, fuel consumption goes down, but - with the opposite effect on emission - the load number of the trucks is more than 10 % lower. This is overcompensated by the change of the modal split, too. Thus the CO_2 emissions smoothly increase (by 25 %), compared to the decrease in demand (look table 1). The percentage is twice as high as for the passenger traffic and the absolute value is near that of the passenger traffic. This demonstrates that goods transport is a fast growing sector which becomes more and more important within the transport sector.

The two reduction cases were calculated without any change of the assumptions. Only the constraints to the carbon dioxide emissions were added. So far the model could only react by varying the technical structure. This means it could be chosen a higher share of diesel cars, or the normal vehicles could be substituted by high efficiency cars, busses, trucks or trains. All road vehicles could be substituted by cars needing alternative fuels (compressed natural gas (cng), electricity, bio-ethanol, hybrid diesel-electricity, liquid petroleum gas (lpg), methanol, and rapeseed oil. They all differ in their costs and emission behaviour. The dates are stored in the IKARUS database and were generated by TÜV Rheinland, Cologne, for the project.

As told before the model chooses a solution in which the total costs of the energy system are at minimum. Without looking into detail one can say that a strategy which is based on the idea "each sector should contribute the same relative share to the reduction targ(." is more expensive than having a global restriction on CO_2. Otherwise the model would have shown this solution in the case "west total". So it can be learnt by that case that it is cheaper to reduce more than 18 % CO_2 in other sectors before reducing CO_2 in the transport sector. Nevertheless there is a small amount of CO_2 reduction in the transport sector, too. Relative to case "west 05" there is a reduction of only 0.5 % in the passenger sector, in the goods traffic sector it is about 10.5 %.
These reductions will be reached in the passenger sector by introducing rapeseed fuelled busses instead of diesel-busses with a share of 10.5 % so that the bus fleet consists of 83.9 % diesel-busses, 5.6 % lpg-, and 10.5 % rapeseed oil-busses. In the private car sector petrol-cars will be reduced from 79.9 % to 79.1 % giving room for 0.8 % lpg-cars. The rest is diesel. Aircraft and trains are unchanged.
In the goods transport sector only the road traffic is modified. The transport services change from 91.6 % diesel to 23.8 % diesel plus 55 % high efficient diesel, 9.4 % Hybrid (diesel-electric), and 3.4 % rapeseed oil. The rest remains unchanged petrol.
In the case "west each" this solution stays almost stable. There is a small decrease in diesel and an increase in rapeseed oil fuelled trucks.
In this case the passenger traffic moves towards a new bus- and car-pool. The new shares of the vehicles can be seen in table 2. The pool changes into high efficient busses and cars. As a new fuel ethanol is introduced

Vehicle	Percent	Vehicle	Percent
bus diesel	15.6	car petrol	43.6
high eff. bus diesel	59.0	*high eff. car petrol*	12.3
bus lpg	5.0	car diesel	20.1
bus rapeseed oil	15.6	high eff. car diesel	10.8
bus ethanol	5.0	car lpg	11.4
		car ethanol	1.8

Table 2 : ***Car pool in the case "west each"***

The table 2 shows that in this case drastic changes will be necessary, and one can suppose that this is expensive. This is the reason for the late reaction of the passenger traffic sector. The reductions are cheaper in the goods traffic sector, for the higher costs per vehicle and year can be related to a higher CO_2 reduction per car and year. The reasons are: trucks have per kilometre a higher fuel consumption and therefore higher emissions (and 10 % reduction is an absolute greater value) and they are driven more kilometres per year than private cars.
In general reductions of CO_2 in the transport sector are expensive in comparison with the costs of the other energy sectors. Figure 5 shows the differences of costs of the

energy sectors in comparison with the normal development that was calculated in case "west 05".

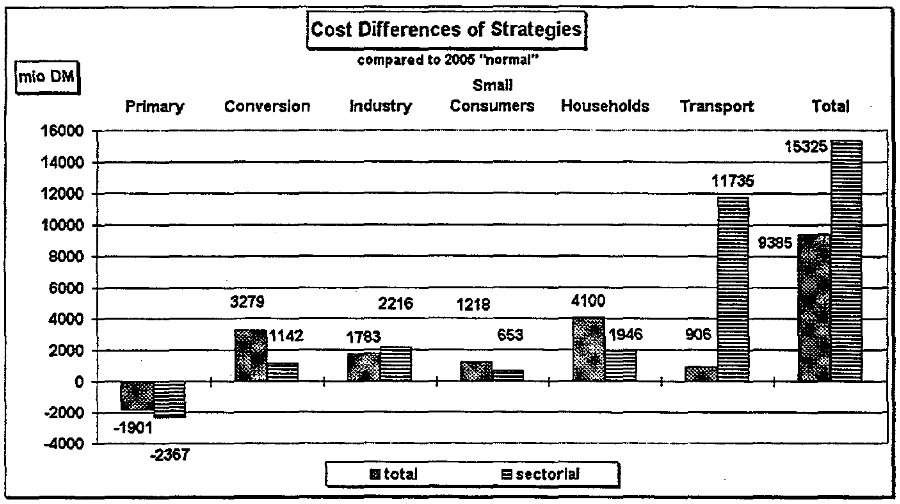

Figure 5: Differences of costs of the cases "west total" and "west each" compared to the case "west 05"

There is a gain of costs in the primary sector because less energy is needed. However this gain cannot compensate the additional costs of the other energy sectors. It is to be seen from the case "west each" that the transport sector is very cost- sensitive to changes and then dominates the total additional costs of the energy system.

For high populated areas the CO_2 emissions are not the real problem. Therefore in figure 6 the calculated development of other exhaust gases is shown. NOx, CO, SO_2, and NMHC (non methane hydrocarbons) are computed. It would have been nice if the CO_2 constraints would indirectly decrease these gases, too.

The figure 6 demonstrates that in contrary to the increasing traffic demands all these gases decrease significantly. This is the success of legislation and technical progress. There is only a small correlation between CO_2 constraint and SO_2. If the CO_2 constraint becomes very stringent there might be a small increase in SO_2 coming from a larger use

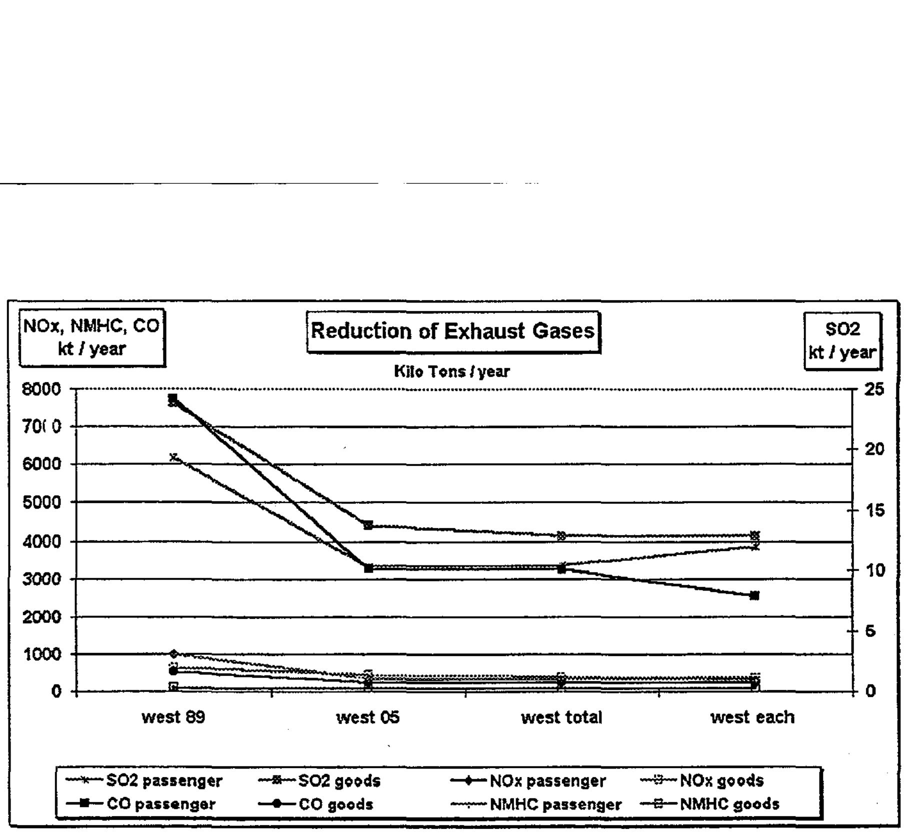

Figure 6 : Development of other exhaust gases

of diesel. This could be compensated by decreasing the sulphur content of diesel fuel. The other gases show no correlation to CO_2, so that there is no "windfall profit" while reducing carbon dioxide.

5. CONCLUSIONS

Germany pledged itself to make a 25 % reduction in national CO_2 emissions by 2005 on the basis of 1990 emissions. With the help of the IKARUS-LP, an energy optimization model for calculating greenhouse gas mitigation strategies, it could be demonstrated that the above mentioned target will not be reached although the emissions will decrease at about the half in the eastern part of Germany (former DDR). Especially the CO_2 emissions of the transport sector will increase significantly. Calculations with CO_2 constraints show that the reduction rates differ from energy sector to energy sector. The contribution of the traffic to the reduction is rather small, for it is cheaper to compensate the low reduction rate of the transport sector by higher ones in other sectors. Forcing the transport sector to the same rates will increase the total reduction costs at about 1/3. Positive is the development of NOx, SO_2, CO, and non methane hydrocarbons which decrease significantly opposite to the development of the traffic demand. From this point of view traffic in high populated areas becomes less problematic.

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THE LONG-TERM DEVELOPMENT OF THE ENERGY INPUT IN TRANSPORTATION, 1970-2020

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EXPOSE DU PROBLEME

This paper is a - modest - statistical and economic analysis of the energy input in the transportation sector over the past twenty-five years (1970 - 1995) and an attempt at looking ahead over the next twenty-five years (1995 - 2020)..

Over my lifetime the energy input in transportation has drastically changed. My grandfather - a reasonable wealthy farmer - delivered up to the late 1920's potatoes from Kampenhout, a small farmers village about 25 km from Brussels, by horse and cart at the house of his customers in mid-town Brussels. Personal transportation was per pedes apastolorum (i.e. on foot): they made nothing about walking 10 à 15 km up and idem ditto back. I do not know how to measure the energy input in this situation. (Horse Power or Man Power?)

In the decade before World War II the bicycle became a current means of transportation: people gained a greater degree of mobility and drove to work or to town for visits and errands. Transportation over greater distance was by public transport: train, streetcar, rudimentary busses.

Again is the energy input of those days difficult to measure (Man Power input into cycling?) or impossible for lack of statistical basis. A possible exception is rail transport.

After World War II passenger cars and trucks became the means of transportation par excellence and are still the main vehicle for moving around, both men and freight. Energy input statistics were born. Let us see what they teach us.

A 1970 - 1995

Transportation is these days (1993) in Western Europe responsible for 29% of total final energy consumption. Twenty-five years ago (1970) this ratio was hardly more than 17%, thus reflecting the higher levels of income and purchasing power, the need for mobility and substantial progress in automotive techniques during this period. Chart I reflects the year to year developments in this period, showing a gradual but steady increase.

Worthwhile noticing also that 80% of increase in total final energy consumption in Europe over the last 25 years, is on the account of the transportation sector. In industry TFEC even went down by 10%.

table 1 - Final energy consumption in E.U. by sector
(M t.o.e.)

	Industry	%	Transport	%	Domestic and Tertiary	%	TOTAL	%
1970	339	43	137	17	308	39	784	100
1980	345	36	197	22	362	40	904	100
1990	318	34	260	28	362	38	940	100
1995	298	30	277	29	384	40	959	100

Looking at figures for individual countries, two conclusions can be reached:

1) trends in the 15 E.U.-countries don not deviate much from the long-term development on a European level.
2) for some countries the data must be considered unreliable.
   For instance: - 1970 and 1980 figures for Luxembourg
   - the persistently high figures for Greece and 1990/1995 data for Spain

chart I: Total final energy consumption by sector

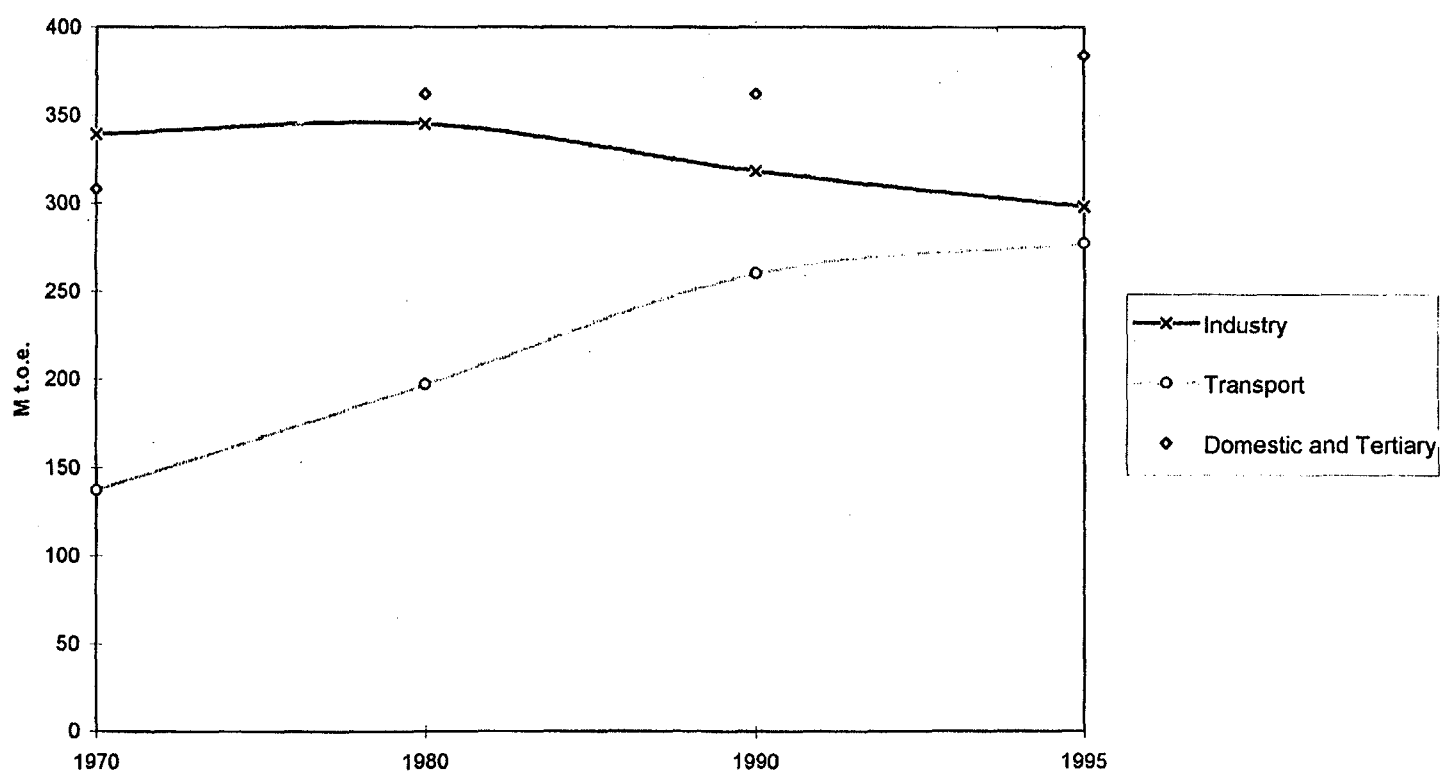

table 2 - Share of transportation in total final energy consumption in Western Europe
(in %)

	Austr	Bel	De	Fi	Fr	Ger	Gr	Ir	It
1970	21	14	19	13	17	15	29	24	19
1980	24	17	24	16	23	18	35	27	24
1990	25	23	32	19	30	24	39	26	29
1995	28	23	30	18	30	27	43	29	31

	Lu	Ne	No	Por	Sp	Swe	Swi	UK
1970	5	17	20	28	26	15	24	19
1980	15	17	19	31	32	17	25	25
1990	30	20	23	30	38	23	32	31
1995	35	20	26	34	40	22	31	31

The above figures suggest following conclusions:

1. Some countries have a relatively low share (below 25%) of TFEC going to transportation: Belgium, Finland, Netherlands, Germany, Norway, Sweden.
2. Other see a remarkably higher share (around 30%) of TFEC going to transportation: Austria, Denmark, France, Ireland, Italy, Switzerland, United Kingdom.
3. Have an unbelievable high share in transportation (above 30%): Greece, Luxembourg, Spain, Portugal.

Looking in another way at the geographical differences in the energy input in transportation and eliminating the difference in size of the countries is to calculate the annual energy input in transportation per person.

Table 3 - Annual energy consumption in transportation per inhabitant, 1993
(in t.o.e.)

Luxembourg	3.250	Germany	786
USA	1.993	Austria	775
Canada	1.588	Netherlands	771
Norway	1.093	*E.U. (average)*	*750*
Switzerland	913	Japan	675
Denmark	865	Italy	661
Sweden	862	Greece	640
Belgium	650	Ireland	638
UK	825	Spain	630
Finland	820	Portugal	464
France	788		

B 1995 - 2020

What will be developments over the next twenty-five years?

In order to give a tentative answer to this question, two sets of forecasts were consulted. There are first the four scenario's worked out by D.G. XVII in its recent publication (which I can recommend for its wealth of statistical information and its well-written exposés) "European Energy to 2020 - A Scenario Approach" and second there is the work of the Energy Center Netherlands and Statistics Norway in "Energy Scenarios for a changing Europe - Integration versus Fragmentation".

1. E.U.-FORECASTS

As indicated above 4 scenario's are worked out. The assumptions underlying each scenario can be summarised as follows:

- Conventional Wisdom (C.W.) = business as usual.
- Battlefield (B.F.) = Geopolitical blocs compete. Europe à la carte, protectionist policies; oil price shock beginning early next century, followed by deep recession and economic stagnation.
- Hypermarket (H.M.) = global economic integration. Market mechanisms prevail, incl. liberalisation and privatisation. Government intervention and taxation reduced to minimum. Subsidies and social transfers substantially reduced.
- Forum (F.M.) = global economic integration leads to restructured national, European and international institutions. Policies aim at improved environmental quality and higher economic growth.

Adopting these four scenario's the following forecasts of total final energy demand and the demand for energy by the transport sector are arrived at. (See also chart on p)

table 5 - Total final energy demand in the transportation sector in E.U., 1995-2020 (M t.o.e. and % of TFED)

	C.W.		B.F.		H.M.		F.M.	
	M t.o.e.	%	M t.o.e.	%	M t.o.e.	%	M t.o.e.	%
1990	**254**	*29.4*	**254**	*29.4*	**254**	*29.4*	**254**	*29.4*
1995	**270**	*30.3*	**272**	*30.3*	**264**	*29.6*	**272**	*30.6*
2000	**293**	*30.9*	**292**	*30.6*	**278**	*29.0*	**291**	*31.9*
2005	**314**	*31.7*	**282**	*30.4*	**294**	*28.8*	**311**	*32.9*
2010	**333**	*32.2*	**316**	*31.1*	**311**	*28.8*	**322**	*32.4*
2015	**349**	*32.5*	**324**	*31.4*	**326**	*28.9*	**352**	*34.0*
2020	**364**	*32.8*	**332**	*31.6*	**340**	*29.1*	**371**	*34.5*

Let it immediately be stated that the Luxembourg figure, which is completely out of line with the rest, actually measures energy (gasoline and diesel) that is sold on its territory but not consumed there. Prices of gasoline and diesel in Luxembourg are because of low taxation about 15% to 30% cheaper than in Belgium, France and Germany (the surrounding countries) so that thousands of motorists flock daily to Luxembourg to fill up (an buy at the same time also cheaper cigarettes and liquor).

Now what determines the energy input in transportation or, in simpler terms, what determines how much energy we use for our transportation needs?

One obvious factor is the level of income. Poor people have no money to pay for cars, gasoline and auto-maintenance. On the other hand the affluent society allows families to have two cars. Chart II sets out on one hand income levels (G.D.P. per person at purchasing power parity level) and energy consumption per person for transportation purposes on the other hand. the repression coefficient of the link income/transportation energy input estimated at 0.86 shows that other factors are involved.

The price of transportation fuels in one of them. Size of the country and urban structure are other variable, not easy to quantify. In this study no attempt is made to set up multiple correlation curves. Price - and income - elasticity's of demand would have to be estimated.

table 4 - Price (incl. taxes) of transportation fuels, 1993
(in ECU per 1000 l.)

Italy	817	Denmark, Germany	685
Netherlands	762	United Kingdom	676
France	728	Greece	647
Belgium	719	Spain	620
Ireland	705	Luxembourg	552

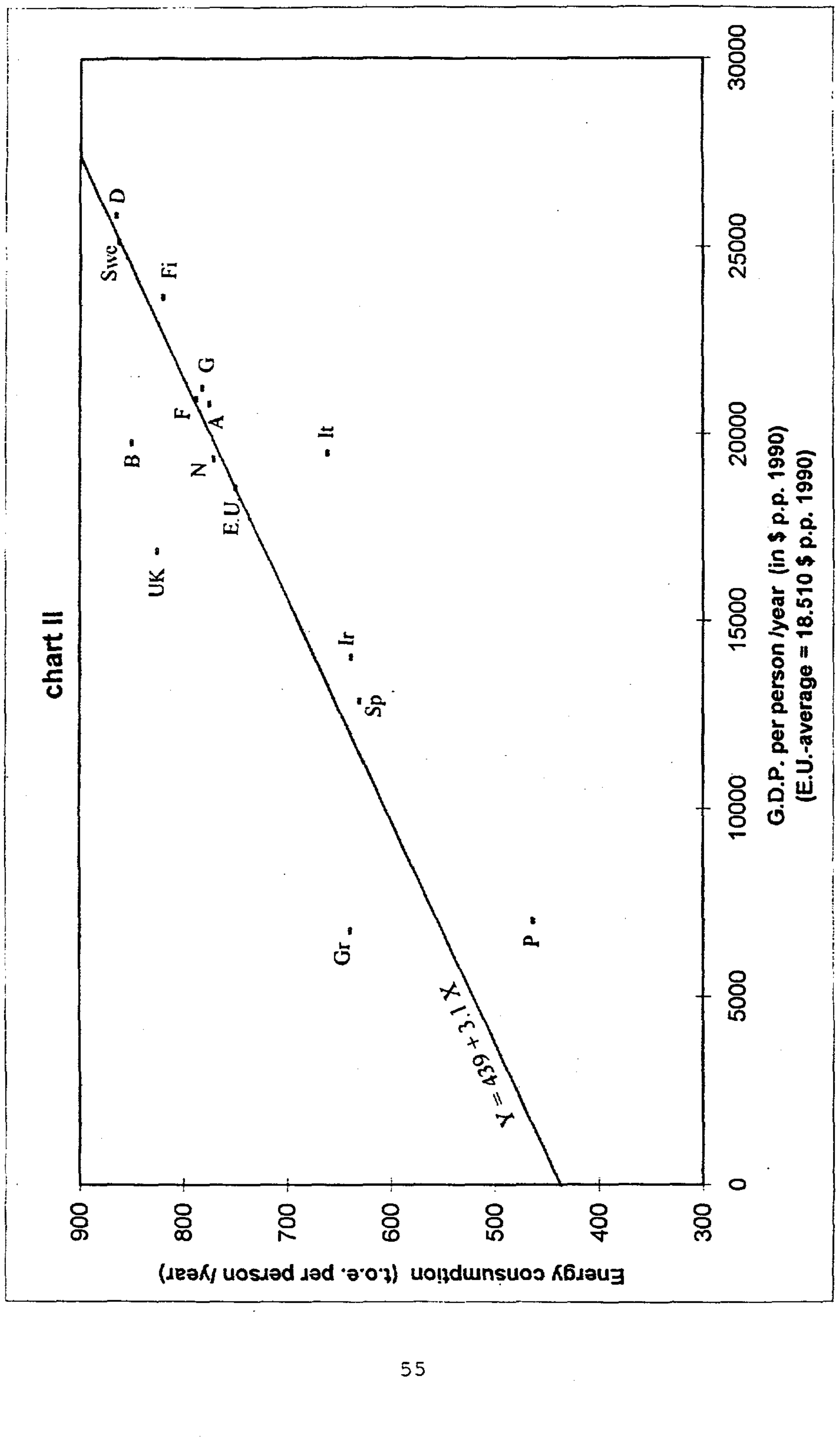
chart II
Energy consumption (t.o.e. per person /year)
900
800
700
600
500
400
300
0
5000
10000
15000
20000
25000
30000
G.D.P. per person /year (in $ p.p. 1990)
(E.U.-average = 18.510 $ p.p. 1990)
Y = 439 + 3.1 X
Swe
D
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All in all and notwithstanding the sometimes very divergent assumptions in the four scenarios, the forecasted values of energy demand in the transportation sector do not deviate substantially (figures are within a 10% range, which over a 25 year period is not very much).

2. ENERGY CENTER NETHERLANDS - STATISTICS NORWAY

The above institutions developed an energy demand model for Western Europe (SEEM) including as sector industry, services, households and transport. The model is a combination of an econometric and a more technology oriented method and consits of thirteen West-European county models, covering about 90% of total energy use in OECD Europe.

Also in this approach the scenario-method has been used: one assuming continued integration in Western Europe (Integration Scenario) and another representing fragmentation of Western Union (Fragmentation Scenario).

Both scenarios lead to a significantly higher energy input in the transport sector by the year 2020 than shown in the E.U.-estimates, whereby it should be indicated that the results of the Integration Scenario are around 20% above the Fragmentation Scenario.

Interesting also to note that the effect of the introduction of a carbon-tax has been analysed. A 100$ /ton carbon tax (8$ barrel oil) does not lead, according to the forecasts, to the sometimes expected large energy savings and CO_2 reductions. A 300$ /ton carbon tax (about 25$ /barrel) seems to provide the necessary incentive to bring about long run stabilisation of CO_2 emissions in Western Europe.

table 6 - Energy demand in the West-European transport sector, 2020
(M t.o.e.)

	ECN / SN		E.U.
	F.S.	I.S.	(range of 4 scen.)
1990	260		260
2020	389	473	332 - 371

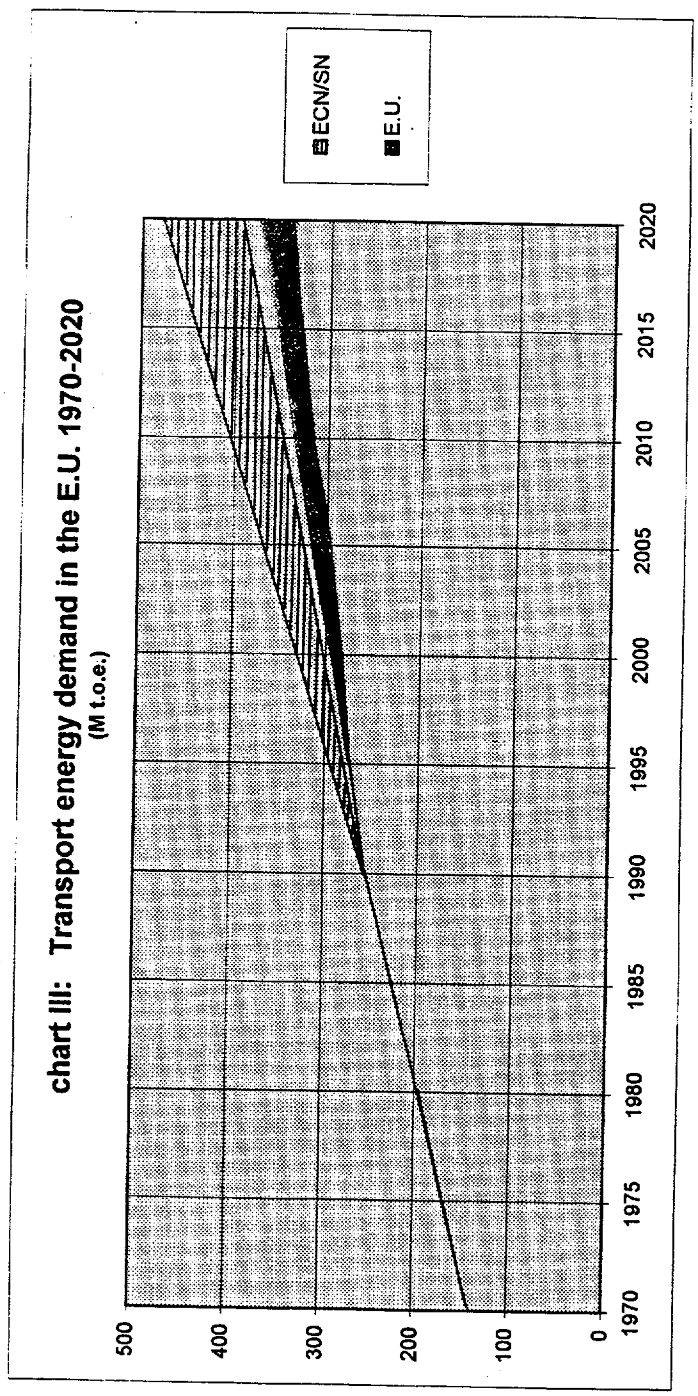
chart III: Transport energy demand in the E.U. 1970-2020
(M t.o.e.)
ECN/SN
E.U.
500
400
300
200
100
0
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

C LONG-TERM DEVELOPMENTS

Linking the data for 1970-1995 with the forecasts for 1995-2020, a fifty year trend of European energy input in transportation can be arrived at.

As the figures for 1995-2020 are mere forecasts, the data are presented in the form of ranges, thus indicating clearly the uncertainty about future developments. (See Chart)

What to conclude from this chart?

1) The trend development 1970-1995 showed a steep increase, followed according to the E.U.-forecasts by a definitely slower increase in 1995-2020 but, according to the ECN/SN-scenario (at least in the Integration-Scenario) , at about the same place as before.

2) At any rate the transport sector is the major contributor to the increase in final energy demand in the E.U. 42% to 55% of the increased TFED is accounted for by the transportation sector.

3) The figures shown reflect the outcome of two opposite developments on one hand technological progress will bring engines which can save up to 40% of fuel consumption per mile over the next decades.

   On the other hand rising incomes will increase demand for the personal mobility offered by the car.

   The outcome is probably more final demand. How much? Those who will be around at the 30th anniversary of the Danish Association for Energy Economics, will be able to tell.

Session 2. Technological development and new transport systems

Chairman:
Ulf Hansen, Universität Rostock, Germany

DEVELOPMENT IN THE TECHNOLOGY OF INTERNAL COMBUSTION ENGINES FOR PASSENGER CARS OVER THE NEXT 10 TO 15 YEARS

By Jürgen Willand, Daimler Benz, Germany

INTRODUCTION

The mainly use of fossile fuels and their limited ressources and also the requirement of a 25% reduction of CO_2-emissions in Germany caused by the motor traffic, force the pressure to the car manufacturer to reduce the fuel consumption by respecting the emission limits given by the legislative instituts.

The development of the worldwide vehicle population shows, that we can expect that markets like eastern Europe and developing countries will book the biggest amount of growing during the next decades (Fig. 1). Related to this fact is also the amount of CO_2-Emissions caused by this countries (Fig. 2). Of interest is that the emissions produced by cars will stagnate which is basicly caused by the falling fuel consumption and in opposition the emissions of heavy trucks will expand overproportional. The reason is the strong expanding infrastructure in new markets and the fast growing number of heavy trucks in those countries.

The target for Mercedes Benz is to reach a fuel economy until 2005 for the vehicle fleet of at maximum 6,0 liter / 100 km (Fig. 3). Results concerning fueleconomy could only be achieved on the base of progressive technologies. The introduction of new combustion concepts respectively new technologies has specific limits. With regard to the real results there are already cars from our company today, that do not consume more than 3l of fuel for 100 km - a corresponding driving style provided. Figure 4 shows, that you can achieve a consumption of below 3liter / 100 km with a C200 Diesel by driving speeds between 40 and 70 km/h in the 5th gear. Certainly this requires a driving style wich does not allow significant accelerations and is only possible with continuous traffic flow. We can assume that nearly no driver is able to drive his car under such conditions. Additionally our traffic flow will not allow this driving style for a longer period.

In figure 5 we can see the fuel consumption of a diesel car over vehicle speed. It is obvious that the fuel consumption in low gears is corresponding to the average speed. In the direct gear we reach a minimum of 4 l/100 km at 40 km/h. Both left diagramms show the speed profile of the New European Driving Cycle (NEDC). In the city part (ECE) of the NEDC the speed is gradually increased four times up to 50 km/h. In the Extra Urban Driving Cycle (EUDC) the speed is increased up to 120 km/h as shown in the profile. The ■- points show the different driving cycles regarding their corresponding average speed and fuel consumption. Under this test conditions this car reaches an average fuelconsumption of 9 l/100 km. The next figure shows the influences which dominates the fuel consumption (Fig. 6). First of all the vehicle influence on the fuel consumption. Beside the vehicle concept the loading, tyrepressure and the drag coefficient are the key parameters. Furthermore the driver influences the fuelconsumption with his driving style, gearselection, driving time (Rushhour) and route selection. Last but not least we can recognize an influence of the local strategies for traffic control like traffic lights and speed limits. These 3 main factors determine the fuel consumption.

Lightweight Design

One important theme concerning consumption reduction is the use of lightweight components in the whole power train (Fig. 7). Especially the cylinderhead and the piston group cover potentially big improvements. The change from conventional gliding bearings to roller bearings and the introduction of light and very strong materials as Carbon, Ceramics, Titan and Aluminium lead by consequent use of this technology to a significant reduction of friction loss. This makes it possible to reduce the fuel consumption up to 5 % (Fig. 8). Looking on the whole engine we detect the friction loss caused by the power demand of the accesories (Fig. 9). There is also further reduction potential by using new technologies and intelligent control units.

Variable Valve Timing

The high part load fuel consumption of SI-engines is caused by the high throttling losses. The use of Variable Valve Timing (VVT) is one way to drive an SI-engine without throttling losses and with optimized Valve Timing (Fig. 10/11). VVT is in opposite to conventional valve trains able to realize steeper control flanks by free selection of the valve timing for all engine speeds. Therefore VVT reduce the fuel consumption under = 1 conditions, this means further use of a conventional 3-way catalyst, and furthermore significant torque gains especially in lower engine speed. Because of its flexibility this valve train must not respect the normal compromise between good idle, part load and full load behaviour. Further economy potential is given by the possibility of cylinder deactivation, which is easy to describe.

SI-Engine Direct Injection

Another possibility for a throttleless load control for SI-engines is given by direct injection with stratified charge. SI-engines with inner mixture formation try to connect the advantages of SI- and Diesel technology by preventing the disadvantages (Fig. 12).
By producing stratified charge using inner mixture formation we expect especially under part load conditions comparable to VVT significant reductions in fuel consumption. (Fig. 13). Beside the dethrottling this is also caused by the reduced wall heatlosses in operating points with high air surplus. In opposite to the stratified part load operation the engine can be driven in 1 = 1 operation under full load conditions. Caused by the inner cooling of the direct into the combustion chamber injected fuel it is possible to increase the maximum amount of charge in comparison to manifold injection, which leads to a detectable power rise.
Unfortunately this consept needs - like all lean burn engines - an emission aftertreatment with DENOX-catalyst or Nox-memory catalysts to reduce the Nox, but this technology does not have a production like developing state.
Looking on the further development for the next 10 to 15 years we notice a reduction of fuel consumption and emissions of up to more than 20 % for SI-engines (Fig. 14). Regarding future emission limits like EZEV shows us that there is a strong need for further research and development concerning raw-emissions and emission aftertreatment.

Diesel Engines

The most important emission of Diesel engines are Nox and Particles. Fig. 15 shows the trade off between fuel economy and emissions for Diesel engines. Normally all engine strategies to reduce the Nox emissions will increase the fuel consumption or increase the emitted particle mass. Therefore also Diesel engines have a need for an emission aftertreatment with DENOX Technology. One way is a stepped injection, this means a post injection to reduce the Nox in the combustion chamber or in parts of the exhaust system. Normal injection system like PLD-Injection does not give the possibility to realize a post injection (Fig. 16). The new common rail injection give the possibilty to do that. The standard solenoid injectores of common rail systems are only able to open or close the injector in a limited speed. New designs like piezo actuated injectors give full flexibility for the injection contour and timing which influences the fuel consumption, the emission aftertreatment and also the noise caused by the burning process (Fig. 17).

Diesel-EGR

A common technolgy to reduce the NOx-Emission of Diesel engines is the Exhaust Gas Recirculation (EGR) as shown in figure 18. This technology mix a portion of the exhaust gas to the fresh air in the inlet manifold. The exhaust gas has an higher heat capacity than fresh air which reduces the maximum temperatures during the burning process and also the production of NOx as a function of the burning temperature. Unfortunately this Nox reduction is combined with an increased particle emission.

Diesel-Water-Diesel Injection

To pass this trade off a new injection technology - called Diesel-Water Injection was developed based on the same physical principle as EGR.The higher heat capacity than fresh air but without its disadvantages, the increased particle emission (Fig. 19). Caused by the right timing of the water injection into the combustion chamber during the injection process the technology will work without any influence on the particle emission while reducing the Nox emissions. With these technologies we are able to realize emission reduction rates up to 40 % by reducing the fuel consumption up to 20 % (Fig. 20).

Conclusion

The consequent further improvement of conventional technologies by using new materials and optimized parts is able to give us today a consumption reduction of up to 5 %. In the first decade of the next century new technologies will be used under the legislative pressure in terms of fueleconomy and emissions. The intelligent combination of different technologies for both systems Diesel- and SI-engines will give us further improvements and the chance to save the position of individual traffic for the next decades.

Sources:

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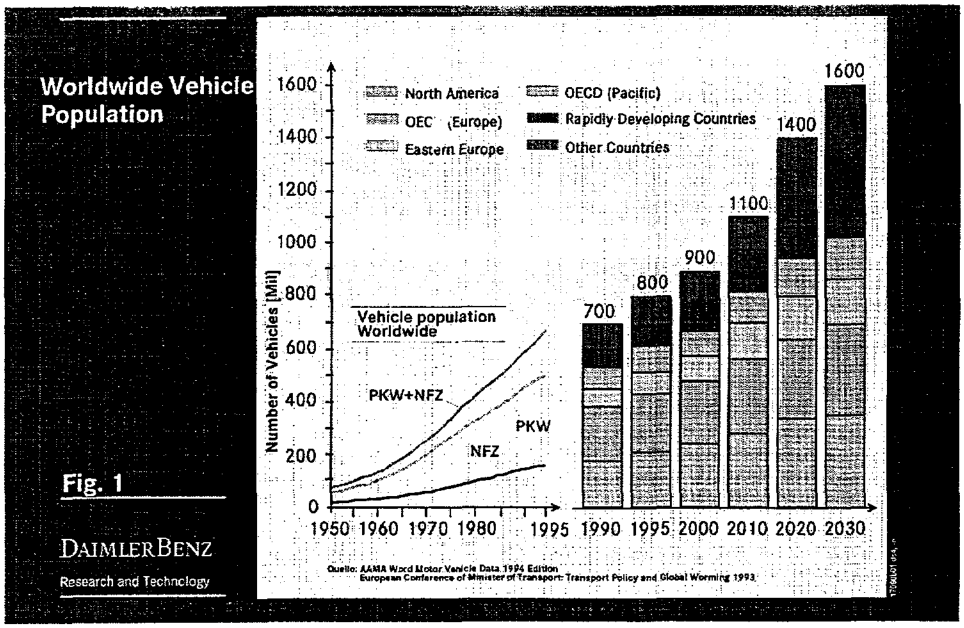

Worldwide Vehicle Population
Fig. 1
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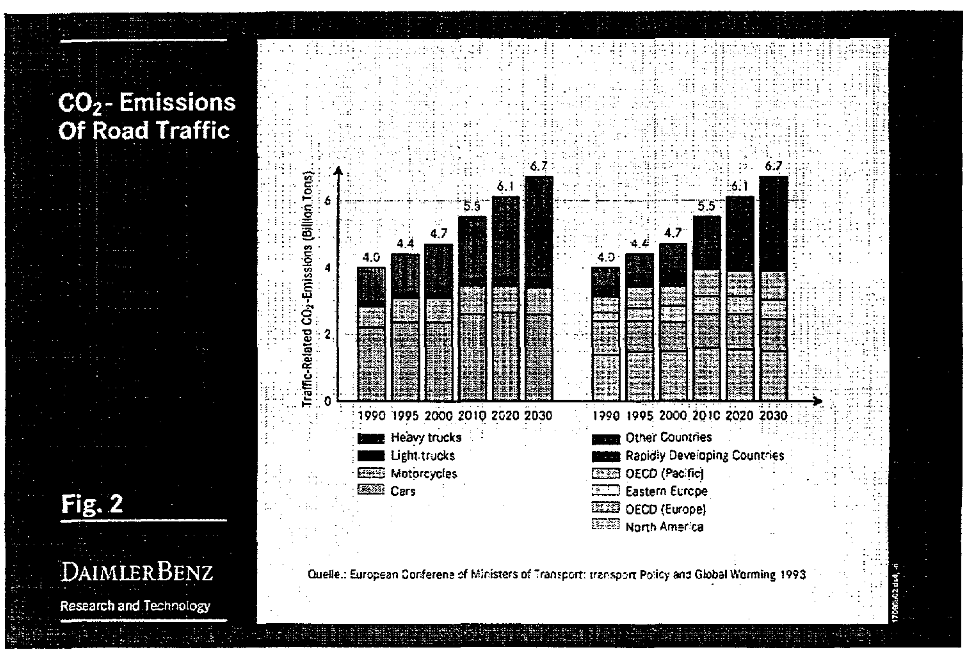
North America
OEC (Europe)
Eastern Europe
OECD (Pacific)
Rapidly Developing Countries
Other Countries
Number of Vehicles [Mil]
1600
1400
1200
1000
800
600
400
200
0
Vehicle population Worldwide
PKW+NFZ
PKW
NFZ
700
800
900
1100
1400
1600
1950 1960 1970 1980 1995
1990 1995 2000 2010 2020 2030
Quelle: AAMA Word Motor Vehicle Data 1994 Edition
European Conference of Minister of Transport: Transport Policy and Global Worming 1993



CO_2- Emissions Of Road Traffic
Fig. 2
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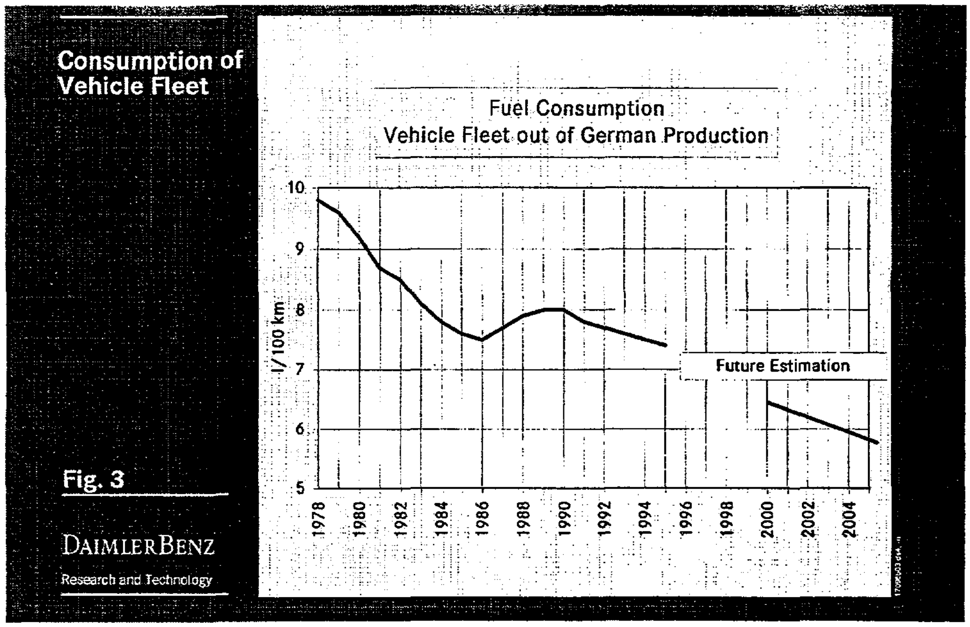
Traffic-Related CO_2-Emissions (Billion Tons)
0
2
4
6
4.0
4.4
4.7
5.5
6.1
6.7
1990 1995 2000 2010 2020 2030
Heavy trucks
Light trucks
Motorcycles
Cars
Other Countries
Rapidly Developing Countries
OECD (Pacific)
Eastern Europe
OECD (Europe)
North America
Quelle.: European Conferene of Ministers of Transport: transport Policy and Global Worming 1993



Consumption of Vehicle Fleet
Fuel Consumption
Vehicle Fleet out of German Production
l / 100 km
10
9
8
7
6
5
Future Estimation
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
Fig. 3
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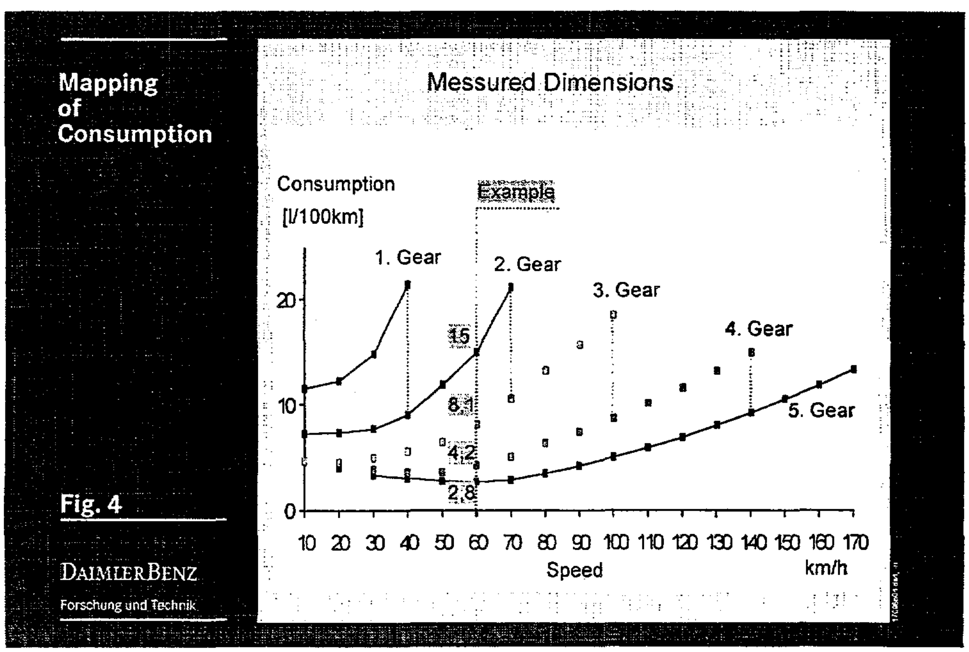

Mapping of Consumption
Messured Dimensions
Consumption
[l/100km]
Example
1. Gear
2. Gear
3. Gear
4. Gear
5. Gear
15
8.1
4.2
2.8
20
10
0
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170
Speed
km/h
Fig. 4
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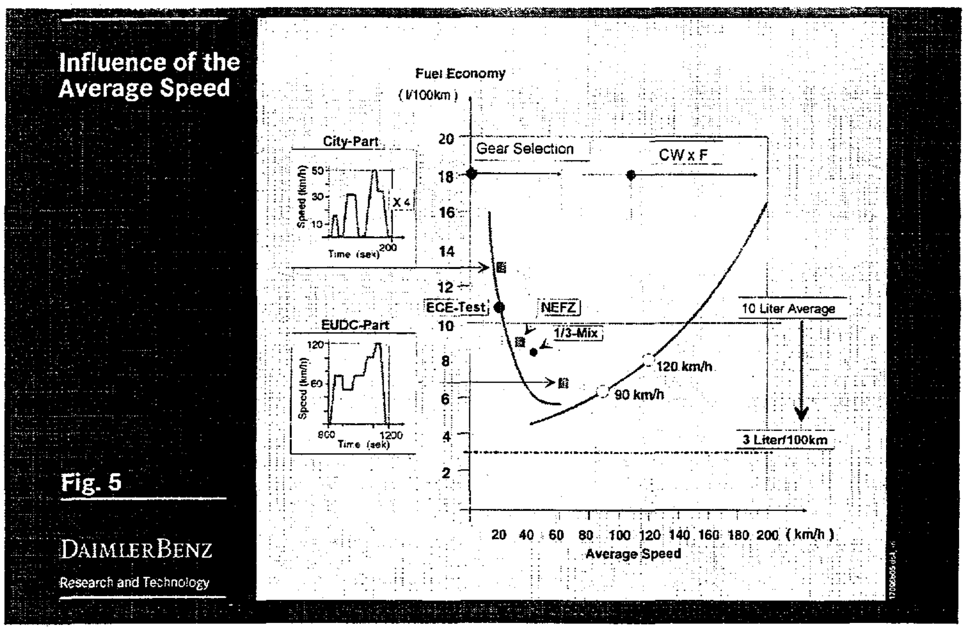
Influence of the Average Speed
Fig. 5
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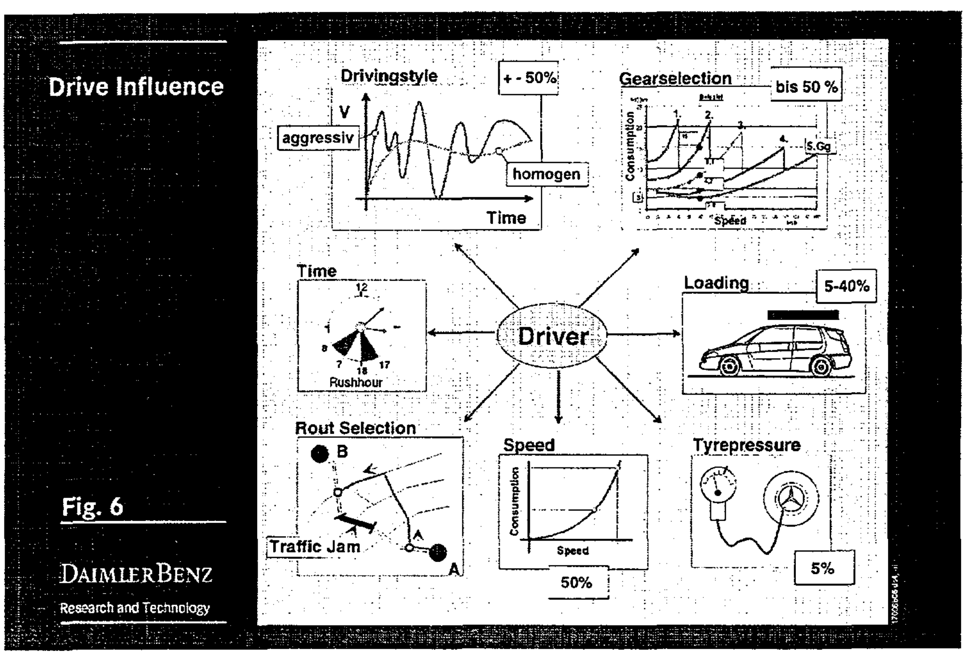
Fuel Economy
(l/100km)
City-Part
Speed (km/h)
X 4
Time (sec)
EUDC-Part
Speed (km/h)
Time (sek)
Gear Selection
CW x F
ECE-Test
NEFZ
1/3-Mix
10 Liter Average
120 km/h
90 km/h
3 Liter/100km
20 40 60 80 100 120 140 160 180 200 (km/h)
Average Speed


Drive Influence
Fig. 6
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Drivingstyle
+ - 50%
V
aggressiv
homogen
Time
Gearselection
bis 50 %
Consumption
5.Gg
Speed
Time
Rushhour
Driver
Loading
5-40%
Rout Selection
B
A
Traffic Jam
Speed
Consumption
Speed
50%
Tyrepressure
5%

Weightreduction by Leightweight-komponents

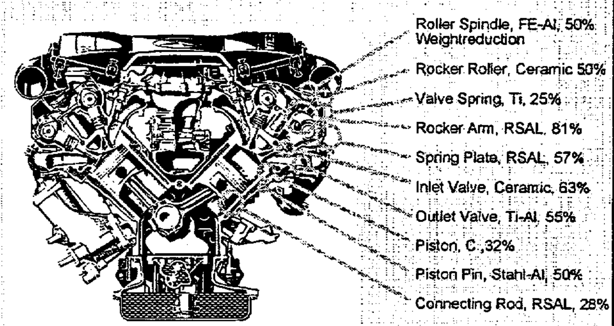

Fig. 7

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Fuel Economy by Leightweight-komponents

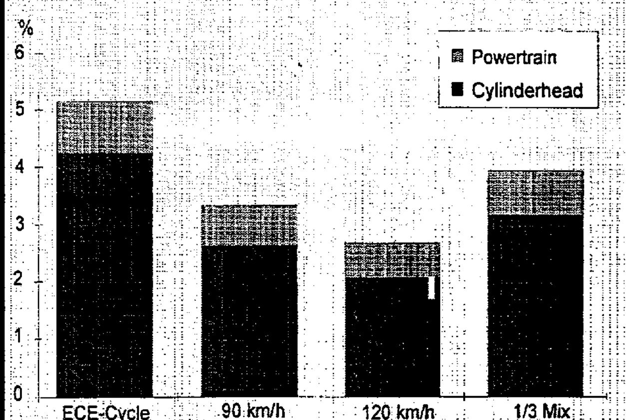

Fig. 8

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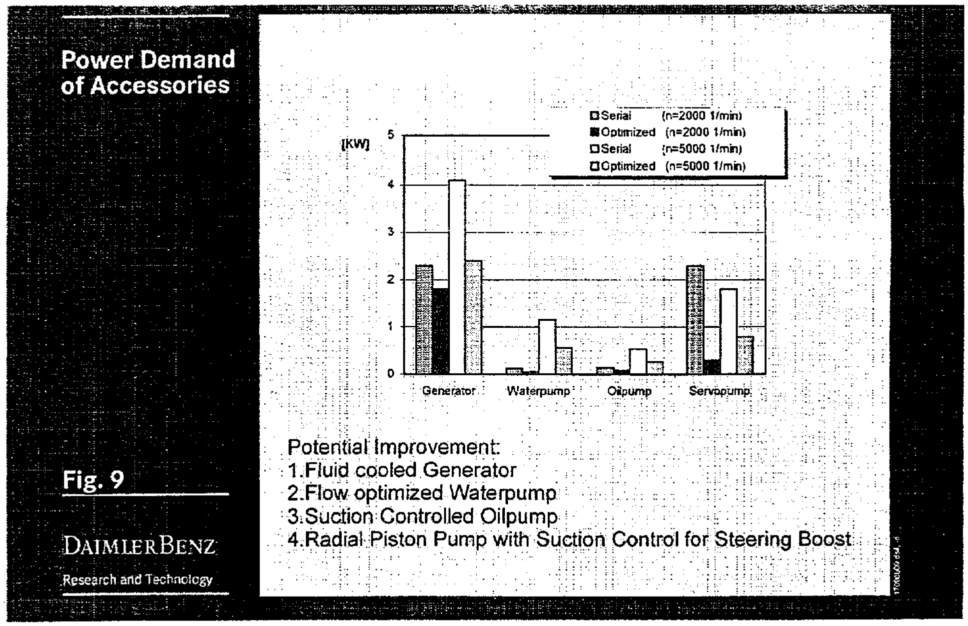
Power Demand of Accessories
Serial (n=2000 1/min)
Optimized (n=2000 1/min)
Serial (n=5000 1/min)
Optimized (n=5000 1/min)
[KW]
5
4
3
2
1
0
Generator
Waterpump
Oilpump
Servopump
Potential Improvement:
1.Fluid cooled Generator
2.Flow optimized Waterpump
3.Suction Controlled Oilpump
4.Radial Piston Pump with Suction Control for Steering Boost
Fig. 9
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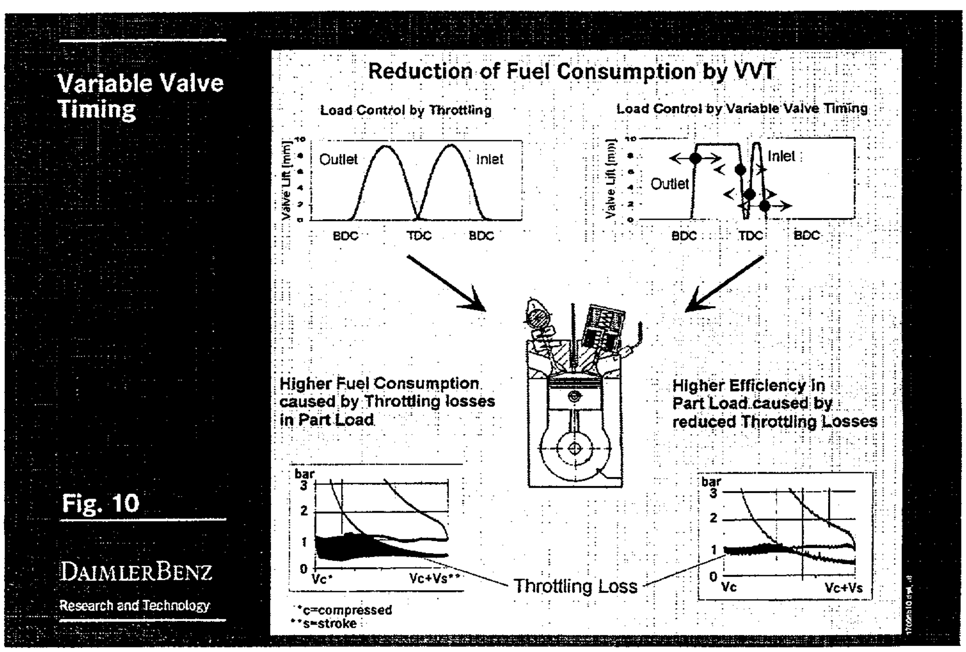
Variable Valve Timing
Reduction of Fuel Consumption by VVT
Load Control by Throttling
Load Control by Variable Valve Timing
Valve Lift [mm]
Outlet
Inlet
BDC
TDC
BDC
Higher Fuel Consumption caused by Throttling losses in Part Load
Higher Efficiency in Part Load caused by reduced Throttling Losses
bar
3
2
1
0
Vc*
Vc+Vs**
Vc
Vc+Vs
Throttling Loss
*c=compressed
**s=stroke
Fig. 10
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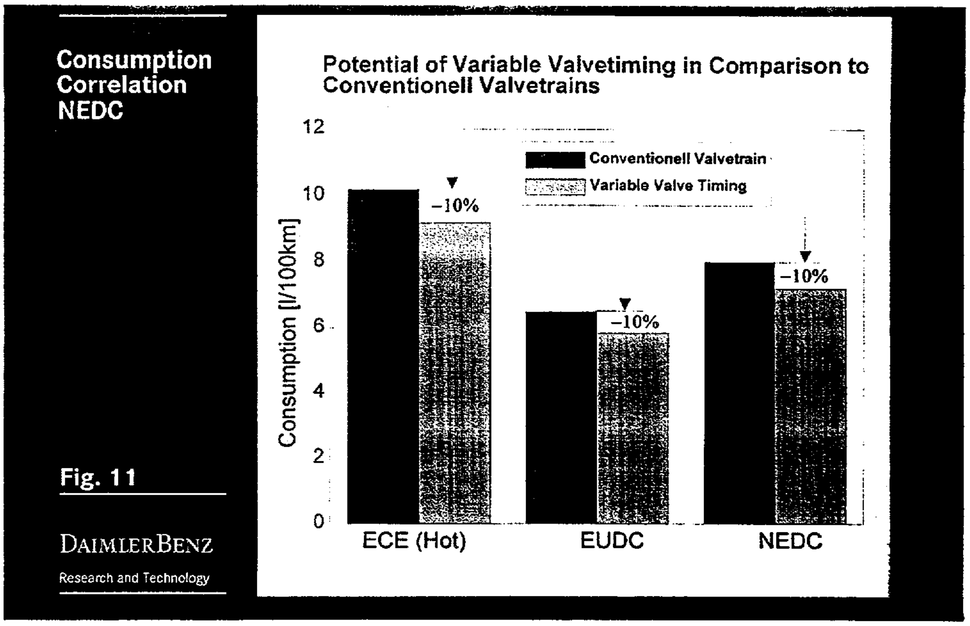
Consumption
Correlation
NEDC
Fig. 11
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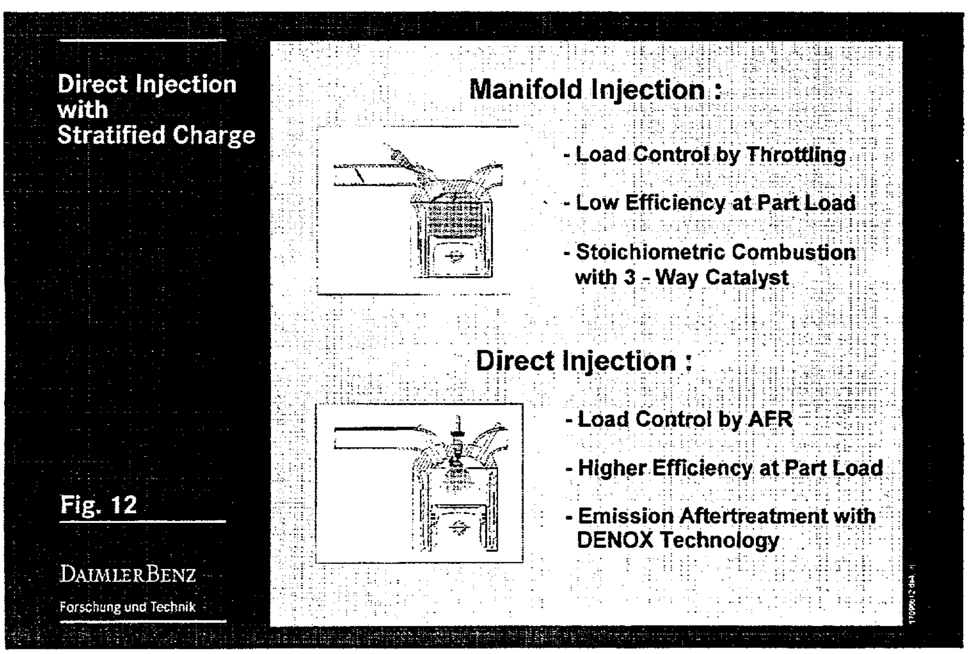
Potential of Variable Valvetiming in Comparison to Conventionell Valvetrains
Conventionell Valvetrain
Variable Valve Timing
Consumption [l/100km]
12
10
8
6
4
2
0
−10%
−10%
−10%
ECE (Hot)
EUDC
NEDC


Direct Injection
with
Stratified Charge
Fig. 12
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Manifold Injection :
- Load Control by Throttling
- Low Efficiency at Part Load
- Stoichiometric Combustion with 3 - Way Catalyst
Direct Injection :
- Load Control by AFR
- Higher Efficiency at Part Load
- Emission Aftertreatment with DENOX Technology

Inner Mixture-formation

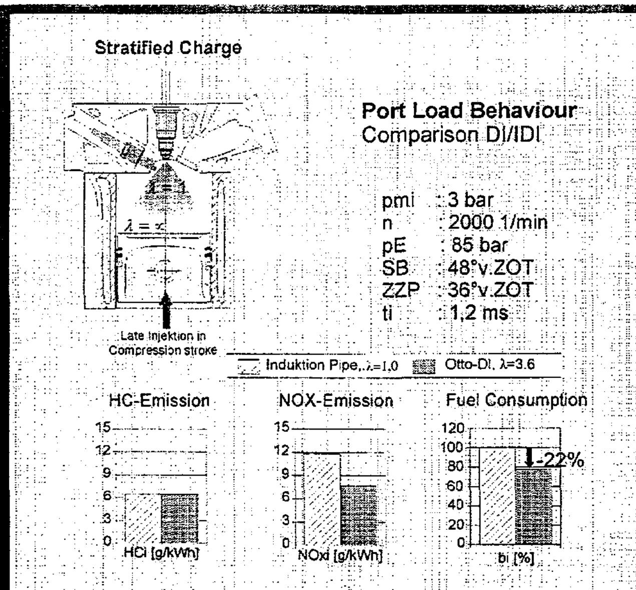

Fig. 13

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Future Development

Pkw-SI-Engine

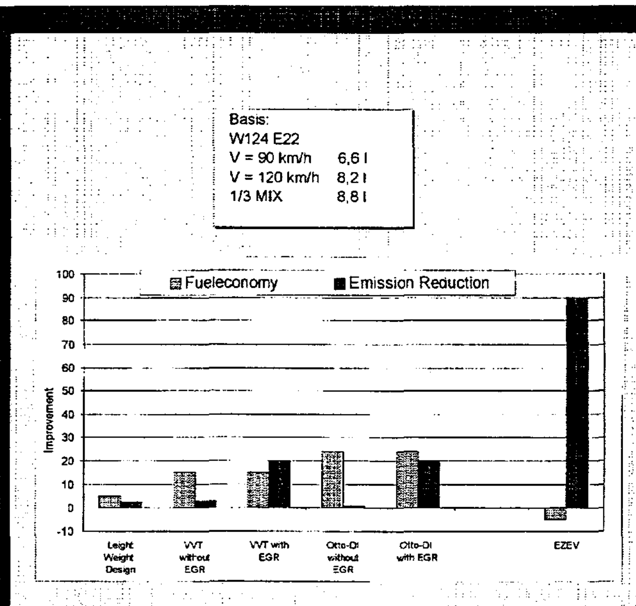

Fig. 14

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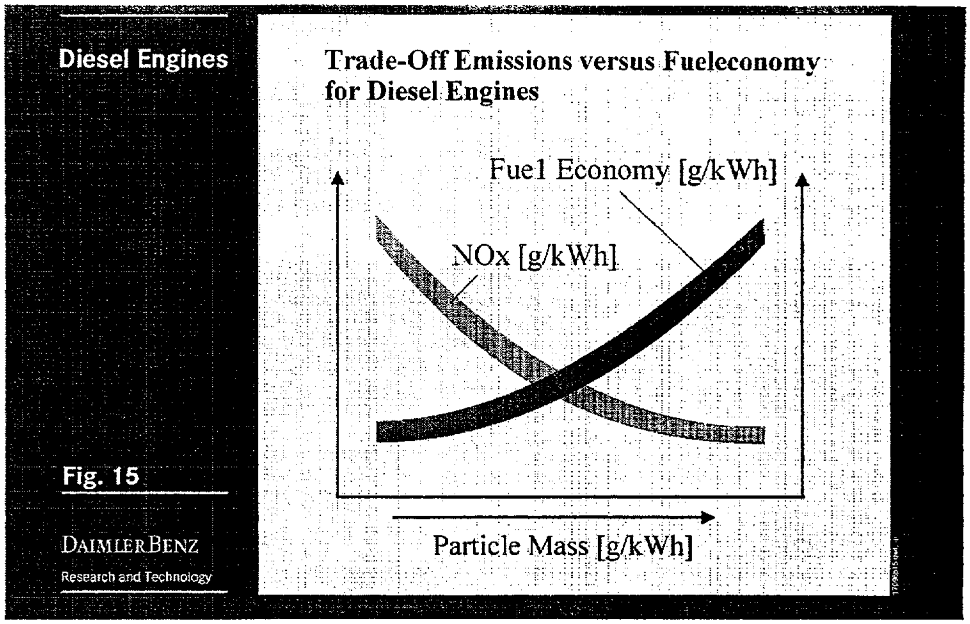
Diesel Engines
Trade-Off Emissions versus Fueleconomy for Diesel Engines
Fue1 Economy [g/kWh]
NOx [g/kWh]
Particle Mass [g/kWh]
Fig. 15
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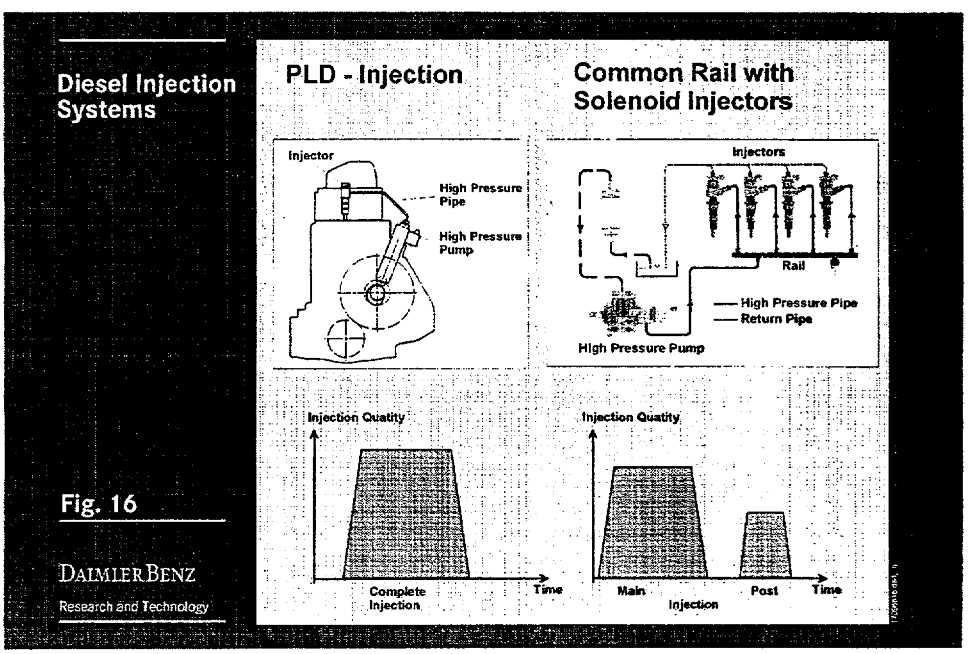
Diesel Injection Systems
PLD - Injection
Common Rail with Solenoid Injectors
Injector
High Pressure Pipe
High Pressure Pump
Injectors
Rail
High Pressure Pipe
Return Pipe
High Pressure Pump
Injection Quatity
Complete Injection
Time
Injection Quatity
Main
Post
Injection
Time
Fig. 16
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Injection System

Advantage:

- Free Forming of Injectioncontour for Consumption Reduction
- Flexible Post Injection for Efficient Emission Treatment
- Variable Pree Injection and Stable Minimum Fuel Quantity

Solution:

- System with Direct actuated Injector Needle
- Injection Quantity

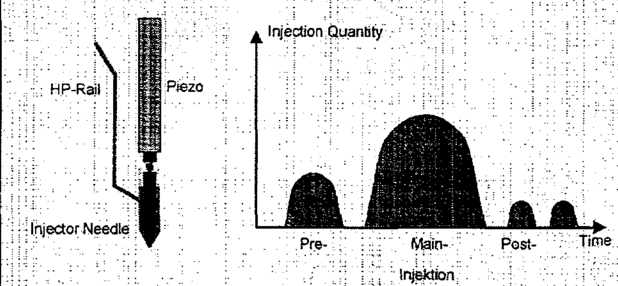

Fig. 17

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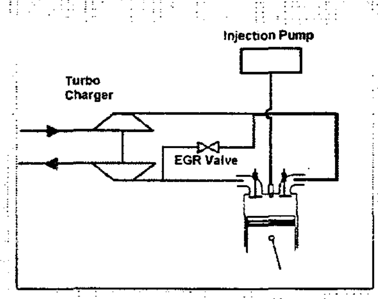
Diesel - EGR

NOx-Reduction by Exhaust Gas Recirculation



Advantage:

Standard Technology

Disadvantage:

Increased Particle Emission

Fig. 18

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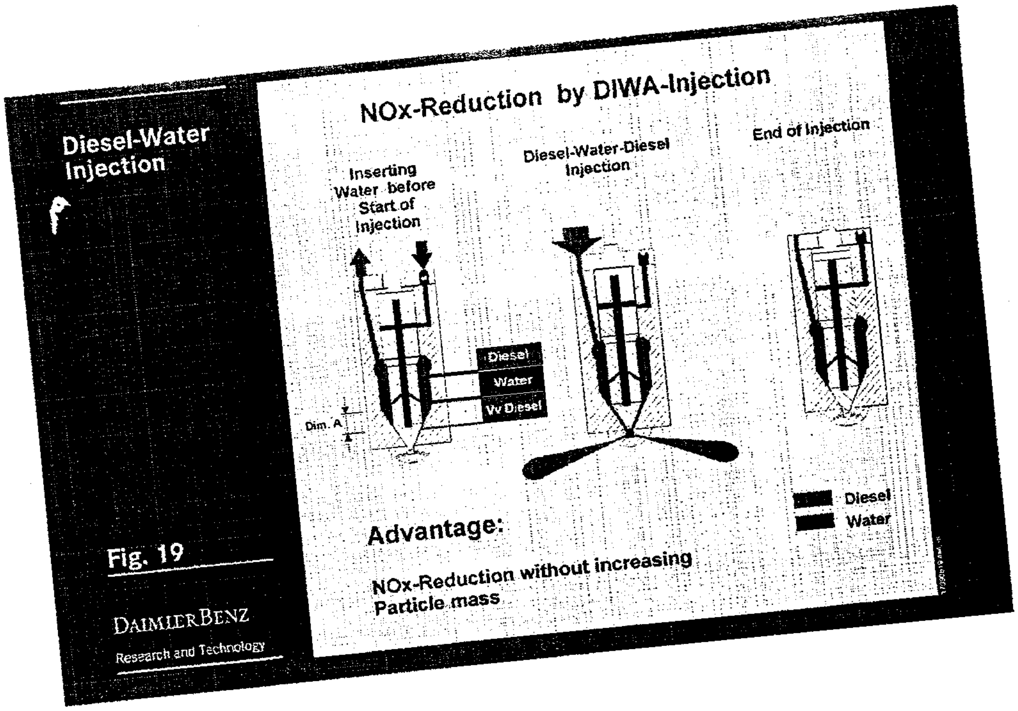
Diesel-Water Injection
NOx-Reduction by DIWA-Injection
Inserting Water before Start of Injection
Diesel-Water-Diesel Injection
End of Injection
Diesel
Water
Vv Diesel
Dim. A
Diesel
Water
Advantage:
NOx-Reduction without increasing Particle mass
Fig. 19
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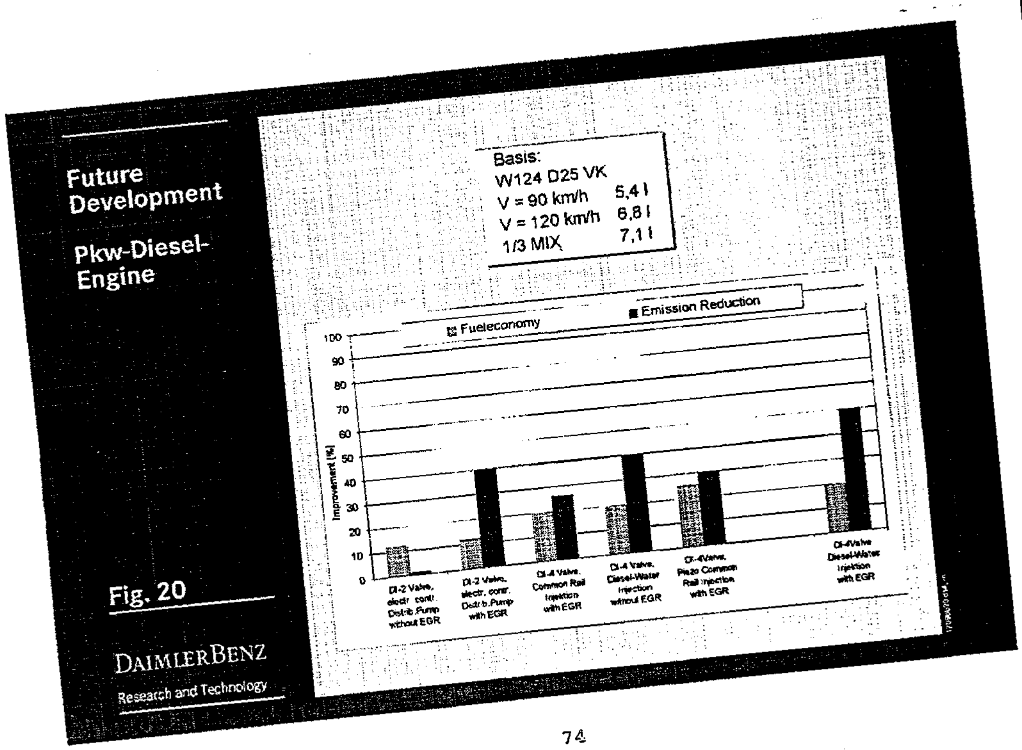
Future Development
Pkw-Diesel-Engine
Basis:
W124 D25 VK
V = 90 km/h 5,4 l
V = 120 km/h 6,8 l
1/3 MIX 7,1 l
Fueleconomy
Emission Reduction
Improvement [%]
100
90
80
70
60
50
40
30
20
10
0
DI-2 Valve, electr. contr. Distrib.Pump without EGR
DI-2 Valve, electr. contr. Distrib.Pump with EGR
DI-4 Valve, Common Rail Injektion with EGR
DI-4 Valve, Diesel-Water Injection without EGR
DI-4Valve, Piezo Common Rail Injection with EGR
DI-4Valve Diesel-Water Injektion with EGR
Fig. 20
DAIMLERBENZ
Research and Technology

SUBSTANTIAL IMPROVEMENTS OF FUEL ECONOMY - POTENTIALS OF ELECTRIC AND HYBRID ELECTRIC VEHICLES

By Kaj Jørgensen, Technical University of Denmark, Lars Henrik Nielsen, Risø, Denmark

1 INTRODUCTION

This paper evaluates the scope for improvement of the energy and environmental impacts of road traffic by means of electrical and hybrid electric propulsion. These technologies promise considerable improvements of the fuel economy of vehicles compared to the present vehicle types as well as beneficial effects for the energy and traffic system.

The paper - based on work carried out in the project "Transportation fuel based on renewable energy", funded by the National Energy Agency of Denmark and carried out by Department of Buildings and Energy, Technical University of Denmark and System Analysis Department, Risø National Laboratory - assesses the potentials for reduction of the primary energy consumption and emissions, and points to the necessary technical development to reap these benefits. A case study concerning passenger cars is analysed by means of computer simulations, comparing electric and hybrid electric passenger car to an equivalent reference vehicle (a conventional gasoline passenger car).

Terminology. While the paper concerns economising with energy, it does not deal with economics in monetary terms. The main indicator of the energy economics is termed the "fuel chain efficiency" - measured as the primary energy input per km (i.e. the conversion of the primary energy to vehicle motion). In addition, the concept "vehicle efficiency" is used to describe the efficiency converting fuel and/or electricity by the vehicle to vehicle motion (i.e. disregarding the efficiency of the power generation system). In line with this, a distinction is made in the paper between "primary energy demand" (measured at the source) and "fuel or gasoline demand", referring to the products delivered at the vehicle. Power demand generally is measured at the vehicle (i.e. off the grid), unless otherwise noted. "Summer conditions" in the power supply system means that the process heat is not assumed to be utilised (or referred to the heating side), while "winter" means power generation with heat utilisation (referred equally to the electricity and heating side) of the energy production system. "Exhaust" refers to the output from the exhaust pipes of the vehicle, whereas the term "emissions" means total emissions, unless otherwise noted.

2 BACKGROUND

Given the targets for CO2-reductions, there is a considerable demand for improved fuel economy of vehicles and/or switch to fuels with low CO2-emissions. This need is reinforced by the growth in transport demand and by the still greater percentage of the transport demand covered by motor vehicles. For instance, the projected growth of the official Danish transport demand prognosis would, all other things being equal, lead to an increase in the CO2-emissions by 40-50% by the year 2030, as compared to the targets in the same plan: stabilisation on the 1988-level by 2005 and a 25% reduction by 2030 (Ministry of Energy and Environment). Moreover, these targets are more moderate than the general Danish energy planning targets, aiming at a reduction of the CO2-emissions by 20% in the year 2005 and by 50% in the year 2030 (not a binding target), and the required reductions would be even greater to cater for a more equal distribution of the global emissions.

In addition, there are other emission reduction targets to be taken into consideration. These are aiming at a reduction of the emissions of nitrogen oxides (NOx) and hydrocarbons (HC) by 40% before the year 2000 and by 60% in 2010, whereas particle emissions in urban areas are required to be halved by the year 2010 (Ministry of Transport 1993).

On this background, there is an urgent requirement for much cleaner vehicles. There has been substantial progress with regard to emissions of NOx, HC, CO (carbon monoxide) and particle matter, and further improvements can be expected in the coming years. In contrast, the fuel economy of vehicles on the market has shown little improvement over the last 15-20 years and recently has even started to deteriorate, despite the existence of several prototypes with much higher fuel efficiency. The fuel economy may improved 2-3 times through refinements of the present vehicle technologies, depending on the cost increases accepted (Moore & Lovins 1995). One of the main obstacles to further improvement is the internal combustion engine, being poorly suited to the typical driving patterns of most light duty vehicles with much stop/go traffic, frequent idling and varying loads.

Further improvements may be achieved by shifting to other fuels. Bio-fuels potentially offer very low CO2-emissions with moderate technical changes, provided the energy for processing and distributing the fuel can be kept down. However, the resource base of bio-fuels (biomass) is limited, due to the limitations on the yield per hectare land imposed by the poor efficiency of the photo-synthesis process. Fuel cell technology could reduce this problem by substantially increasing the overall vehicle efficiency, but the large-scale application of these for vehicles is unlikely to take place within the next 10-20 years, and even with fuel cell based vehicles the overall efficiency of bio-fuels vehicles is poor.

3 ELECTRIC PROPULSION

Electric vehicles are mostly promoted to improve local air quality and (less frequently) to reduce oil dependency. Hence, they are mostly being pursued as an option in urban traffic, also offering the driving patterns best suited for electric vehicles. Frequently, though not always, the pollution is simply transferred to the power stations without many considerations on the overall energy and environmental effects (i.e. the fuel chain effects).

However, electrical propulsion potentially offer a substantial improvement of the fuel chain effects of the vehicle and at the same time can be an instrument for introducing renewable energy into the transport sector. Whether the fuel chain effects are improved depends on two main factors: the vehicle efficiency, determining the power demand off the grid, and the power generation system, determining the energy and environmental effects of covering this power demand.

The vehicle efficiency, in turn, is determined partly by the tractive forces that the vehicle encounter during its motion and partly by the efficiency of the on-board drive system converting the electricity to torque at the wheels. The main issue as regards the former of these factors is the vehicle weight, increased by the added weight of the battery. This has a major impact on the vehicle efficiency as 60-80% of the vehicle load is linked to the vehicle weight in typical driving patterns (the remainder being linked to the air resistance and on-board accessories). For electric vehicles, therefore, there is an inherent conflict between range, demanding the heaviest possible battery, and vehicle efficiency, demanding the battery to be kept as light as possible. Advanced batteries, with higher energy density, can alleviate this limitation, but with today's predominate battery types - notably lead/acid - the vehicle range is limited to about 50-100 km per battery charge.

4 HYBRID ELECTRIC VEHICLES

Hybrid vehicles is a generic term for a wide range of very different drive systems, with the common characteristic that they include both internal combustion engines (ICEs) and electric motors in the drive train. A distinction is made between configurations in which both the ICE and the electric motor are connected to the driving wheels (parallel hybrid) and designs with only the electric motor provide while the ICE forms part of a on-board power generation unit (series hybrid).

The variations of the hybrid vehicles can be illustrated by the extremes of the category (Burke 1992, Sperling 1995). On the one side, there is the concept termed "electric vehicle with extended range", which is designed maintain the exhaust-free driving of the electric vehicles while countering the main limitation of these - namely their limited range. Basically, this vehicle is designed as an electrical vehicle, except that it is equipped with a small auxiliary power unit (ICE/generator), mainly for emergency purposes. The demand for this design is closely linked to the present generation of short-range electric vehicles, which means that it probably disappears with the advent of advanced batteries (or if these remain expensive). At the opposite extreme is a design which may be termed "ICE-drive with load-levelling", which is aimed at achieving high overall vehicle efficiencies, while exhaust free driving is not given priority. It is basically designed as an ICE-vehicle, but using a battery as a load-levelling device to provide better operating conditions for the ICE.

In this paper, the main emphasis is on energy efficiency, and therefore the latter approach is the most interesting option in this context (Moore & Lovins 1995). In the longer term, it may be rendered superfluous if fuel cells are made available at affordable prices.

5 VEHICLE FUEL ECONOMY

The electricity and fuel consumption of electric and hybrid passenger cars have been computed for a passenger car case study by means of model simulations, cf. Table 1. These take a gasoline driven model vehicle - corresponding to an average Danish passenger car - as point of departure, calculating the gasoline demand per kilometre in selected driving patterns. This reference vehicle is then used as basis for analysing three equivalent vehicles, namely two electrically driven and one hybrid electric. These vehicles are similar to the reference vehicle, except that the drive system (engine, fuel tank, exhaust system etc.) is replaced by electrical or hybrid electrical drive systems - i.e. no downsizing has been assumed in conjunction with the shift. The two electric vehicles are similar, except that one is based on state-of-the-art technology while the other is based on advanced technologies (battery, motor etc.). The hybrid is of the type "ICE with load-levelling" (series hybrid). The main focus in the paper is on the comparison of conventional and electric vehicles, whereas the hybrid vehicle is included to illustrate a different path to improved energy efficiency, in which it is not necessary to sacrifice vehicle range.

The following procedure has been used in the calculations:

1. the tractive forces (air resistance, rolling resistance, acceleration/braking losses) are computed using a dynamical simulation model;
2. the gasoline and electricity demand (delivered at the vehicle) are calculated for the four vehicle types, using a spreadsheet-based model, which calculates the specific electricity and fuel consumption through iteration (which is needed due to the link between vehicle/battery weight and efficiency).

	Range, electrical mode, km	Electricity demand kWh/km	Gasoline demand kWh/km
<u>Urban driving (ECE)</u>			
Gasoline, conventional	-	-	0,76
Electric, state-of-the-art	60	0,21	0,04
Electric, advanced	180	0,11	-
Hybrid,	-	-	0,53
<u>90 km/h (constant)</u>			
Gasoline, conventional	-	-	0,47
Electric, state-of-the-art	70	0,21	0,01
Electric, advanced	230	0,10	-
Hybrid	-	-	0,54

<u>Table 1.</u> The calculated electricity and fuel demand of different versions of the model passenger car: conventional gasoline drive (reference vehicle); state-of-the-art electric; advanced electric; series hybrid. In addition, the range in electric mode is shown (if applicable). Ref: Jørgensen & Nielsen (1996).

Two driving patterns have been analysed: ECE Urban Cycle test pattern and 90 km/h constant speed. It has been assumed that the heating of the cabine is provided by gasoline in the state-of-the-art vehicle and by a heat pump in the advanced drive system.

The <u>model vehicle</u> used as basis for the calculation is a medium-sized passenger car, corresponding to the average of the Danish passenger car stock. It could be argued that a smaller passenger car would be a more appropriate choice, since this is the most likely market for electric vehicles. On the other hand, a large-scale introduction would probably require that other market segments are included. The principal characteristics of the reference vehicle are: curb weight 975 kg; frontal area 2.05 m2; cW-factor 0.31; maximum engine output 50 kW.

6 ELECTRIC VEHICLES AND THE ELECTRICITY SUPPLY SYSTEM

Table 2 shows the calculated total electricity consumption of electric vehicles with different penetration rates (5%, 10% and 25%) compared to the overall Danish electricity demand. The penetration rates take the present stock of privately owned passenger cars - 1.6 millions (Danmarks Statistik 1995) - as starting point. Other segments of the transport sector (e.g. vans, light duty trucks and buses) has not been covered in the paper. The study is based on electric vehicles only, not hybrid vehicles.

The calculation is based on a split of the passenger car stock into 5 curb weight categories (under 700 kg, 700-800 kg, 800-900 kg, 900-1000 kg, over 1000 kg). The electric vehicles are distributed on the weight categories, assuming highest penetration rates in the lightest categories:

- 5% penetration: nearly all electric vehicles in the two lightest categories;
- 10% penetration: continuing growth in the two lightest categories and the middle weight category (800-900 kg) starts to gain impact (conversion of 6% of the vehicles);
- 25% penetration: the two lightest categories approach the assumed saturation level (65% of the vehicles in the category) and greater percentages in the three heaviest categories (conversion of 28%, 11% and 1% respectively).

For each category, the average annual driving per vehicle has been assumed based on practical averages and specific gasoline consumption and electric consumption figures (before and after) have been calculated.

All three penetration rates result in total power demands - up to 4% of the present power demand on an annual basis - that should not pose any significant problems for the present power supply system, provided it is ensured that the batteries are not recharged to any significant extent during present peak periods.

	Transport sector fuel substituted %	Electricity demand TWh/a	% of total electricity demand
State-of-the-art			
5% of passenger cars	1.8	0.20	0.6
10% of passenger cars	4.0	0.45	1.4
25% of passenger cars	11	1.2	3.8
Advanced			
5% of passenger cars	1.8	0.10	0.3
10% of passenger cars	4.0	0.20	0.6
25% of passenger cars	11	0.55	1.8

Table 2. Illustration of effects of different penetration rates - by vehicle numbers - of the passenger car market. The columns show the calculated substitution of transport sector energy (% by energy content), the total annual electricity demand off the grid to meet the demand of the electric vehicles, and this demand's share of the total Danish power demand.

7 LOAD MANAGEMENT WITH ELECTRIC VEHICLES

Large-scale introduction of electric vehicles would mean that a considerable electrical storage would be available, which could be used to improve the flexibility of the power generation system. This is particularly useful in systems with a high percentage of fluctuating energy from renewable energy sources such as wind power and photovoltaics (see Section 9), but even in the present system, with a considerable share of combined heat and power production, flexibility on the demand side would improve the system. In a longer term, the on-board batteries may be used as a flexible storage capacity on the demand side, which may be used as a supply source in peak demand situations.

Table 3 shows different indicators of the size of the battery stock linked to different penetration rates, comparing each of them to the total average power supply off the national grid: the total storage capacity (in GWh) and the maximum power demand for recharging if the batteries are recharged at the same time and over 8 hours. As can be seen the 25% penetration rates result in a total storage capacity corresponding to about 1 hour of average total power supply for 10 kWh/vehicle and to 2 hour 45 minutes for 25 kWh/vehicle.

If the batteries are recharged over an 8 hour time period, the maximum charging power has been calculated to be 1,25 GW, or about 10% of the present maximum power demand. This demand can be provided by the present electricity supply system during the low load periods.

	Total storage capacity GWh	Capacity/ avg. load minutes	Max. charge (8 hours) MW	Charge/ avg. load %
A - 10 kWh/vehicle				
5% of passenger cars	0.8	15	100	2.8
10% of passenger cars	1.6	25	200	5.6
25% of passenger cars	4.0	65	500	14
B - 25 kWh/vehicle				
5% of passenger cars	2.0	35	250	6.9
10% of passenger cars	4.0	65	500	14
25% of passenger cars	10.0	165	1250	35

Table 3. Battery size indicators for different penetration rates for electric vehicles: total storage capacity of installed batteries (GWh); the ratio between capacity and the total average power supply from the Danish national grid, including import (minutes); the maximum recharge power demand (MW) if all batteries are charged at the same time over 8 hours; and the ratio between the maximum recharging power and the total average power supply. Two cases are included: an average battery capacity of 10 kWh/vehicle, e.g. 300 kg lead/acid batteries (A); and a "future situation" based on an average of 25 kWh/vehicle, e.g. 250-300 kg lithium-batteries (B). The average power demand is assumed to be 3.6 GW.

GW	5% penetration	10% penetration	25% penetration
1 hour storage			
10 kWh/vehicle	800	1600	4000
25 kWh/vehicle	2000	4000	10000
4 hours storage			
10 kWh/vehicle	200	400	1000
25 kWh/vehicle	500	1000	2500

Table 4. The average power that can be stored over 1 and 4 hours in the total on-board storage capacity of electric vehicles depending on the penetration rates (passenger car stock) and average battery size (Jørgensen & Nielsen 1996).

This presumes, however, that the recharging of batteries is regulated, since uncontrolled recharging at undesirable moments may turn the electric vehicles into a liability rather than an asset. In particular, it is crucial to limit the fast recharging during periods with high power demand (e.g. in the late afternoon), either by means of restrictions or economical incentives. Tariffs can be a means to this end, but at the same time technological development plays an important role, since advanced batteries are set to reduce the problem - namely the range - resulting in the need for fast recharging.

Table 4 provides a different view on the same problem, showing the electrical power that can be stored in the battery capacity presuming different storage time periods. Presuming 4 hours storage, the battery capacity of the electric vehicles can serve as a "sink" for between 1 GW and 2.5 GW of electrical power supply.

8 ENERGY CARRIER FOR RENEWABLE ENERGY IN THE TRANSPORT SECTOR

Electricity may serve as an energy carrier for renewable energy in the transport sector, and at the same time electrical vehicles may play an important role supporting fluctuating renewable electricity sources, such as wind energy, photovoltaics and wave energy.

There are two aspects of electric vehicles' role in this context: they represent an efficient utilisation of renewable resources and they may provide a demand side flexibility to improve the utilisation of fluctuating energy from renewable resources (load management).

The utilisation efficiency is significant even for renewable resources. While these resources as a whole occur in much larger quantities than the energy demand, the resources that can be used in practice are generally much smaller. The utilisation efficiency determines that land that is needed for the conversion of the resources into useful energy, and land is a limited resource, not least in Denmark. Bio-fuels, due to the poor efficiency of the photosynthesis, typically have an overall utilisation efficiency (solar radiation to vehicle motion) in the range of 0.1-0.5%, whereas electrical vehicles based on photovoltaics show efficiencies approaching 10%.

The load management possibility is provided through the option of flexible charging of batteries, in accordance with the power demand, cf. (Nielsen et al 1994). As can be seen from Table 4, the battery capacity of the vehicles equals up to 1000 MW stored for 4 hours based on present battery technology, and 2.5 GW based on advanced batteries. The present windpower installed is around 600 MW (Ministry of Environment and Energy 1996).

9 PRIMARY ENERGY CONSUMPTION AND CO2-EMISSIONS

Based on the specific electricity and fuel consumption figures (as delivered at the vehicle), the overall energy and environmental effects can be assessed by taking into account characteristics of the power generation and distribution system and the gasoline refinery and distribution system. Generally, the calculation of the energy and environmental effects is based on average conditions in the present power supply system.

Table 5 illustrates the calculated primary energy consumption and CO2-emissions of the model vehicle from Section 5, that is for an average passenger car. To facilitate comparisons with the present vehicle stock the primary energy consumption figures have been converted into "equivalent gasoline economy" figures - that is, the fuel economy (as measured at the vehicle) that would have the same effect on the primary energy consumption.

When the equivalent gasoline economy calculation uses emissions - e.g. of carbon dioxide - as basis for the conversion, the results turn out quite differently, as the average

CO_2-emissions per kWh fuel input is about 30% higher for the Danish power system (based on average fuel supply) than for gasoline.

Model Vehicle	Specific primary energy kWh/km	Specific CO2 emissions gram/km	Equivalent gas. econ. (energy) km/litre	Equivalent gas. econ. (CO2) km/litre
Urban driving (ECE)				
Gasoline (conventional)	0.87	225	12	12
Electric, state-of-the-art	0.31 - 0.52	105 - 180	20 - 34	15 - 26
Electric, advanced	0.13 - 0.22	45 - 75	47 - 84	36 - 60
Hybrid, load-levelling	0.61	160	17	17
90 km/h (constant)				
Gasoline (conventional)	0.54	140	19	19
Electric, state-of-the-art	0.27 - 0.52	90 - 175	20 - 39	15 - 30
Electric, advanced	0.14 - 0.25	50 - 85	43 - 76	32 - 54
Hybrid, load-levelling	0.62	160	17	17

Table 5. Calculated primary energy consumption, CO_2-emissions and equivalent gasoline economy (based on energy) of the model vehicle for the drive systems analysed. The ranges for electric vehicles indicate winter and summer conditions in power supply system (i.e. with and without heat utilisation). Ref: Jørgensen and Nielsen (1996).

In urban driving, electric vehicles have particularly great advantages. Based on primary energy, there are significant improvements even for state-of-the-art systems and even without utilisation of the heat in conjunction with power generation. For advanced systems, the utilisation efficiency has been calculated to increase 4 times if the heat is not used and 7 times if the heat is utilised for district heating. For a constant speed of 90 km/h, the advantages diminish for state-of-the-art systems, unless the surplus heat is used for district heating. For advanced systems, the efficiency is improved by a factor 2-4. Using CO_2-emissions as basis, the improvements are more moderate and only occur provided at least one of the following conditions are met: urban driving; heat utilisation; and advanced drive systems. For the hybrid vehicle there is a significant improvement in urban driving patterns, roughly equivalent to state-of-the-art electric vehicles based on electricity without heat utilisation - but the hybrid vehicle has much greater range. The hybrid vehicle has not been optimised and is based on state-of-the-art technology.

It should be noted that these results are based on present vehicles, except for the drive systems. That is, the improvements do not presume weight reduction, improved aerodynamics or the like.

Figure 1 compares the primary energy consumption of conventional gasoline passenger cars and different electric vehicles. The electric vehicles are based on state-of-the-art technologies, but the impact of battery weight is illustrated by alternative calculations based on high energy density batteries (100 Wh/kg). The primary energy consumption linked to the electricity consumption has been computed with and without utilisation of the process heat (winter and summer conditions). As can be seen, attempts to increase the range results in a rapid increase of the primary consumption for the present batter types. High density batteries would alleviate this link.

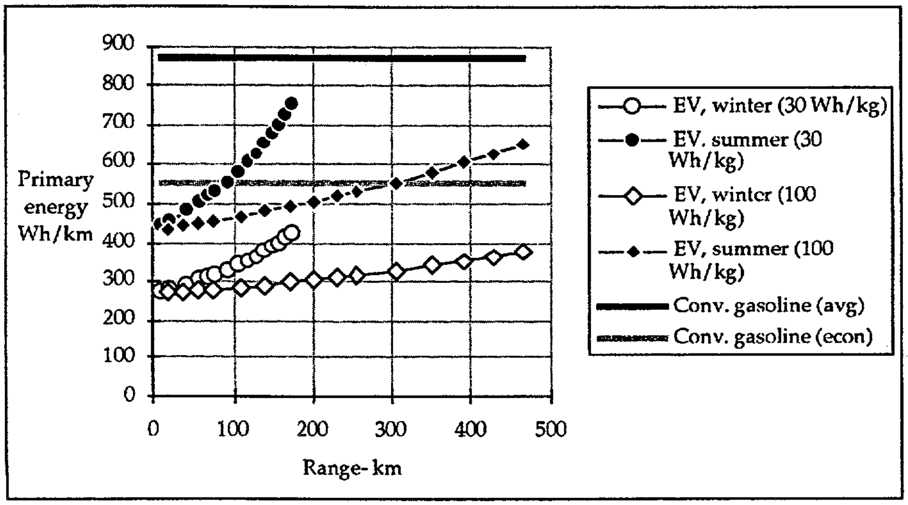

Figure 1. Specific primary energy consumption per kilometre versus range for gasoline and electric versions of the model passenger car. The electric vehicles (EVs) are all state-of-the-art, but analysed with two energy densities of the batteries (30 Wh/kg and 100 Wh/kg).

Finally, Table 6 provides an overview of the total changes in primary energy consumption and CO2-emissions in conjunction with the three penetration rates investigated (defined in Section 6). The calculated reductions of the primary energy consumption are up to 8%, while the CO2-reductions are slightly smaller. Hence, the findings of Section 6, namely that the demand on the power supply system is limited, should be seen in context with the relatively limited effect on the total transport sector energy consumption and CO2-emissions.

Generally, the electric vehicle maintain its advantage for most realistic operating conditions, regardless of whether primary energy or CO2-emissions are used as criterion. But if the advantages are minor, the range limitation can hardly be justified, and in this case other improvement options probably would be more appropriate.

Reduction	Primary encrgy GWh/a	Primary energy %	CO2 emissions 1000 t	CO2 emissions %
State-of-the-art				
5% of passenger car stock	320 - 560	0.8 - 1.4	45 - 130	0.4 - 1.2
10% of passenger car stock	670 - 1200	1.6 - 2.9	95 - 270	0.9 - 2.5
25% of passenger car stock	1800 - 3200	4.5 - 7.9	260 - 730	2.5 - 6.9
Advanced				
5% of passenger car stock	570 - 680	1.4 - 1.7	130 - 170	1.3 - 1.6
10% of passenger car stock	1200 - 1400	3.0 - 3.6	280 - 360	2.6 - 3.4
25% of passenger car stock	3300 - 3900	8.1 - 9.7	750 - 980	7.1 - 9.2

Table 6. Reductions in primary energy consumption (winter/summer) and CO2-emissions in conjunction with three different penetration rates (Jørgensen & Nielsen 1996). Given in absolute terms as well as percentages of the total primary energy consumption and CO2-emissions of the transport sector.

10 TECHNOLOGICAL DEVELOPMENT - DEMANDS AND POTENTIALS

There are two (interrelated) main aspects of technological requirements in connection with electrical and hybrid vehicles:

- development requirements to overcome some of the weaknesses of these vehicles from a marketability point-of-view - particularly range and performance
- developments to make the vehicles more energy efficient

While the former improvements are needed to promote large-scale application of electric vehicles, the latter are the key issues in this context, focusing on energy efficiency. Three main factors are particularly important in this respect: vehicle weight; on-board component efficiencies and the efficiency of the energy systems supplying electricity and fuel. The main on-board improvement areas are the battery/charger, the motor/controller and (for hybrids) the auxiliary power unit.

11 CONCLUSION

Electric and hybrid vehicles do not solve - or even address - all problems of traffic, but they contain a scope for substantial improvements of the fuel chain efficiency of vehicles, the magnitude of which depend on the vehicle efficiency and the cleanliness of the power generation. In addition, electric they may have beneficial effects on the energy system.

The penetration rates investigated do constitute a major problem for the Danish power supply system. On the contrary, the conversion to electric vehicles offers an opportunity for a flexible power demand, which may improve the system performance both in the present system and in a future system based on renewable energy. The state-of-the-art electric vehicles appear to improve the specific energy consumption in urban driving patterns, especially if the heat is utilised. Advanced electric vehicle technology, however, can improve the energy efficiency substantially regardless of driving patterns and utilisation of heat. However, its impact of this fairly substantial undertaking - conversion of up to 400.000 vehicles - is relatively limited, namely a reduction of the primary energy consumption by up to 8%. A cleaner power supply system, preferably based on renewable energy, would improve the effects. On the other hand, renewable energy does not substitute the need to maximise the fuel chain efficiency. At the moment, electric vehicles are more costly than conventional vehicles, but this drawback is envisaged to be reduced substantially - or eliminated altogether - through technological development (IEA 1992; Sperling 1993; Kalhammer 1996). The limited range is the major obstacle to electric vehicles, and attempts to extend the range based on the present technology result in deteriorated energy efficiency. Advanced batteries may reduce this problem - otherwise hybrid electric vehicles could be an option. In a longer term, fuel cells may be an option.

These vehicles do not substitute the need for general regulation of traffic, and they cannot counter any amount of traffic growth. Moreover, regulation of traffic is needed to promote electric vehicles, and electric vehicles entering an unregulated market would not necessarily be energy efficient, as they would have to compete with other vehicles on the present market conditions. Thus, it is important to regulate energy efficiency to ensure development of vehicles, as is emphasised in the Swiss electrical vehicle programme (Jørgensen & Nielsen 1996). In particular, it is important to avoid unregulated fast recharging of batteries by tariffs and other instruments - and, in the longer term, by development of advanced batteries and fuel cells.

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NATURAL GAS IN THE TRANSPORTATION SECTOR

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The transportation sector is responsible for more than 50 % of all oil products consumed, and it is the fastest growing oil demand sector and the fastest growing source of emissions.

During the last 10 years there have been a considerable and growing effort in developing internal combustion gas engines. This effort has resulted in gas engines with efficiencies comparable to the diesel engines and with emissions considerably lower than engines burning conventional fuels. This development offers us opportunities to use natural gas very efficiently also in the transportation sector, resulting in reduced emissions.

Natural gas as engine fuel.

Natural gas composition depends on the origin and after treatment. Content of methane is typically 82-95 %, the rest being heavier hydrocarbons (C_2H_6, C_3H_3, C_4H_{10} and C_{5+}) and inert gases, mainly N_2. The share of nonburning gases is typically between 1-15 %.

This large variations in gas composition affects the properties of the gas. In general the natural gas has a high octane number, low ignition energy, high H/C ratio and a simple molecule structure. This make natural gas a high quality fuel for Otto engines, and makes it possible to realise the lean burn concept, described on page 3-5. This means that natural gas gives the possibility to design a high power and high efficiency engine with very low emissions of harmful combustion products.

However, to utilize all the built in abilities natural gas has as engine fuel, the natural gas composition must be kept within relatively narrow limits. This is the case with bout diesel and gasoline today. A further development require therefore specified natural gas compositions, and the direct use of pipeline natural gas as today would only in limited areas be acceptable. An interesting possibility for producing a specified natural gas composition is by LNG (Liquid Natural Gas) production.

The natural gas could be stored as LNG or CNG on the vehicle, but experience with city buses shows '.at the CNG on the roof is a very practical and elegant solution in such vehicles.

A very large reduction in NOx (75-80 %) and particles (~90 %) can be achieved when natural gas replace diesel fuel in high speed engines in buses and trucks. If natural gas could replace diesel oil as fuel in medium speed engines in see transport, the gain in reduced emissions would be even higher, as shown in page 6. A LNG fueld 75 Cars ferry are planned to be built in 1997 and will enter ordinary traffic in 1998 in the western part of Norway.

Use of Natural gas in the Norwegian Transport sector.

Trondheim project:

-The project objectives have been to:

*Demonstrate the applicability of low emissions gas engine concept (lean burn concept) for city buses, focusing on reliability and emissions.

*To evaluate CNG and LNG storage on board the buses, based on distribution and storage of natural gas in LNG form.

*Compare the level of costs for city buses in natural gas and diesel operation.

The experience from this project is given in the attached paper; Natural gas as fuel in city buses.

1 INTRODUCTION

Norway has great resources of natural gas and is one of the main supplier of natural gas to the European marked. Gas pipelines from the North Sea are landing at three different sites at the west coast of Norway. At one of the landing sites close to Haugesund, there is a small local distribution pipeline for utilizing natural gas in the industry and transportation sector. Norway is scarcely populated and have a topography typically with high mountains and deep fjords, which make it very costly to distribute natural gas in pipelines to the main parts of the country.

Another possibility is to distribute natural gas in liquid form (LNG) by ships along the cost line and by road tankers in the same way as diesel oil and gasoline are distributed to day. This is likely the only way that natural gas will be utilized on a large scale in Norway.

Natural gas is on top of the list of alternative fuels for the transportation sector in Norway. Based on the idea of distribution of natural gas as LNG, it was decided by the Norwegian Ministry of Transportation to carry out a demonstration project on natural gas (LNG) as fuel for city buses in Trondheim.

The demonstration project
The demonstration project started in 1991 and is to be concluded in 1996. The project is a cooperation between MARINTEK and the local Transit Authority in Trondheim, Trondheim Trafikkselskap (TT). MARINTEK has been in charge of the project.

The main activities in the project have been:

- Distribution and handling of natural gas as LNG
- Construction and operation of a LNG to CNG refuelling station.-
- Construction and operation of a LNG refuelling station.
- Converting five city buses to operate as natural gas powered buses.

The aims of the project can be summarized as follows:

- Demonstrate the applicability of the low emission gas engine concept for city buses, focusing on reliability and emissions.
- To evaluate CNG and LNG storage on board the bus, based on distribution and storage of natural gas in liquid form.
- Compare level of cost for city buses in natural gas and diesel oil operation

The project is financed by The Norwegian Ministry of Transportation, and is a part of the Alternative Fuel Demonstration Programme presently run by Norwegian authorities.

2 TECHNICAL SPECIFICATION

The main bus park at TT comprises Volvo and Scania and therefore it was decided to use buses from the same makers in the project. Totally five buses have been in operation during the project, four CNG-buses and one LNG bus. A Volvo bus was converted to LNG operation.

Engine specification

In table 1 the engine specification is given:

Parameter	Scania 113	Volvo B10R
Engine type	DS1104, converted by MARINTEK	THG103, OEM delivered
Operation principle	Lean burn	Lean burn
Displacement	11.04 litre	9.6 litre
No of cylinders	6 in line	6 in line
Compression ratio	12.8:1	12.7:1
Intercooler:	Air to air	Water to air
Rated output	185 kW at 2200 rpm	185 kW at 2200 rpm
Max. torque	1050 Nm at 1150 rpm	950 Nm at 1200 rpm
Gas system	Electronic control gas system with PWM-controlled fuel injectors operating at 10 bar inlet pressure, MARINTEK prototype system	Electronic control gas system with PWM-controlled fuel injectors operating at 10 bar inlet pressure, Volvo system.
Ignition system	Altronic DIS 600, capasitive system	Volvo inductive system, one coil per cylinder
Engine management system	Electronic control, MARINTEK prototype system	Electronic control, Volvo system

Table 1. Engine specification.

A detailed technical specification is given in references /1/ and /2/.

The Volvo LNG-bus had the same engine specification as the CNG bus, but due to the variation of gas composition in gas and liquid phase in the LNG tank some modification had to be done on the engine management system. The engine control system was programmed to compensate for the variation in heating value. Further more the engine cooling system was modified and used for evaporation of LNG. A further description of the LNG system is given below.

CNG storage on buses

The general trend in city-bus development in the Scandinavian countries, is towards low floor buses making it easier to get on and off the bus. This leaves no available space under the bus for storage purposes, either for CNG or LNG tanks. CNG cylinders mounted on the roof of the bus is the likely alternative choice. The Volvo design with two rows of cylinders along both sides of the bus, is shown in figure 1. This gives also a possibility to optimize the load on the front and rear axles. For these two type of gas buses the passenger capacity have been the same as for the diesel version.

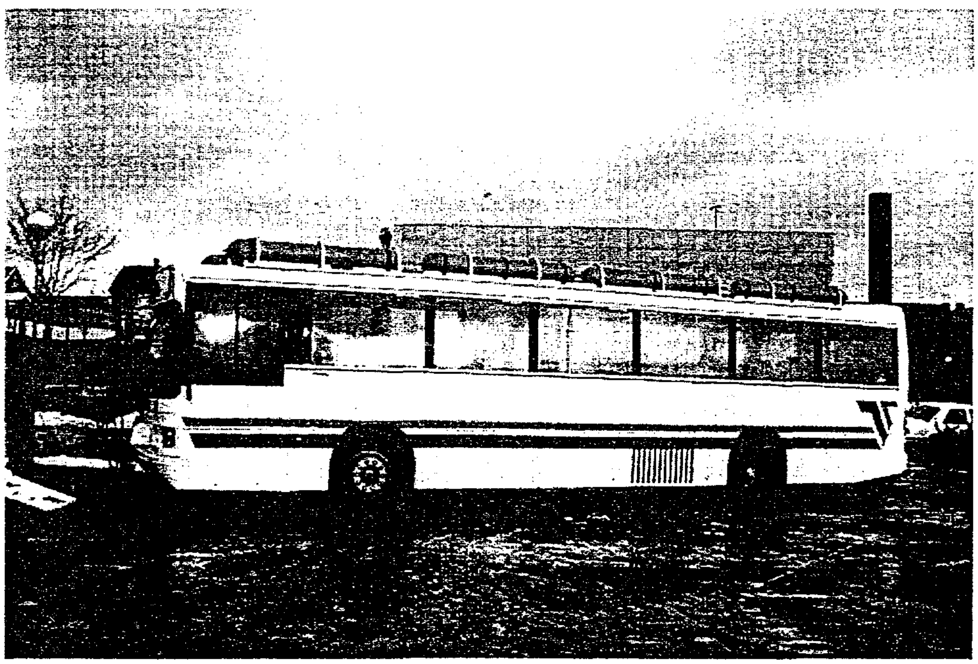

Figure 1 CNG storage on the roof of a Volvo city-bus operating in the City of Trondheim, Norway.

The bus in figure 1 has a storage volume of 1340 litres, and at a pressure of 200 bar the bus can operate in city traffic with an operating range of 500 km on one filling. The total weight of the system is app. 900 kg.

A further reduction of weight for CNG cylinder storage systems are today commercial available. A complete CNG storage system from Raufoss Technology, Norway, of 1000 litres based on aluminium composite cylinders has a total weight of 475 kg including all valves, mounting frames etc.

Refuelling, CNG-buses

The filling connection for CNG is arranged in the front adjacent to the connection of compressed air and the electric heating. By putting all connections in the front of the bus the arrangements at the parking lot is practical and efficient. A picture of the arrangement is shown in figure 2.

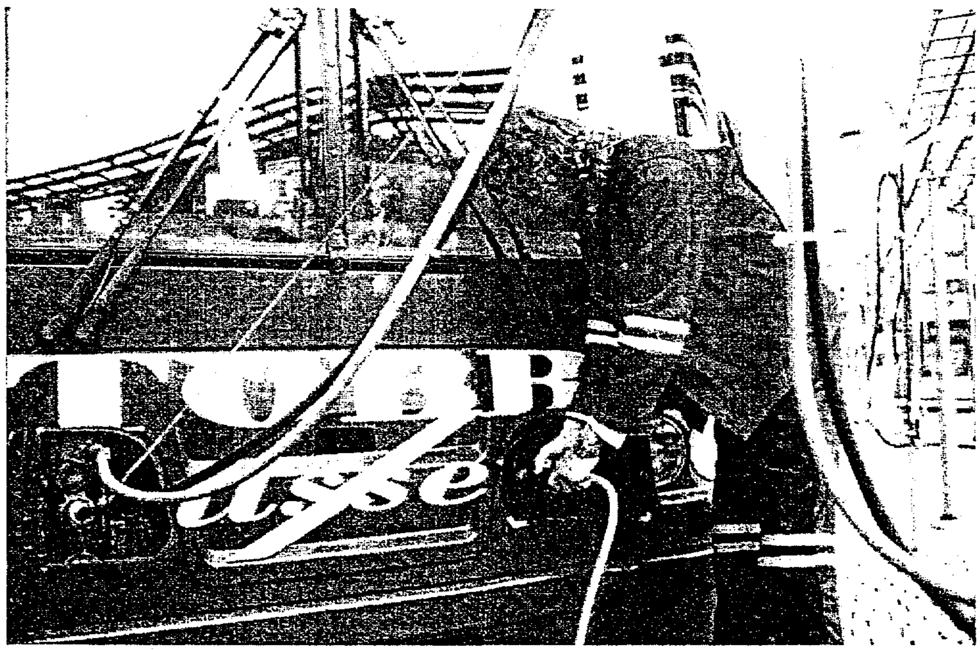

Figure 2. Connection of the refuelling nozzle in front of a CNG bus. Note the electric heating and compressed air connections as well.

Refuelling of the CNG buses are based on a slow-fill system. The buses are refuelled during the night at the normal parking area for the buses. CNG is made from LNG. The liquid gas is pumped up to the right pressure (200 bar) by a simple cryogenic pump, and is heated to ambient temperature in an evaporator. The system is automatically operated, and the LNG pump starts as soon as a bus is connected to the gas supply line and the gas pressure drop below a specified set-point.

The LNG storage tank and the LNG to CNG refuelling station is shown in figure 3.

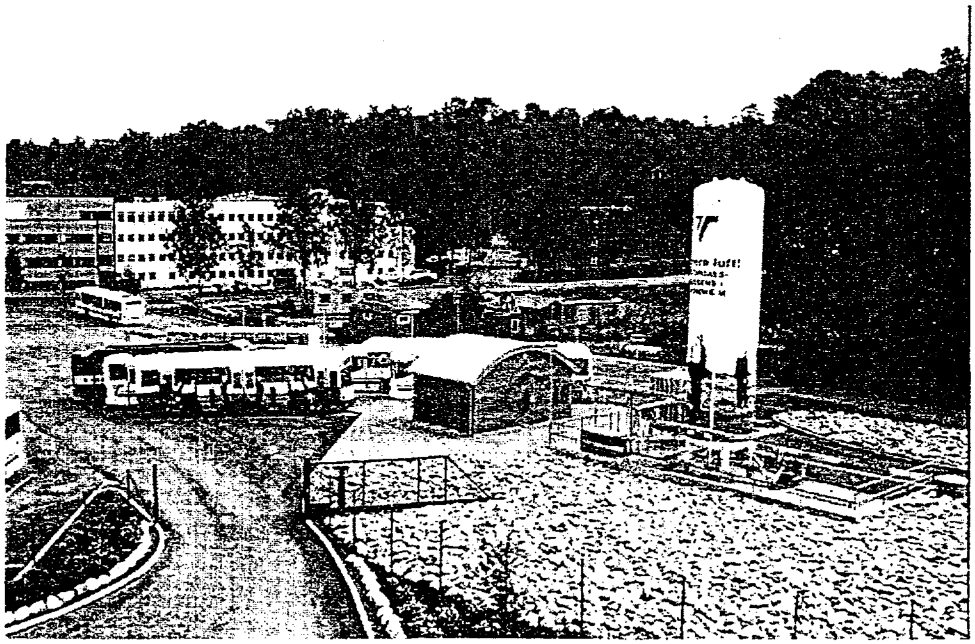

Figure 3. LNG to CNG refuelling station. The LNG tank is of 30000 litres and is sufficient for four CNG buses for about 3 weeks.

The refuelling station is unmanned, and as can be seen from the picture it is an integrated part of the parking lot for the buses.

The LNG tank is installed with a containment. As an example of safety measure a set of temperature sensors detect any serious leakage of LNG in the containment. Dependent of the criticality of the leakage, the system operator or the fire department will be alarmed.

LNG storage on bus

The gas metering system in the electronic engine control is based on sonic flow through the solenoid gas injection valves. The injection pressure is of approximately 10 bar. There are several means to rise the pressure from a LNG system. A LNG tank for elevated pressure was chosen. The negative aspect in addition to cost is the complexity regarding refuelling and a reduced holding time because of the increased storage pressure.

A tailor made storage system for high pressure (10 bar) was made by Messer Griesheim, Germany. The tank system is also featuring an option for one way filling, which make it possible to avoid return vapour to the refuelling tank and by this prevent accumulation of vapour.

A picture of the LNG tank system for installation on board the bus in shown in figure 4.

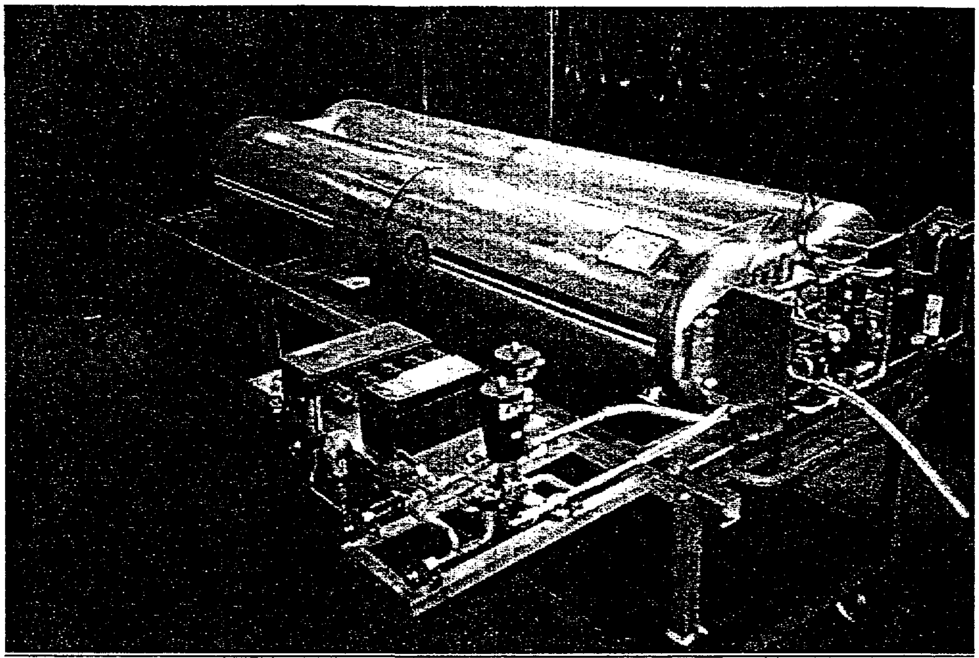

Figure 4 LNG storage unit for installation in the bus chassis.

LNG refuelling

A high pressure LNG refuelling system matching the LNG tank on the bus was also made by Messer Griesheim. The refuelling unit, featuring a centrifugal pump was supposed to fill the LNG tank against a tank pressure of 10 bar. LNG could also be filled just through spray nozzles on top of the tank for condensation of the vapour in the vehicle tank. By this a one way filling system can be obtained. Figure 5 shows refuelling of the LNG bus.

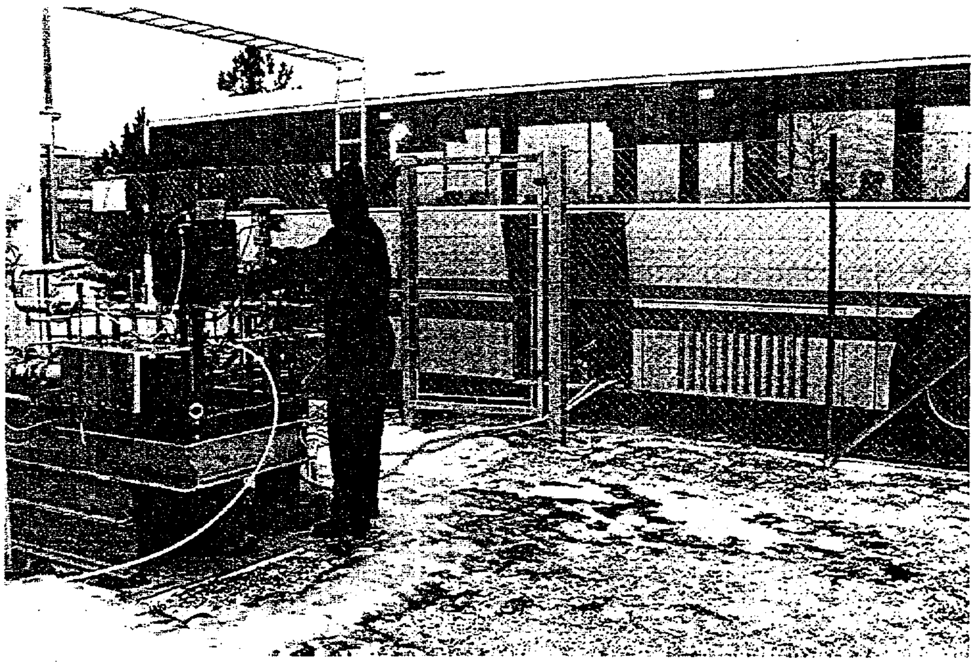

Figure 5. Refuelling station for LNG.

Because of the condensation of the vapour in the storage tank on board the bus, the pressure at the end of the refuelling sequence was well below the set point of 10 bar. A typical value was 5 - 6 bar. Since the bus was parked and the engine turned off, the heating process was slow. This was solved by employing a start up sequence in the engine control system accepting a lower injection pressure. When the engine is running, the pressure regulating system is acting and relatively quickly raised the pressure.

The LNG tank volume was totally 400 litre with a practical filling level of about 70 %, giving a maximum operating range of approximately 250 km between each refuelling.

The LNG refuelling procedure was rather comprehensive, due to the fact that this was a prototype system. The total filling time for the single LNG-bus in operation was in the range of 25 minutes. A further refinement of the refuelling system would obviously have reduced the filling time.

3 OPERATIONAL EXPERIENCE

The operational experience during about four years of operation has given important information of the systems in use, their durability and reliability.

A rewriting of the aims of the project could make it easier to judge the results of the project.

- The bus company should operate the natural gas fuelled buses in the same way as the diesel buses, not notice any difference in the availability of the buses, which means the gas bus should do the job as good as any diesel bus.

In the first three years of operation, the project was far from meeting such a goal. However, actions carried out during the last year have brought us closer to an achievement of this aspiring goal.

One should also bear in mind that all the five buses should be looked upon as prototypes with respect to the natural gas related equipment. Hence, durability problems with single components and systems could be expected.

Engine

Mechanically the gas engines have met the expectations. Typically values of service intervals have been:

- Oil shift 40.000 km
- Change of spark plugs 30-35.000 km

which are considered satisfactory.

The operational disturbances have been related to the electronic control system. Single components (pressure sensors and switches, cables) did not have the required durability for automotive application. They were replaced with alternative components, which improved the durability.

The electronic control system for gas mixing has mainly been operated as an open loop system. An accurate calibration of the gas injectors are required. Based on input parameters from engine mounted sensors and pick-up's, the electronic control unit simply controls the opening time of the gas injectors. The system is therefore sensitive for variation in gas quality.

So finally the key component is the gas injector. Following problems were observed in relation to the gas injectors:

- malfunction of injectors, stuck in open or closed position
- changing of flow characteristics due to deposits in the flow area.

The natural gas quality in Trondheim is based on LNG and are very clean due to the purification process of producing LNG. No water, oil or other contaminations usually found in gas from compressor systems should be expected. However, the injector problems still occurred. Various means of filtration (2 micron filter) were implemented in the low pressure gas line on the buses without success. Analyses from the deposit on the injectors showed various compositions like iron oxide, aluminium oxide and graphite. The oxides of iron and aluminium came from CNG tanks and a CNG buffer at the bus depot. Washing and treatment of the surface of CNG tanks reduced the amount of deposits of oxides, but the tendency was still there. The origin of the graphite was the cryogenic pump, from the lubrication system to the mechanical drive. Even if the level of contaminations has been reduced the problem is still present and was considered fundamental for this kind of injectors.

Closing the loop by employing an oxygen sensor helped to some extent but the change of flow characteristic exceeded the limitation for adjustments. This change in flow characteristics resulted in leaner and leaner combustion until unacceptable driveability be cause of reduced power or misfiring.

Since there were no likely way to solve the gas injector problems or use another metering devise, in the time frame of the project, it was decided to replace the electronic gas injection system with a mechanical gas mixing system. The mechanical gas mixing system put the buses right away to a level of reliability and durability which was anticipated. A yearly driving distance of approximately 40.000 km with the electronic control system have increased to approximately 70-80.000 km with the mechanical gas control system which is within the project targets.

Emissions

During the project on road measurements of exhaust emissions have been carried out. Exhaust emissions from a Scania CNG bus with electronic control system was compared to the diesel bus counterpart. The test results verify laboratory measurements, and THC, CO and NO_x from the gas engine are significantly lower than from the diesel engine. Results are presented in figure 6, where the exhaust emissions are an average of three typical routes in the city of Trondheim.

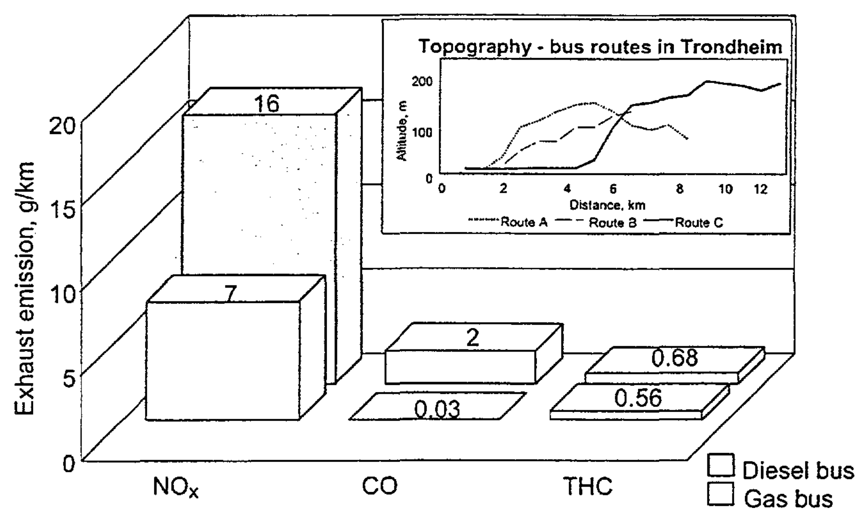

Figure 6. Exhaust emissions as an average of the three routs from a CNG-powered and diesel powered Scania city-bus. On road measurements. (CNG-bus fitted with oxidation catalyst).

Gas system - CNG
The over all operational experience of the CNG system has been good. In spite of some initially malfunction of a few cylinder valves. The burst disc was released at too low

pre sure and the pipe rupture valves were stuck in closed position. These problems where solved by modifications of the valves and change of burst disc specification.

No operational problems have been observed related to the cylinders. They are approved and certified for a specific period. In the Trondheim project prototype cylinders from Mannesmann Stahlflaschen and Raufoss Technology were used. Because they were prototypes they were certified for a period of two and three years respectively. The short approval period required a resertification of the Mannesmann cylinders during 1995 and the Raufoss cylinders in early 1997.

The procedures for resertification of the cylinders where rather expensive and interfered with the operation of the buses. Gas bus operators and owners should be aware of this requirement and the influence the total cost of the buses.

Gas system - LNG
The driveability of the LNG bus was just slightly different compared to the CNG-buses. The tank pressure was controlled by a separate PLC unit to 10 bar. Normal operation was withdrawal of liquid. At high tank pressure (> 11.5 bar) the withdrawal was gas phase to reduce the gas pressure. This switching from gas to liquid phase implies variations in gas quality. To compensate for these variations the electronic engine control system was re-programmed. In the switching moment the driver could feel these changes as a jerky behaviour. However, it had no great influence on the driveability of the bus.

The test period for the LNG bus lasted one year. The overall experience with the LNG system was good. Some of the components in use did not have the required durability. A over pressure valve pressure relief at 14.7 bar, had leakages at several occasions and had to be changed. Changing components in the LNG system is comprehensive as emptying the tank and safety procedures are required.

A level indicator build into the tank had an electrical failure. This was not possible to repair without dismounting the tank system and return it to the supplier.

CNG versus LNG storage on board the bus

Using natural gas in liquid form give you the choice of CNG and LNG storage. They have both advantages and disadvantages. CNG has the weight and volume penalty. LNG adds complexity and has the limitation in hold time, the time before boil off gas is vented off.

The choice of storage technique was one of the objectives in this project. The evaluation focused on operation range and operation cost. Figure 7 illustrates the time consumption related to service and refuelling of buses at the depot of the local bus company. The time consumption for daily service and refuelling for the CNG bus is similar to the diesel bus. The

LNG bus becomes more time consuming.

The CNG refuelling has proven to be the most cost effective system compared to the LNG alternative. Provided that the bus has a storage capacity of one day operation, CNG storage is the choice for city buses of this type and in this way of operation.

CONCEPT	TEMPORARY PARKING	SERVICE HALL	TRANSPORT AND OPERATION	PARKING
DIESEL		* WASCHING * REPLENICH OF CONSUM-ABLES * REFUELLING DIESEL		CONNECTION TO: PRESSURE AIR EL. POWER
TIME CONSUMP. (MIN)	-	6	0	1
CNG		* WASCHING * REPLENICH OF CONSUM-ABLES		CONNECTION TO: PRESSURE AIR EL. POWER REFUELLING CNG
TIME CONSUMP. (MIN)	-	6	0	1
LNG		* WASCHING * REPLENICH OF CONSUM-ABLES	REFUELLING LNG	CONNECTION TO: PRESSURE AIR EL. POWER
TIME CONSUMP. (MIN)	-	6	10 - 20	1

Figure 7. Time consumption for different procedures of service and refuelling for diesel oil, CNG and LNG.

Operational costs

The evaluation of the operational costs is not concluded, since the evaluation is going to include the operation experience of 1996. Taking in to consideration that the latest year of operation reflects a more realistic picture of the cost level, it is important to update the calculations. The indictions are that the level of operation cost of CNG buses are in the same order of magnitude as diesel buses.

Fuel consumption for the natural gas buses are in the range of 10 - 15% higher on a energy bases than the diesel counterparts. The cost of LNG has not been an issue in this project since the LNG has been imported form Germany and lately from Finland. The increased fuel consumption for the gas buses has to compensated for by a corresponding lower cost of LNG compared to diesel oil. The challenge is the price of LNG

4 THE NORWEGIAN LNG PROJECT

One of the findings in the demonstration project was that storage and the LNG to CNG concept was in consistence with the operation of city buses in Norway. From an operational point of view, it was also economical feasible. The challenge is to produce and distribute LNG to a level of cost that could compete with the alternative, diesel oil.

At Tjeldbergodden where one of the pipelines from the North Sea is landed, LNG could be produce at a low cost as an integrated part of the process plant producing methanol, air gases and bio-protein, mainly by using surplus cold energy. From medio 1997 LNG is going to be produced on a small scale, about 12000 ton/year.

Tjeldbergodden is located about 120 km from Trondheim and LNG will be transported on road tankers to the bus depot in Trondheim. The number of buses will be extended to about 16 buses in the first hand. The operation of the buses and the filling station are going to change status from a demonstration project to permanent operation on commercial conditions.

In addition to buses and trucks, LNG is going to be used as fuel for ferries and in industry to substitute diesel oil and heavy fuel. A combined distribution system for industry and the transportation sector will make it possible to keep down the cost of LNG, so even on a small scale distribution of LNG will become viable.

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/2/ Einang, P.M., Valberg, I., MARINTEK
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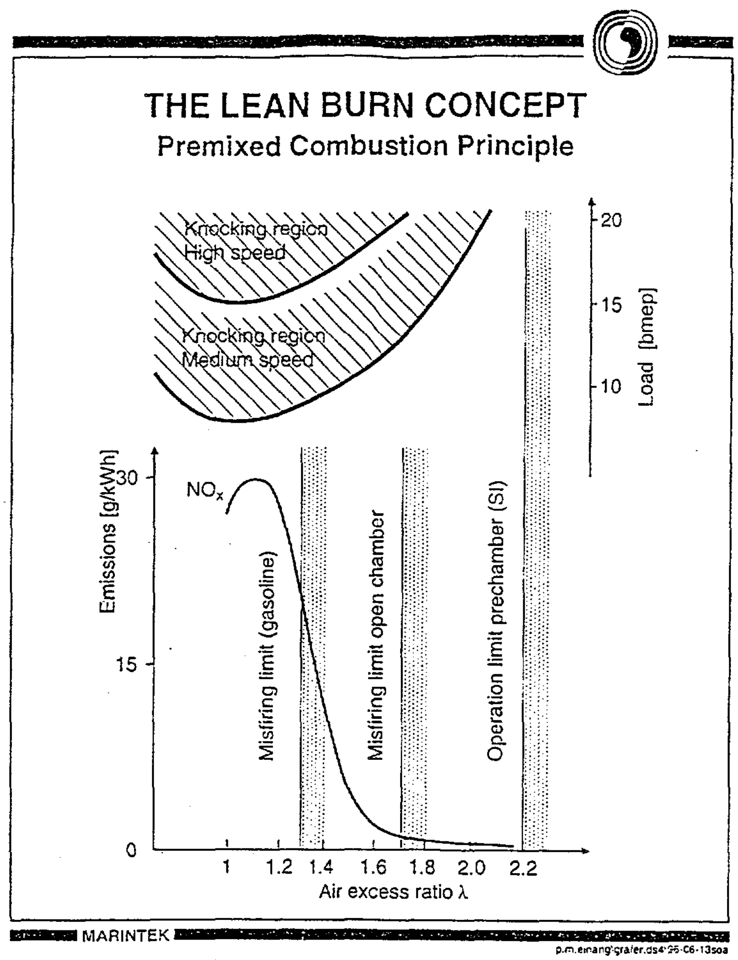


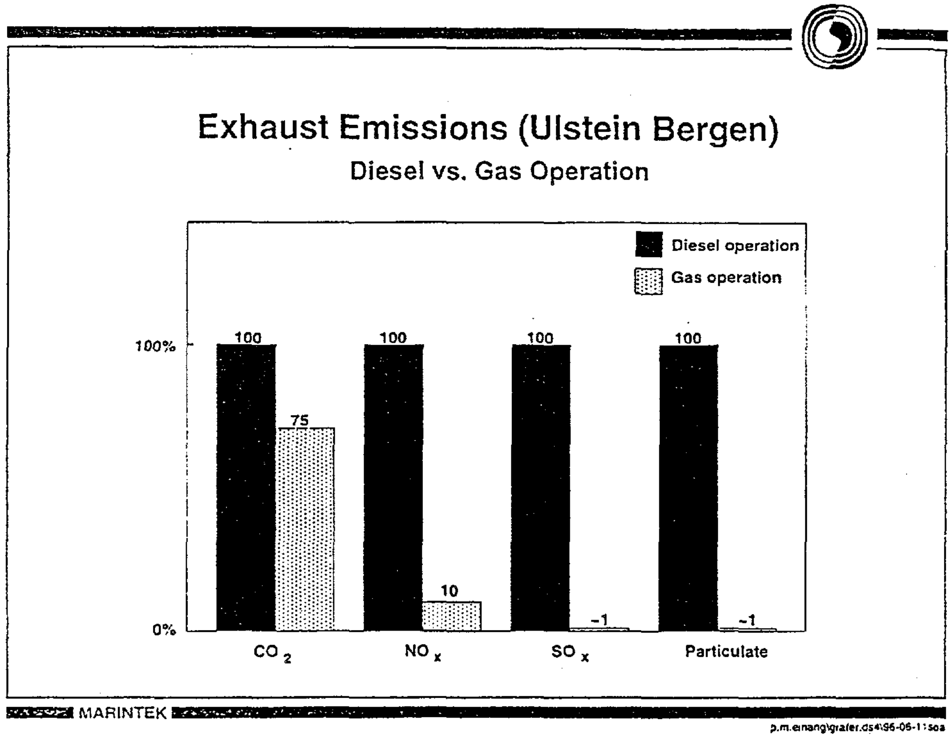
The mixture of air and fuel in the cylinder of a lean burn gas engine is very lean, which means there is more air present in the cylinder than is needed for a complete combustion. Burning lean means lower temperature and lower NOx formation.

This graph shows the NOx emissions as a function of the air excess in premixed combustion.

Natural gas has the ability to ignite lean mixtures. The lean limit for a conventional spark ignition system is 1.7 compared to 1.3 for gasoline.

By burning lean the engine load could be increased be cause of higher tolerance to knocking.

Medium speed lean burn engines are normally operated at $\lambda = 2$. To overcome the misfiring limit at $\lambda = 1.7$, these engines are using an ignition improver, a small prechamber.



Exhaust emissions from the lean burn gas engine is very low. No sulphur and practically no particulate matters. The NOx emission is reduced by 90% compared to diesel counterpart and is about 1 g/kWh.

Since the efficiency is at the same level as the diesel counterpart, there is a significant reduction of CO_2 be cause of less carbon in the gaseous fuel.

Unburned HC and CO emission are still a challenge for these engines.

FUEL CELLS IN TRANSPORTATION

By Georg Erdmann, Technische Universität, Berlin, Bernd Høhlein, Research Center Jülich, Germany

1. Background and technical state of the art

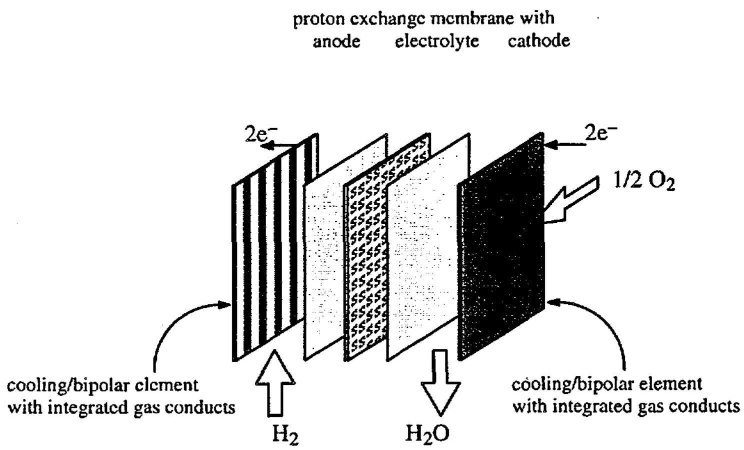
In the past 20 years, the global energy markets have changed significantly. While limited primary energy resources had been the dominating issue 20 years ago, today the environmental consequences of energy conversion has found increasing attention and did already inspire new legal requirements in industrial countries at both national and international levels. Today, road traffic contributes most to the legally restricted emissions of carbon monoxide (CO), nitrogen oxides (NO_x) and volatile organic compounds (VOC) (see for Germany: Bundesminister für Verkehr 1995, Höhlein 1991, Höhlein et al. 1996). Accordingly, a lot of efforts are undertaken in order to reduce the specific primary energy consumption as well as the emissions of the drive system and thereby to improve the atmospheric situation at ground level.

A particular challenge results from the expectation that the transportation will largely expand in the next 20 years (for Germany: Shell AG 1996; for the global development: World Bank 1996), while other energy markets seem to become saturated, at least in the developed countries. Consequently, a number of national and international efforts are being undertaken in the field of innovative and improved drive systems. Specific research and development (r&d) and demonstration programs are currently being initiated on a worldwide basis. Priority is given to the development of more efficient, safer and environmentally acceptable systems for both passengers and freight transportation. These efforts include new drive concepts and energy carriers for road, railroad and waterway traffic systems.

Energy conversion efficiency will have to be improved as well as emission and immission balances. In addition the fuel quality has to be improved. For example, the use of low carbon fuels – natural gas or liquid energy carriers (alcohols) instead of petrol or diesel – could change the tailpipe emissions especially with respect to VOCs, which are – together with NO_x emissions – responsible for the formation of secondary pollutants, e.g. ozone. Another option consists in the introduction of new transport management systems that might contribute to the reduction of traffic flows.

In addition to these efforts, progress might be achieved by the development and the market introduction of completely new drive technologies (e.g. Höhlein *et al.* 1996, MacKenzie 1994). Among the energy conversion processes for drive systems, electric cars with batteries prove – from an engineering point of view – superior in many respects. As far as local emissions are concerned, there is a significant advantage compared to drives with a combustion engine. However, batteries required for energy storage have significant disadvantages with respect to costs, lifetime and transportation range. Therefore, electric cars which – at the turn of the 20th century – had market shares of up to 40% in some countries, are of marginal importance today compared to cars and trucks driven by internal combustion engines.

Figure 1: Basic Concept of a Fuel Cell
source: adapted from Biedermann *et al.* 1995



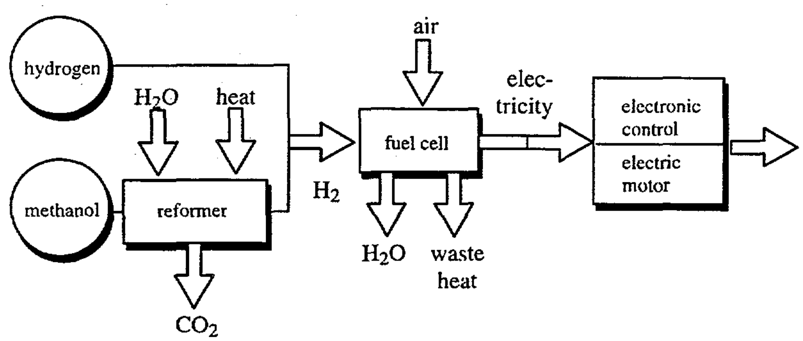
A promising new power source for electric drive systems is the fuel cell technology with hydrogen as energy input. The worldwide fuel cell development concentrates on basic research efforts aiming at improving this new technology and at developing applications that might reach market maturity in the very near future. Due to the progress achieved, the interest is now steadily turning to the development of overall systems such as demonstration plants for different purposes: electricity generation, drive systems for road vehicles, ships and railroads.

Great emphasis is placed on stationary applications for energy generation in buildings and industrial plants based on natural gas as a primary energy carrier (Solid Oxide Fuel Cells

[SOFC], Molten Carbonate Fuel Cells [MCFC] and Phosphoric Acid Fuel Cells [PAFC]). With respect to mobile applications, efforts are primarily directed towards the integration of Polymer Electrolyte Low-Temperature Fuel Cells [PEFC] (figure 1) in combination with electrical drives for road vehicles. Thereby, hydrogen or methanol, with an integrated on-board hydrogen production, are thought as possible energy supply source (figure 2). An overview of the most significant worldwide research and demonstration projects is given in figure 3.

Figure 2: Fuel Cell Drive Concepts

source: adapted from Biedermann *et al.* 1995; see also Höhlein et al. 1996



In some of the projects listed in this figure, as well as in the JOULE–II and JOULE–III projects of the European Union, r&d is focused on using methanol as energy storage in PEFC fuel cell passenger cars (Höhlein et al. 1996). This requires

- hydrogen-rich synthesis gas to be produced in the car on the basis of methanol, and
- hydrogen-rich synthesis gas to be converted by the fuel cell on the anode side and by air on the cathode side.

State-of-the-art low temperature fuel cells [PEFCs] are sensitive to traces of carbon monoxide (CO) on the anode side and other side products of synthesis gas production based on methanol.

For this reason, the above-mentioned projects embark on developments for on-board production of a hydrogen-rich synthesis gas from methanol with small fractions of side products and the fabrication of novel electrode materials for the PEFC. 10 ppmv of CO should be the upper limit in fuel gas, while no limits are defined for other gas impurities yet. At the end, the fuel gas produced from methanol on board of the vehicle must provide a gas composition ensuring a sufficient service life for the fuel cell at a high efficiency. Based on manufacturers' perspectives and capabilities, the characteristics of the PEFC and fuel processing technology are going to be defined in an international r&d effort coordinated through Annex VIII of the IEA Implementing Agreement 026.

Figure 3: International activities in Fuel cell r&d for transportation

	AFC	PEFC	PAFC
Belgium	**ELENCO** 80 kW bus		
Canada		**BALLARD / BC TRANSIT** 125 HP bus [H_2] **BALLARD / NEW FLYER** 275 HP bus [H_2] **BALLARD/HOWALDS–WERFT** (D) Marine vessels **BALLARD** FC for MERCEDES–BENZ (D) FC for ENEA (I). EQHHPP	
EU	**EUREKA** Bus [H_2]	**EQHHPP** Bus/ferry [LH_2*)] **EU–JOULE:**LDV [H_2/MeOH] **TOPSOE/KFA JÜLICH/SIEMENS** 50 kW (SR) **CJB/ROVER** et al. LDV (SR*)) **VOLKSWAGEN/JOHNSON MAT-THEY/ECN/VOLVO** **LDV (MeOH: Hot–Spot™)** **PSA/RENAULT/SOLVAY/CEA/DE NORA/ANSALDO** 30 kW [PH_2]	**EQHHPP** Bus [H_2]
Germany		**MERCEDES BENZ** MDV*) NECAR I (30 kW) [H_2] **LDV*) NECAR II (33 kW) [H_2]** **BMFT / DAIMLER / SIEMENS** **LDV [SR*)]** **SWB** Electric fork lift (H_2)	
Italy/France		**DeNORA / ANSALDO** see EU FC for EQHHPP [H_2] **DeNORA/ RENAULT/ ANSALDO** **FEVER: 30 kW car [LH_2*)]**	
Japan/ USA/ Canada		**MATSUDA/BALLARD** **8 kW Golf cart [H_2/O_2]**	**FUJI ELECTRIC** see USA
USA/Canada		**DOE / FORD/ IFC/ H–POWER/ ENERGY PARTNERS/ et al.** 30 – 50 kW LDV [H_2] **CHRYSLER/ ALLIED SIGNALet al.** **30 – 50 kW LDV [H_2]** **DOE / GM / LANL /BALLARD / DOW/ DUPONT et al.** **LDV 60 kW [SR*)]** **ARGONNE** 50 kW [POX*)] **ENERGY PART.** 30 kW Car [PH_2*)] **BALLARD Georgetown Univ.** **100 kW Engine [SR]**	**DOE / SCAQMD** Bus [SR*)]: see Fuji **ARTHUR D. LITTLE** Bus [EtOH*)] **with 50 kW POX** **DOE/SCAQMD/ H–POWER** **50 kW bus [SR*)]**

*) SR: Methanol (MeOH) steam reformer; POX: Partial oxidation of MeOH; LH_2: Liquified Hydrogen; PH_2: Pressurized Hydrogen; LDV: Light duty vehicle; MDV: Medium duty vehicle; EtOH: Ethanol.

2. Assessment of fuel cell systems in transportation

Provided that the progress of fuel cell r& d will reach the stage of maturity necessary for penetrating the transportation markets and that mass production will be possible at reasonable economic and social cost – both as a result of ongoing industry r&d, IEA Annex VIII and other inputs from different sources –, it is necessary to think about the preconditions, strategies and procedures for introducing this innovative concept into road transportation.

Figure 4 indicates some significant benefits of fuel cell systems used for vehicle drive compared to conventional engines and energy supply systems. Comparative systems include internal combustion engines of different types and electric motors fueled by electric batteries, and all expect to undergo further technical, ecological and economic improvements that should be considered in such a comparison. For that reason they might play a role in future transportation markets.

Figure 4: Advantages of fuel cells in vehicles

source: modified from Willand/Noreikat 1996

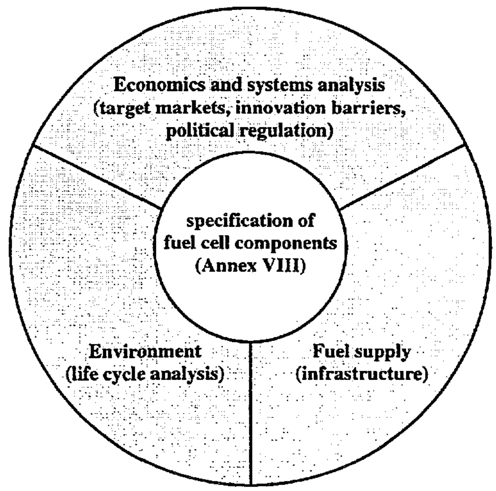
- ☞ high electrical efficiency (no restriction through the Carnot principle)
- ☞ low emissions
- ☞ low noise
- ☞ vibration-free
- ☞ mechanically simple design
- ☞ low maintenance, oil-free system
- ☞ modular design allows high flexibility
- ☞ powerful on-board energy supply (for air conditioning, heating)
- ☞ electrical regulation of the performance

In the last month a group of countries established the Annex X to the IEA Implementing Agreement 026 (Advanced Fuel Cells) in order to study this issue and to co-ordinate international activities on the evaluation of this option. Based on the needs of users and authorities as well as on the results of IEA-Annex VIII and other sources, the work within Annex X will be organized in three parts (see figure 5):

- Subtask A: Economics and Systems Analysis
- Subtask B: Balances of Life Cycles
- Subtask C: Fuel Supply Systems.

The work is scheduled for the time span 1997 until end of 1999.

Figure 5: Structure of the analysis
(Annex X of the IEA Implementing Agreement 026)



Before discussing the outline of the work planned under subtask A "Economics and Systems Analysis", the argument should be mentioned according to which vehicle improvements might be a progress in the wrong direction. Obviously nobody is against the expected overall efficiency increase of the energy chain used for road transportation that will reduce *ceteris paribus* the overall emissions. Also – even more important – the removal of local air pollutions as well as the reduction of noise are most welcome. But other problems of individual road transportation such as traffic jumps and accidents will hardly be solved through fuel cell systems.

However, past experience tells us that the willingness to abstain from using the individual cars is rather weak. As ecological taxes on fuel prices accelerate the diffusion of more energy efficient internal combustion engines, this instrument will have, at least in the long run, a stronger impact of the average vehicle energy efficiency than on the car use and travelled distances. Similar effects are observed for light and heavy duty vehicles. Therefore, energy taxes and environmental standards will not be able to significantly alter the share of individual road transportation in overall transportation. On the other hand, there is a rather limited potential for increasing the attraction of public transport systems, and this is not only due to the investment costs associated with appropriate measures. As a conclusion, there are no practical alternatives to efforts in view that improve the passenger and duty vehicles used on our roads (a philosophical justification is recently presented by Lübbe 1996).

3. Market entry

The potential of the fuel cell technology in transportation systems, particularly in road transport, is based on several advantages of this technology (see figure 4). But successful market introduction requires that the system components of different vehicle types (e.g. small and large passenger cars, light duty vehicles) are optimized in their technical design with respect to economic and ecological criteria. This is primarily an engineering task that is solved through experiments and simulations. Input data covering energy costs, taxation, political regulations and norms as well as social values are provided through scenarios (as a pilot study see Hörmandinger/Lucas 1996).

Parallel to this type of analysis, a market analysis has to assess wether, how and where such basic vehicle innovations can achieve customer acceptance in major markets, beyond initial niche applications. Some criteria for this are listed in figure 6.

Figure 6: Requirements for power systems in passenger vehicles
source: modified from Willand/Noreikat 1996

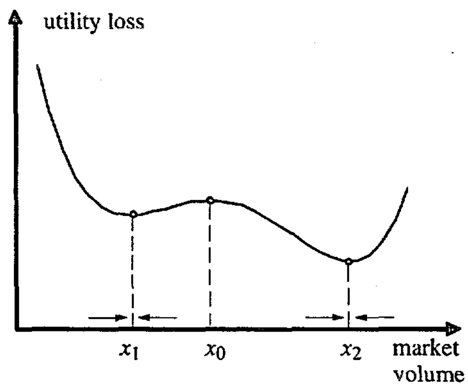
- ☞ economic viability, high fuel efficiency
- ☞ safe, clean and simple fueling and operation
- ☞ low weight, compact design
- ☞ performance characteristics comparable to present drive systems (speed, acceleration, range)
- ☞ high availability and reliability
- ☞ short refueling time
- ☞ zero maintenance
- ☞ no additional price for expensive power unit and energy storage
- ☞ significant reductions of life cycle emissions

An initial market niche might be the fleets of public buses, taxis and municipal trucks which operate in urban and air polluted areas, because here the infrastructure requirements can be met. In addition, the contribution to the reduction of both local emissions and pollutants can be demonstrated.

But if the fuel cell technology cannot expand into markets beyond these niche applications, this innovation would play only a rather limited role in solving environmental problems associated with road traffic. It also would not allow cost reductions resulting from economies of scale with respect to fuel cell production, car manufacturing and fuel supply. As with every basic innovation that is "struggling" against existing networks of technologies, enterprises and interests, it is challenging to open the market and to overcome all types of obstacles, among them also mental and psychological barriers (see Koolmann 1992, Knie/Berthold 1995).

A deeper analysis of these types of problems leads to an interpretation as stylized in figure 7. (see Erdmann 1992). The figure shows a curve representing the utility loss associated with different market volumes of fuel cells. These utility losses include damages due to the local air pollution as well as costs (sunk costs, see the textbook of Scherer/Ross 1990) associated with the efforts to open the market for the fuel cell technology. Even if an initial market niche x_1 had been acquired, there is no obvious trajectory to further market expansion but a threshold x_0 that has to be overcome before the diffusion of the fuel cell technology towards x_2 sets in.

Figure 7: Potential function of barriers to market entry



While the diffusion process is relatively east to be modelled (see Rogers 1980), the efforts, consisting of innovative skills of pioneering enterprises as well as costs and economic risks are crucial for reaching the threshold point from which on the diffusion can work.

Dosi proposes the term "technological paradigm" which defines "the needs that are meant to be fulfilled, the scientific principles utilized for the task, the material technology to be used" (Dosi 1988). The market introduction of the fuel cell technology in road vehicles can be understood as the establishment of a new technological paradigm which – in the case of success – will lead to a different evolution of both the technical systems used in transportation (including energy supply infrastructures) as well as in the behavior and even thinking on cars, duty vehicles, trucks and so on.

4. Work Plan

Based on these theoretical considerations, the study on "Economics and Systems Analysis of Fuel Cells in Transportation" within IEA Annex X is planned as a joint effort of fuel cell producers, car manufacturers and research institutes and includes aiming at identifying barriers to market entry for fuel cell drive systems. The types of economic forces that may restrict different categories of market participants to adopt the new technology are theoretically well described (see figure 8 and Erdmann 1993 for a theoretical discussion of these issues). However, the need for clarifying and quantifying them remains still unsatisfied.

Figure 8: Analysis of market barriers for fuel cells in transportation

☞ vehicle producers (incl. suppliers & distributors),	economies of scale sunk costs Bertrand competition
☞ Energy suppliers (incl. infrastructure)	capacities economies of scale network externalities
☞ consumers (business and households)	needs and values emotions synergetics
☞ government	taxation and regulation institutional economics

In order to accomplish this task, the research work must address at least the following topics:

1. Definition of transportation markets, boundary conditions and evaluation criteria that will be used for comparing different vehicle drives
2. Adjustment of an (existing) energy life cycle data bank for the data requirements and purposes of the study. Technical specifications, costs (including taxation) and environmental emissions are considered
3. Adjustment of an (existing) vehicle data bank that reflect todays performances and cost structures as well as probable future technical developments of different drive systems
4. Cost-Benefit-analysis of vehicles with different drive systems
5. Identification of market barriers of fuel cell systems
6. Sensitivity analysis of uncertain and action oriented parameters (including national and international political legislation).

5. Conclusion

This paper didn't present results concerning the market potential of fuel cells in transportation but rather addresses some questions and reflections that are subject to further research of both engineers and economists. Some joint efforts of this research will be conducted under the umbrella of the IEA Implementing Agreement 026 – Annex X (operating agent: B.

Höhlein, KFA Jülich–IEV, D–52425 Jülich), but there is a lot more to be done in this challenging but also promising fields.

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Session 3. **Lifestyle changes and the transport sector covering information, e.g. technology, mobility and urban planning**

Chairman:
Per Thorkildsen, Statoil, Denmark

"PEOPLE ON THE MOVE AND GOODS ON THE GO" BEHAVIORAL FACTORS DRIVING CARBON-DIOXIDE EMISSIONS FOR TRAVEL AND FREIGHT IN OECD COUNTRIES

By Lee Schipper, Lawrence Berkeley Laboratory, USA

1. Introduction: Why the Concern for Transportation

Concern has been expressed in many government and private studies over the costs of externalities from transportation, which include safety, air pollution, noise, competition for urban space, balance of payments associated with oil imports, and risks from importing oil (Barde and Button 1990; Houghton 1994; Government of Denmark 1995; CEC 1996; KOMKOM 1996; World Bank 1996; TRB 1997). While few doubt that these costs in total are still less than the total social benefits, there is a strong case that in many places, and at many times, marginal social costs of transport do exceed private benefits or even total social benefits. Recent attempts to evaluate external costs (MacKenzie et al. 1992, Kaageson 1993; COWI 1993; Roelofs and Komanoff 1994; OECD 1995; Pearce et al. 1996; COWI 1995a; COWI 1996; Oekonomiske Raad 1996) suggest that even the lower range of valuation placed on these externalities for cars is comparable to the pre-tax marginal fuel cost of driving a car requiring 8.5 l/100 kilometers of fuel, the rough average for W. Europe. If the individual (s) benefiting at the time faced those costs, the travel (or shipment) behind the externality might not take place, or technology would be applied to reduce the extent of the problem. For large trucks and busses, the costs (per vehicle-km) are considerably higher. Expressed as per unit of travel (passenger kilometers) or per unit of freight, ie., taking into account the utilization of the vehicle, the specific cost change because of economics of scale. Transportation is a valuable part of our economy, but it is no free lunch.

Emissions of CO2 or carbon from road transport are also on government agendas in industrialized countries. (IPCC 1990; Houghton 1994; TOK 1994, 1995; Gov. of Denmark 1995; BTCE 1996; KOMKOM 1996; TRB 1997). Not surprisingly, CO2 emissions from travel and freight have increased in most industrialized countries faster than population, albeit less rapidly than GDP (Schipper et al. 1996). This paper reviews some of the factors driving that increase.

Whatever the "real" external costs of each mode, all studies suggest two important findings: First, these costs are sometimes comparable to, or higher than, direct fuel costs per kilometer at the margin; Second, the value attached to the externality for carbon emissions tends to be low compared to those associated with other problems. Hence this suggests that CO2 by itself may not "felt" as a strong stimulus for change, but that changes to deal with the other problems may affect traffic, and therefore CO2 emissions, profoundly.

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While the other externalities in transportation may be more serious than CO_2, they threaten us today and in that way lead to feedbacks, by which technologies and policies could be brought to bear to reduce the problems. In this sense, these are not necessarily threats to "sustainable transport", if we use a definition of sustainability limited to imploring not to pass on costs to future generations, costs arising while reaping the benefits in the present. Present beneficiaries of the system are beginning to realize that they are not paying their full costs. In another sense, however, "sustainable transport" may also mean creating a system whose beneficiaries are bearing their real social costs and at the same time not propelling growth in the system that still raises those costs for the future.

This leads to a special concern over CO_2 emissions from transport. CO_2 emissions threaten future generations by an uncertain degree but cost little or nothing to present users of transportation. Were CO_2 emissions not increasing, authorities could wait for more information on possible damages before taking action. But the increases themselves may be hard to reign in, hence the interest in a better understanding of the factors underlying the increases. Moreover policy makers have discovered transportation's rising share of CO_2 emissions, and are asking why? This brief review addresses the main trends in personal and goods transport, and points to some of the underlying causes of increased emissions.

2. Trends in Transportation Activity, Energy Use, and Carbon Emissions

Automobile ownership (Figure 1) has risen with income or GDP per capita, although it is showing some saturation in the most motorized countries. Distance traveled per vehicle (vehicle-km, or v-km) is rising slowly, but distance traveled per capita on all modes (Figure 2) is rising more rapidly because of increasing car ownership. Because the number of people per car has fallen, travel in cars (in passenger-km) has not risen as fast as total vehicle-km. This means that energy use and CO_2 emissions rise faster than travel, all else equal.

Figure 3 shows per capita travel by mode in the U.S., Japan, and aggregates of four European countries and four Nordic ones (France, W. Germany, Italy, and the U.K.; Denmark, Finland, Norway, and Sweden). Knowing the energy use for each mode we can tabulate emissions of CO_2 in a straight forward way. Figure 4 shows these patterns (in tonnes of carbon per capita) for travel (Schipper 1995; Scholl, Schipper and Kiang 1996). Figure 5 shows how the level of freight activity (within a country, including the domestic portion of foreign trade but excluding transit goods) itself is coupled to industrial GDP, and Figure 6 shows the CO_2 emissions patterns for freight (Schipper, Scholl and Price 1996).[2] Emissions per capita for both travel and freight rose in every country between 1973 and 1993 except in the U.S., but that situation ended in 1993. Moreover, the share of transportation energy use and carbon emissions in total energy use or emissions increased in every country studied. What drove these changes?

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[2] Behind these figures lie careful tabulations of gasoline and diesel fuel (also LPG and natural gas) for each mode of road traffic, a split of energy use for domestic rail and water traffic into passenger and freight shares, and a determination of the domestic share of fuel used for air travel. Energy uses not included here include military vehicles, international marine and air fuel, civil aviation, and some miscellaneous vehicles. See Schipper et al. (1992) for the first decomposition study, Schipper (1995) for a review of trends in automobile energy use, Scholl Schipper and Kiang (1996) for the analysis of CO_2 from travel. Kiang and Schipper (1996) for the analysis of Japan, Schipper, Scholl and Price (1997) for the analysis of freight or Schipper, Meyers et al. (1992) for detailed information on how these splits (and original data) were obtained. Many of the data used in this study are published by the Oak Ridge National Laboratory in their "Energy and Transportation Handbook".

3. Underlying Factors Increasing CO2 Emissions for Travel and Freight.

To answer the question how emissions changed, Lawrence Berkeley National Laboratory carried out an index decomposition of the factors underlying changes in CO2 emissions from both freight and travel, as well as from other sectors (Schipper et al., 1996; Scholl, Schipper and Kiang 1996; Schipper, Scholl and Price, 1997; Greening, Ting and Schipper 1997). Recognizing that petroleum fuels dominate this sector and that the differences in emissions per unit of energy contained are relatively small (except when the "fuel" is electricity), we write

emissions for travel = (total travel) x (share of travel in each mode) x (energy use/unit of travel in each mode) x (carbon emissions per unit of energy for each mode)

and similarly for freight. This relation can then be used study changes over time, and the results expressed as indices (Greening, Davis, Schipper, and Khrushch 1996). Many indices serve this purpose, but LBNL chose Laspeyres for simplicity. Comparison with Divisia indices shows that the results are similar. The carbon emissions from electricity generation are apportioned to each mode in proportion to the share of final electricity used in that mode (for rail, metro, and tramways).

3.a Travel

For travel, higher per capita travel (total activity) increased emissions in every country, as Figure 7 shows for the group of aggregates. Modal shifts towards more energy-intensive modes (cars, air) increases emissions by as much as 30% (in Japan), but in most countries by up to 5%.[3] Falling energy intensities of vehicles themselves reduced emissions in more than half of the countries, but falling load factors in cars (and bus and rail in many countries) offset this restraint, leading to a net increase in energy use (and CO2 emissions) per passenger-km in cars. Shifts in fuel mix and utility mix had almost no impact, for two reasons. First, the emissions per unit of energy released from diesel and gasoline are very close, but diesel is actually higher. Second, the role of electricity for travel (rail, trams) is so small that even the almost complete transition away from fossil fuels in some countries (Sweden, France, Finland) had only a very small impact on emissions from this sector. Thus by 1993, behavior factors had clearly increased CO2 emissions, even after a period of more than a dozen years of relatively high road fuel prices.

Closer examination of trends in automobile characteristics confirm this finding. While the average tested fuel use per kilometer driven and per kilogram of new cars fell dramatically in all countries, the weight (and performance) of new cars increased in all countries, absorbing much of the effects of improved technology. Worsening driving conditions -- both more high-speed vacation driving and more driving in congested areas, raised fuel use/km above what tests would predict (Schipper and Tax 1994). The result is shown in Figure 8: actual fuel use (gasoline and diesel weighted for actual consumption, and by energy content) per km fell dramatically in the U.S. (and Canada, not shown), but barely changed in Japan and most European countries. Note that the figures for the early 1990s reflect car fleets that have been almost completely renewed since the early 1970s.

Factors related to vehicle performance are absorbing some of the savings of fuel technology offers. Figure 9 shows that indeed fuel use per km per kilogram of new car, averaged over

[3] For Denmark this factor led to reduced emissions, a result of our use of a falling load factor for cars, in contrast to practice by Vejdirektorat.

each year's new cars, is falling steadily and uniformly in every country, and in fact differs little from country to country. But Figure 10 shows that weight (like power or motor size) is also growing steadily, propelled mainly by higher incomes.

Travel patterns are also changing. Figure 11 gives a snapshot of travel by purpose, based on the national 1-day surveys of the countries shown (Schipper, Gorham, and Figueroa 1995). Note the relatively constant pattern: work travel (mostly commuting, but some trips within work) accounts for 20-30% of travel, services for about 25% (except in the U.S.) leisure for the rest. The car dominates the latter two categories, but outside of the U.S., the car accounts for only 40-60% of work trips, since these are more easily taken on collective modes. Including walking and cycling has little impact on total travel, but an important impact on total trips, since these can account for as much as 1/3 of trips. But it is travel in cars (or by air) that accounts for the growth in mobility, except for the few exceptions (Denmark and Sweden) noted earlier. Not shown in these figures but clear from comparing surveys taken in different years is the growth in Europe in use of the car for work trips. By contrast, non-work trips seem to be leading growth in the U.S., probably the result of much greater saturation of trips to work by car since the 1970s (over 85% of trips, of which only 1 in 10 as a passenger). People are not only moving more, but the structure of mobility, in terms of mode and purpose, is changing slowly.

One interesting result from comparing the travel surveys suggests that a single journey in a car in America is about as far as one in Europe, around 13-15 km. What explains the enormous gap between the U.S. and Europe in per capita distance traveled by car is thus the <u>number</u> of trips per capita and not America's allegedly sprawling distances. However, the sprawl of America's suburbs certainly contributes to reducing walking and cycling trips to work, services, and leisure time. More subtly, however, it appears that it is the large number of short trips Americans make by car (which Europeans make with their feet, their cycles, urban transit, or simply don't make) that reduces the average distance an American travels when she uses a car. That is, Europeans have virtually the same access to travel destinations as Americans, but they do not travel as far or as often to achieve this access.

Figure 12 shows this similarity in car use in a way very critical for CO2 emissions. We plot the share of all trips less than a given length (in km) vs. that length. Note that nearly 65% of all car trips are less than 10 km in all countries. Many or most of these trips are on cold engines, which raises fuel consumption/km (and emissions of many local air pollutants as well.) Consumers are both using their cars for increasing numbers of short trips they previously walked or did not take, and also for longer trips at higher speeds. The result is increasing fuel consumption/km, all else equal. Combined with increasing congestion for much of the driving cycle, this raises fuel consumption over what is obtained in tests at relatively controlled conditions. This has important implications for technology: increasingly cars appear to be optimized for longer trips at relatively high speeds, yet the predominant use is in short trips with many stops and some congestion.

The continual development of behavior and lifestyles had predictable effects on the use of cars over other modes. More Europeans became the first car owners in their families, as a majority of households approaching 75% had access to at least one car. This point had already been passed in North America before 1973, and explains why Europe appears to be "catching up" to the U.S. in many of the indicators presented in Figures 1-3. Life-cycle factors are also important in explaining the continued rise of car ownership and differences among countries (Greening, Schipper, Davis and Bell 1996). Increased women working noted above often resulted in two-car households with each adult driving in a different directions. Liberalized shopping hours and more automobile-oriented services in general also increased the utility of cars, as noted by Schipper et al. (1989). Company car taxation policies, which may have a big influence on new-car market decisions in the U.K., Sweden, W. Germany, and Holland, and tax treatment of commuting expenses in general also encouraged more use of larger cars. Finally, higher incomes in general permitted more families to own cars and larger, free-standing homes in suburbs: In Paris or Stockholm, for example, the inner city populations have barely grown, while populations in the near and distance suburbs grew significantly. Whether these changes are short-term or even reversible has been discussed in terms of the CO2 problem (Michaelis et al. 1996), but there no simple solution: Changes in travel behavior contribute to greater CO2 emissions.

3.B Freight

Figure 13 shows the CO2 emissions for freight decomposed in the same way as for travel. Here the results are both stronger (in terms of increase) but at the same time more diverse. In all of the countries studied, absolute emissions increased, and in half of the countries studied, this increase was greater than that of GDP. In a majority of countries, modal shifts (towards trucking) increased emissions, often by more than was the case for travel. In contrast with travel, the modal energy intensities of freight (energy/tonne-km) changed to reduce emissions. The impacts of changes in fuel mix (including fuels used to generate electricity) were small, except where railroads underwent significant electrification and electricity was generated by low-CO2 sources. Unlike travel, (electric) rail plays a more prominent role in carrying freight. Still, as Figure 6 shows, emissions from freight are dominated by those from trucks, so it is this mode, like cars, whose evolution is the most important for that of the sector's emissions.

Looking more closely at the coupling between energy and trucking reveals many surprises. Figure 14 shows a wide spread in the ratio of fuel use to tonne-km hauled, calculated to include local freight (and light trucks or vans) as well as intercity haulage. Since the trucks are produce by large, international firms, difference between the figures shown cannot be very much attributed to actual differences in the energy efficiency of trucks. Instead the differences arise largely because of differences in fleet mix (between large, medium, and light trucks), differences in traffic, and above all differences in the capacity utilization of each kind of truck (Schipper, Scholl, and Price 1997). Actual figures for fuel use/vehicle km of trucks by size class show declines in all countries, but not always in countries where the modal intensities fell. Again, it is changes in the loading and utilization of trucks that affect the overall evolution of each country's freight modal intensity the most. These changes have explanations in the need for just-in time deliveries, the rising value (as opposed to tonnage) of freight, and above all the importance of other costs besides those of fuel in determining the optimal use of trucks.

4. Summary and Conclusions: Behavior Drove Changes in Emissions.

Changes in the way people (and goods) travel have been the dominant cause of rising emissions. Technical factors, as the vehicle and modal energy intensities represent, led to some restraint of emissions in a few cases for cars and trucks but only gave a net reduction in per capita emissions (for travel) in one country. Behavior and managerial factors (ie., modal choices and utilization), as well as overall increases in activity coupled to GDP, clearly boosted emissions overall. In households, by contrast, behavioral factors, such as lower indoor temperatures, persisted to some degree to restrain fuel use and emissions, and technologies added a large component as well. But in both travel and households, consumer lifestyles became increasingly "emissions intensive" as more space was occupied at home, in and in the service sector, and consumers' mobility between these places increased (Schipper 1996).

Did higher fuel prices not affect fuel use or emissions? It is often forgotten that for most countries, real fuel prices were higher for two brief periods, 1974-7 and 1979-1985, periods too short to expect radical changes in both vehicle technology and use and modal choice to occur, let along major rearrangement of the housing and mercantile infrastructure affecting the origin and destinations of travel and freight respectively. Still, emissions per unit of GDP did fall somewhat in these periods, and emissions unit of activity fell as well. Some of that decline continued after oil prices crashed because of the technological gains that were started in the high-price years, gains still working their way into the fleet through vehicle turnover. Figure 15, however, shows that there is a significant relationship between car fuel intensity (or per capita car fuel use) and real fuel price (with diesel included at its share of car fuel in each country). Figure 16 shows less of a relation for trucking fuel intensity, but a similar relation for trucking fuel use relative to GDP is stronger. Thus in a cross-national comparison, prices appear to affect both fuel intensity and fuel use in most cases. If fuel use for cars in Figure 13 were normalized by GDP instead of population, the U.S. point would fall somewhat closer into the line.

The fact car fleet fuel intensities appear to be almost linearly related to fuel prices, and that U.S. vehicle fuel intensity in 1993 appears consistent with the points from the other countries is striking. This suggests that automobile fuel intensity is a function of fuel price. But automobile efficiency in a technical sense now varies little among countries (cf. Figure 10), since, as for trucks, vehicles are produced by international companies sharing largely the same technologies. Instead fleet-average automobile size or weight (cf. Fig. 10), power, and features that differentiate the points for fuel intensity in Figure 15, with vehicle ownership and use taxation, including the impact of company car taxation, certainly explaining some of the scatter, since these policies affect not only the ultimate cost of fuel to the user but the cost of using the vehicle as well, which is much more significant (Schipper and Erickson 1995; Schol and Smokers 1993; NEDC 1991; Fergeson 1990). It is not unreasonable to assert, without formal proof, that these characteristics depend on incomes (including car taxation) and fuel prices, but this dependence will have to be subject of future study.

Thus factors causing changes in CO_2 emission are intimately related to the nature of transportation -- comfort, convenience, speed. Those driving activity -- distance -- as well as modal choice are related to individual and societal choices about housing, work and leisure location. The same is true for freight. But the cost of fuel is but a small fraction of the total cost of either travel or freight, even before the cost of the transport infrastructure is considered. And the choices noted here are deeply-rooted in a transportation context. This means that these choices -- today's slowly-evolving transportation patterns -- may be difficult to stop simply because of CO_2 concerns. To be sure, natural limits (saturation of distance or time of travel, potential saturation of the distance physical goods are sent around) or local constraints (congestion, parking problems, local pollution) may slow or reverse some of these trends. But most national transport plans still foresee increases in personal and goods transportation with GDP if no policies intervene.

It is significant nevertheless that emissions from freight, in contrast to those from travel, show restraint from lower energy intensities in roughly half of the countries studied. We speculate that this may be because freight is a business. Although the importance of fuel costs to total freight costs, or to the total costs of products delivered is small, there is clearly always room for saving fuel at the margin, subject to the constraints imposed by costs for equipment, labor, and maintenance. The same is true for air travel, which showed uniform and deep reductions (50-60%) in fuel use or emissions per passenger-km in all countries from both improved technology and higher load factors. In this case, however, fuel reached to as much as 20% of operating costs and even in 1997 remains a source of cost pressure to airlines. Thus the distinction between enterprises and private automobile use may be important for explaining differences in the evolution of fuel intensities and CO_2 emissions from these different branches of transportation.

There are many propulsion sources that offer <u>nearly</u> the same performance as gasoline and diesel but with lower net CO_2 emissions (Sperling and Deluchi 1989; 1993; Wang and Deluchi 1992; Sperling 1994). These are only making slow progress in the market place, most likely because of the higher costs of vehicles, but in some cases because the sources themselves are more costly than gasoline or diesel fuel. Or it is possible that "nearly" the same performance is not really correct. Diesel engines themselves offer significant potential for lower net fuel intensity and CO_2 emissions (Wester 1992, priv. comm.). But it must be remembered that diesel fuel is taxed much more lightly than gasoline in some countries; not surprisingly, its consumption is associated with significantly higher car travel. And as noted, diesel releases more CO_2 per unit of energy in combustion than gasoline, although its production may require less energy in refineries. Therefore, the net impacts of switching to diesel, or indeed any other fuel, must be evaluated using both full fuel cycle studies that take into account the marginal release of CO_2 anywhere in the fuel chain. And the use of any propulsion source must be evaluated under realistic conditions taking into account human behavior: electric propulsion may offer attractive ways of removing combustion from cars to power plants, often released away from cities. But if that use remains untaxed as a road fuel while incentives are offered to provide easy entry to cities or low-cost parking, then consumers may again find a cheaper way to use cars than before, resulting in more driving. It is clear that alternative propulsion may offer significant CO_2 benefits at little perceived loss of driving amenity, but until we better understand all the costs, all the emissions, and above all the real interaction between alternative propulsion as a system and travel behavior, our expectations should be at best guarded.

We noted above important feedback loops relating fuel economy and efficiency to car performance. That car size and performance are absorbing some of the benefits of new technology, rather than giving larger reductions in fuel use per kilometer, is one that may be hard to avoid if incomes grow while fuel prices are steady or falling. It is possible that if technology jumps more quickly to reduce the energy (and CO_2) costs of that performance, or if a fuel truly low in CO_2 emissions becomes available, that emissions could head downward for a long time as the new technologies appear in the market. Nevertheless, some countries, notably Denmark and Sweden, anticipate this in their CO_2-related policy discussions, and are considering higher fuel taxes to offset the lower costs of car use afforded by greater efficiency. For Danish calculations, it is assumed that at 10% reduction in fuel costs/km leads to a 4% increase in km driven (COWI 1996), but others (Green 1992) find that coupling much smaller, closer to 1.5%. Either way, however, this kind of feedback cannot be ignored, particularly of the increases in car use raise more external costs associated with noise, congestion, and safety than the net reduction in fuel use save from lower CO_2 emissions

As noted in the introduction, at all levels, from local to national to international (Michaelis et al. 1996, CEC 1996) have taken note of these problems related to transportation. Since the studies cited find the likely costs to society of externalities besides CO_2 greater than the costs of CO_2 (at least per km of vehicle, personal, or goods travel), than it may be more reasonable to expect that the greatest changes in transportation will be motivated not by CO_2 concerns but by those concerns rooted in problems of transportation. As the COWI study suggests, measures that integrate CO_2 concerns into a larger packet of transportation environmental reforms may lead to both serious restraint in emissions and in growth in other externalities from transportation with a net gain in overall social welfare. We believe these kinds of results, while only approximate and only validated for a model for Denmark, point the way to both how to inlays the CO2 problems in a transport context, and, more important, where to find solutions.

5. The Future.

Lest the trends presented appear to herald continuing increases in CO2 emissions from transport, there is a positive message from this work. From each national study there appears to be a combination of technological change (including that driven by RDD and pricing policies), higher costs for lower-emitting fuels, and application of transportation measures that could improve transportation and restrain or even reduce CO2 emissions over the next decade. These could change both emissions per km and total km enough to make a real break in travel fuel consumption, as clearly happened in the U.S. in the 1970s and 1980s. For trucks, technological improvements and low-CO2 fuels can also make a significant dent in CO2 emissions, but it appears that there is also a very large potential for changing the way trucks are used. This utilization may not respond radically to the CO2 question alone, but to policies designed to increase modal competition, reduce congestion, pollution and noise in built up areas, lower road damage, and deal with other externalities that are focused more on freight than travel. Thus while the bad news is that CO2 policies alone, or technologies aimed at CO2 alone may not have a great enough impact on emissions to reduce them, CO2 measures in intimate combination with transport policy measures could leave European, Japanese, and N. American transportation systems with lower total CO2 emissions in the early part of the next century than at present.

We will not speculate here on which policies might affect these variables in the future, and therefore restrain or reduce CO2 emissions from travel or freight. However, the opening comments about transport externalities served to emphasize that only a broad framework that integrates concerns for CO_2 with strategies to solve other transport-related problems can be successful. If the transport problems are indeed as serious as the literature suggests, then their prompt and thoughtful treatment, together with measures designed to address CO2, including taxation, could break the links shown in the opening figures. And if governments are really as concerned both about "Sustainable Transport" and with CO2 emissions as their prolific reports suggest, the forces could be mustered for this important integration.

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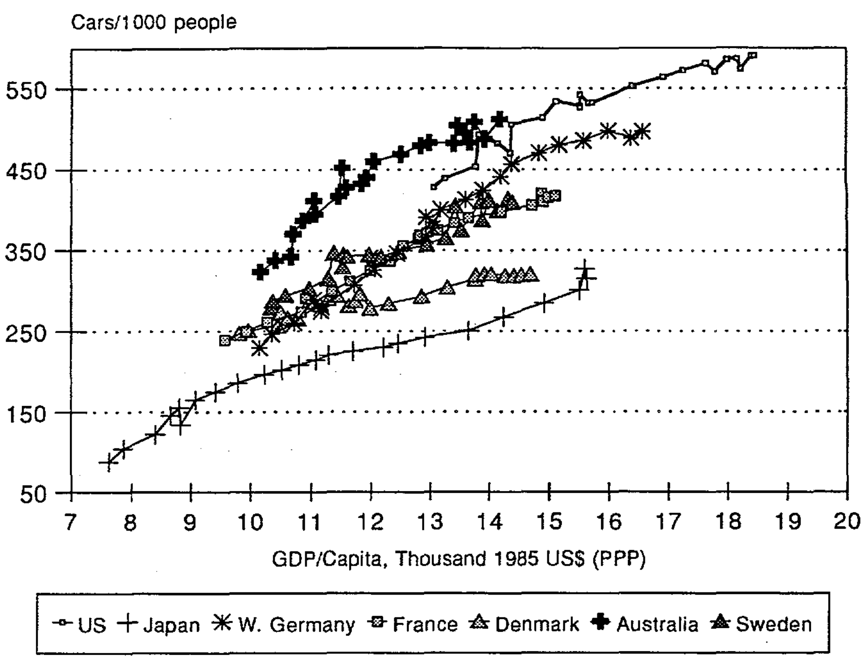
Figure 1: Automobile ownership and GDP



Includes diesel and LPG vehicles, household light trucks/vans

Figure 2: GDP and Domestic Travel

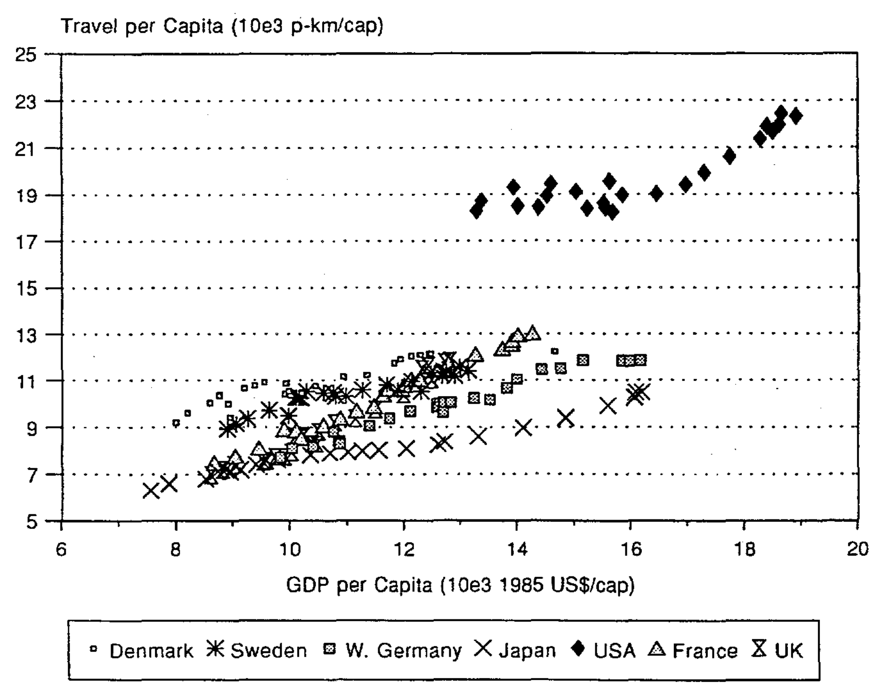


Figure 3: Per Capita Travel in OECD Countries

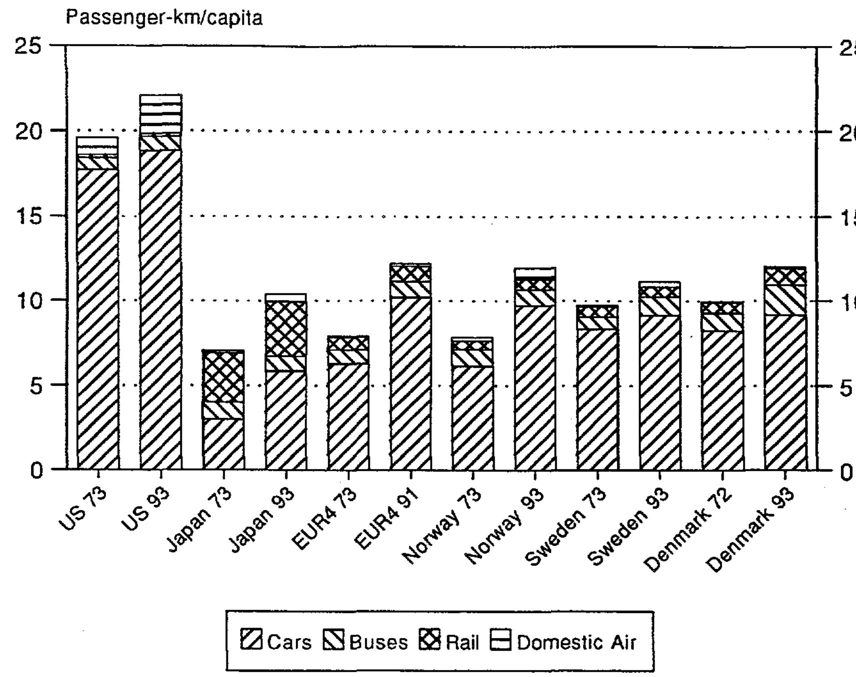


Figure 4: OECD Travel
CO_2 Emissions 1973 & 1992/3

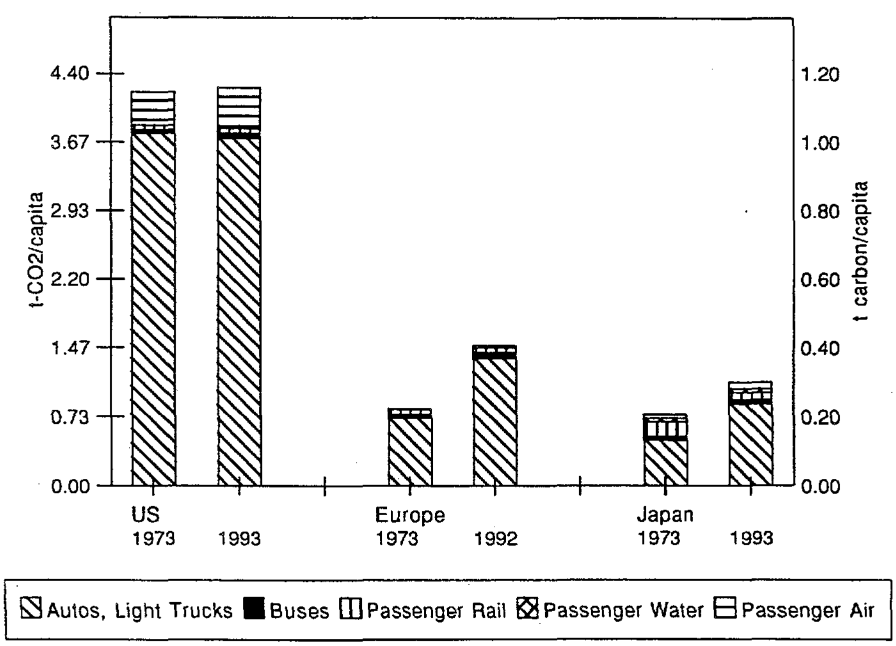


Figure 5: Freight Volumes and Industrial GDP

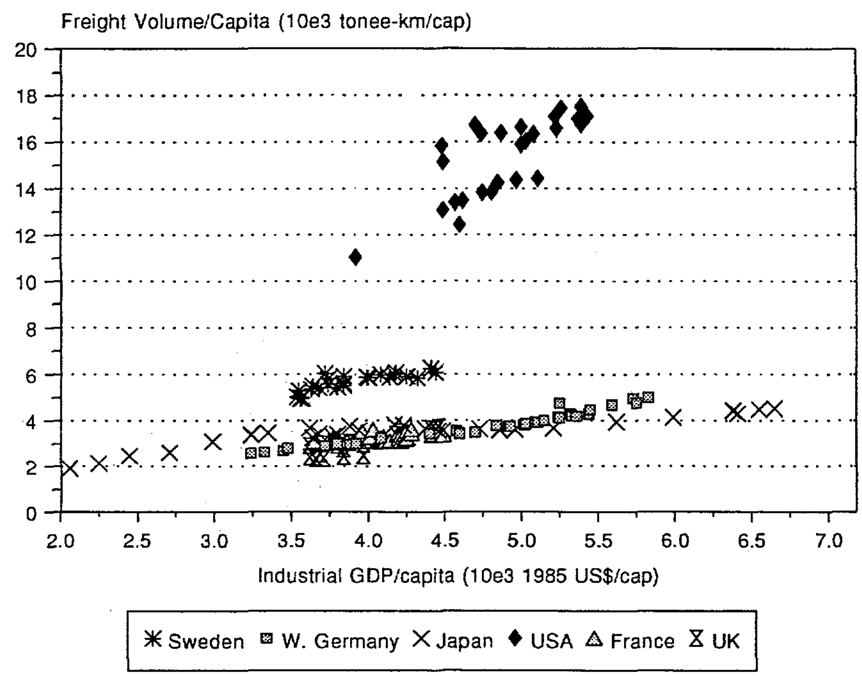


Figure 6: OECD Freight CO2 Emissions 1973 & 1992/3

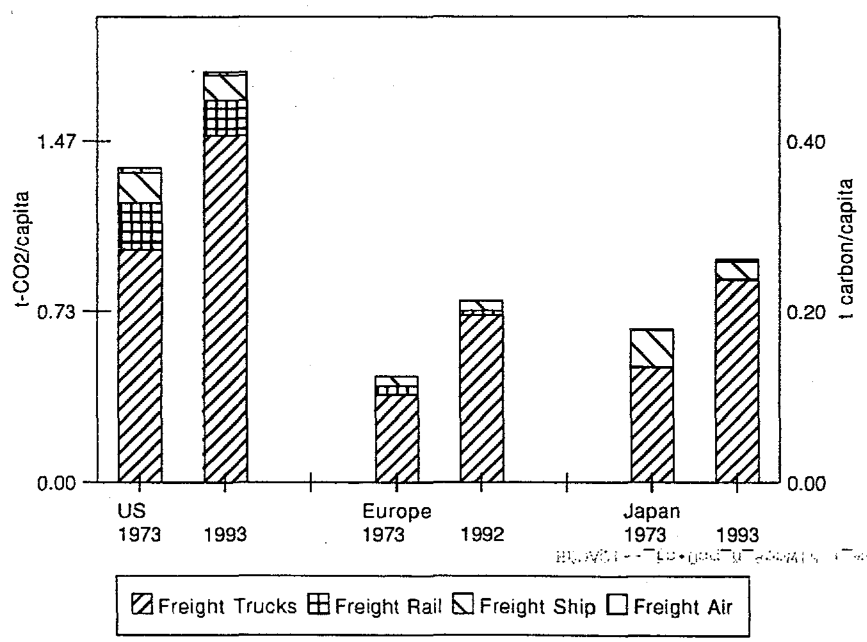


Figure 7: Changes in CO_2 Emissions from Travel
Factoral Decomposition 1973-1991/2

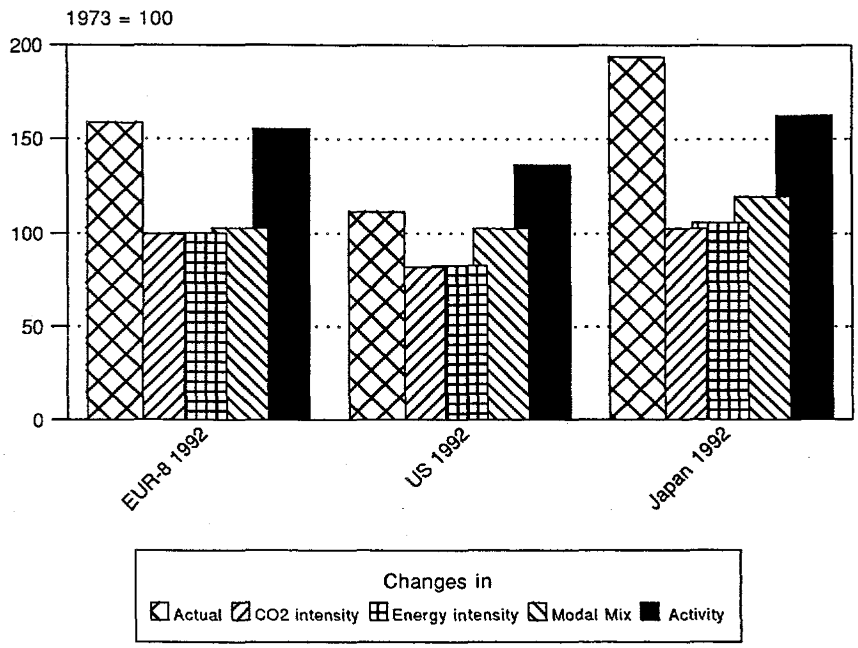
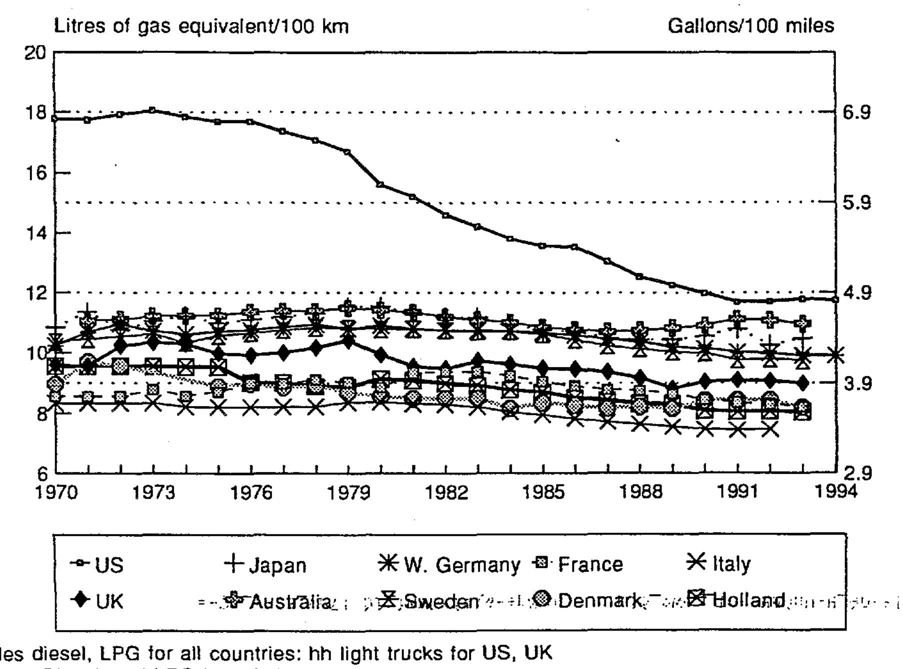


Figure 8: On-road automobile fuel intensity in OECD countries



Includes diesel, LPG for all countries: hh light trucks for US, UK
Gasoline, Diesel, and LPG included at energy content

Figure 9: "Efficiency of New Cars"
Ratio of Fuel Consumption to Weight

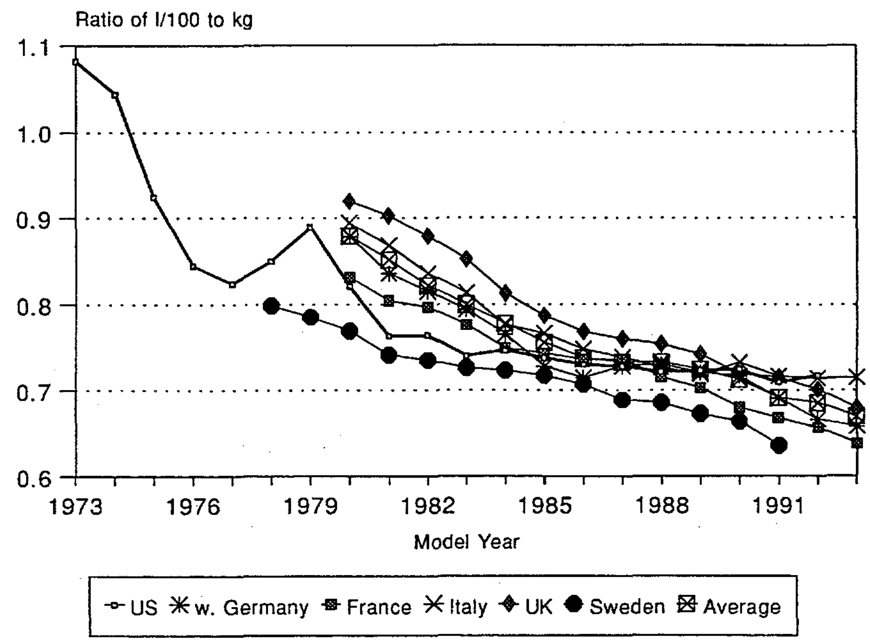


Figure 10: Average Weight of New Cars

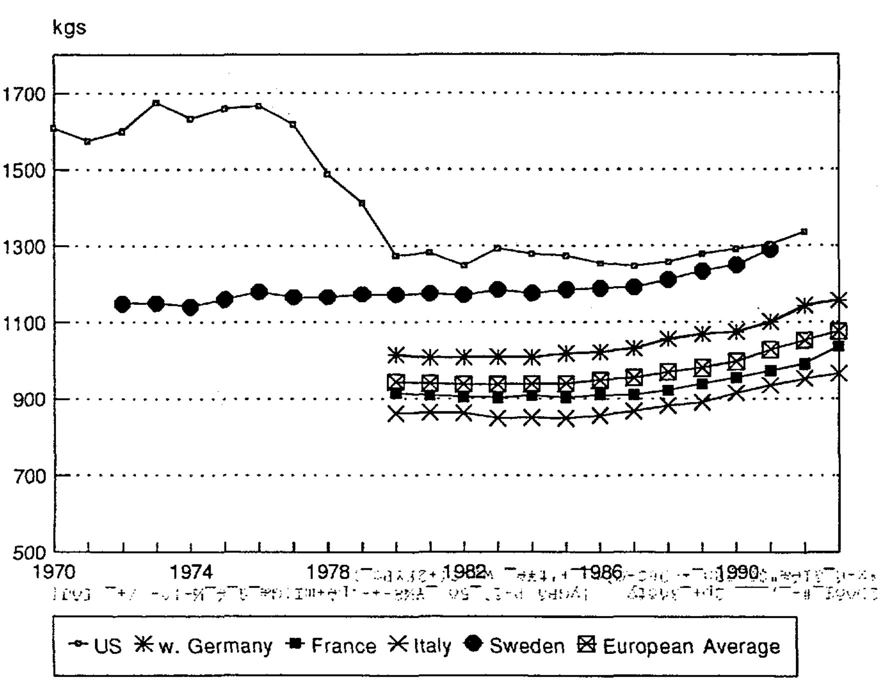
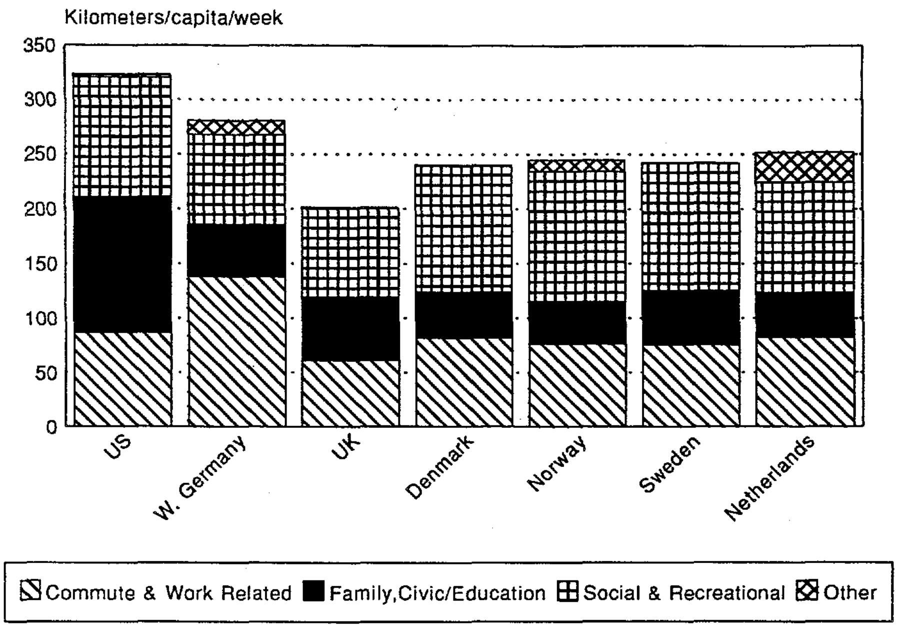
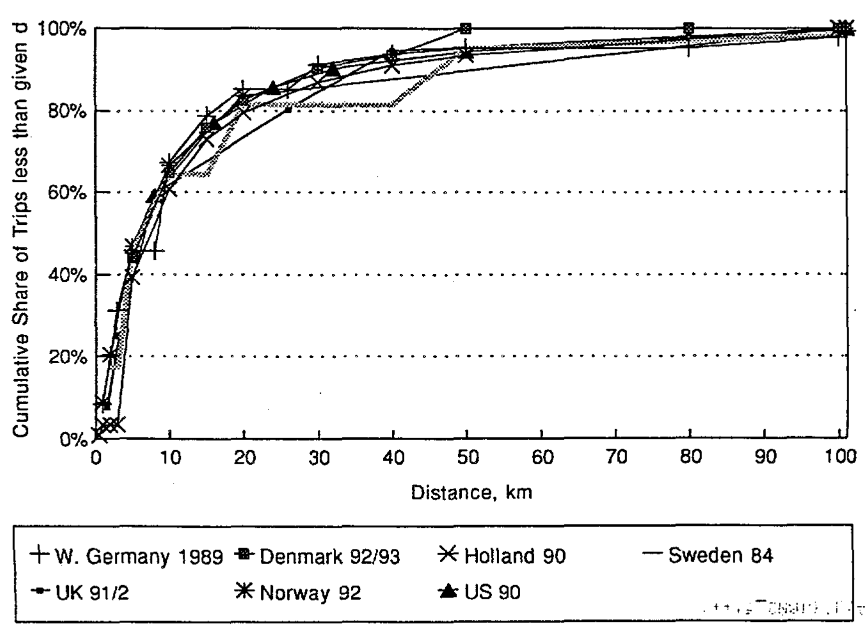


Figure 11: Travel By Purpose



Travel Day data all countries
Unweighted Data for Norway and Sweden

Figure 12: Length of Car Trips*: Number by Distance



Points right of 100 are "greater than 100 km", 50KM Germany, 20 KM Norway
* Trip means "car, driver"

Figure 13: Changes in CO2 Emissions from Freight Factoral Decomposition 1973-1992

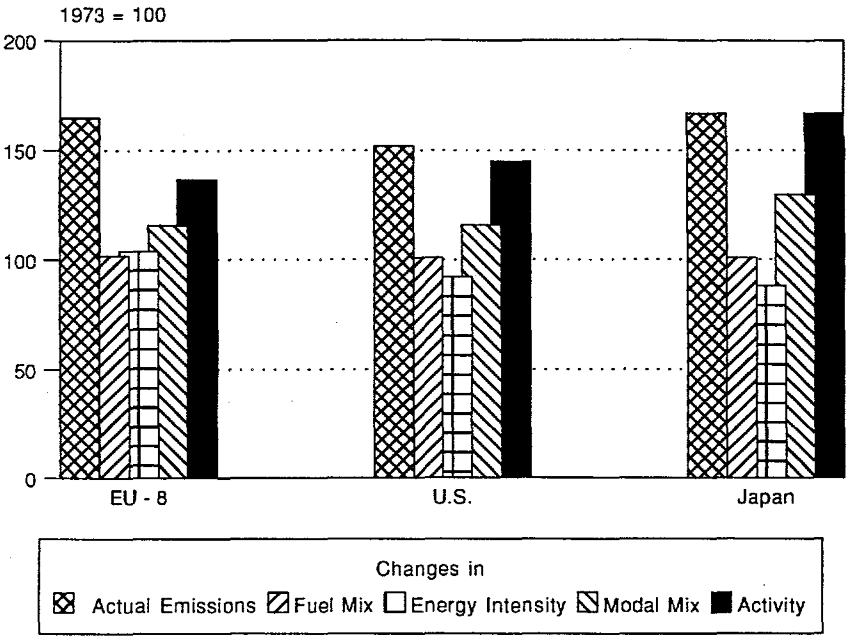
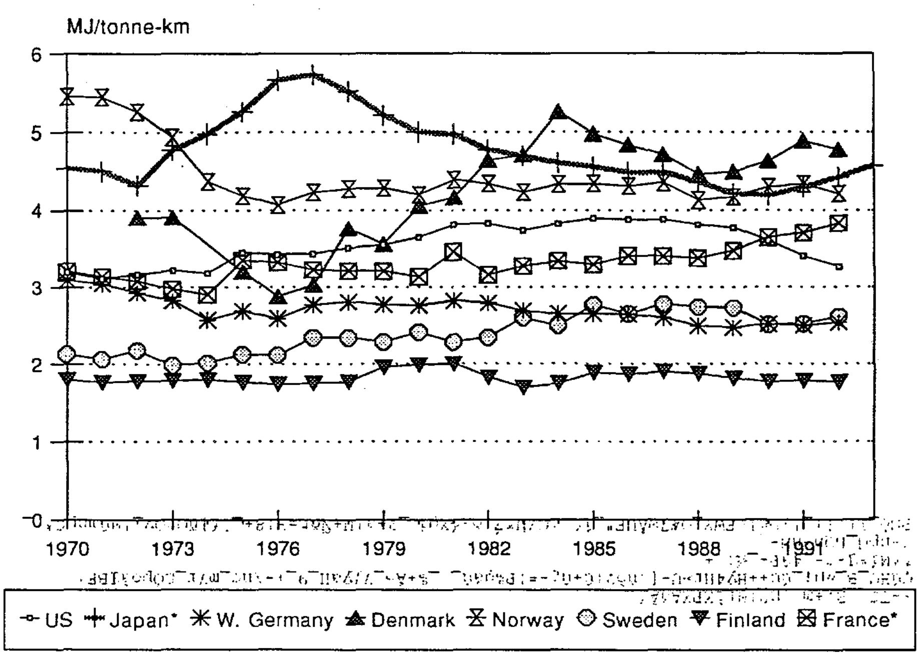


Figure 14: Modal Intensity of Trucking



* Revised values.

Figure 15: Fuel prices, fuel use and fuel intensity in 1993

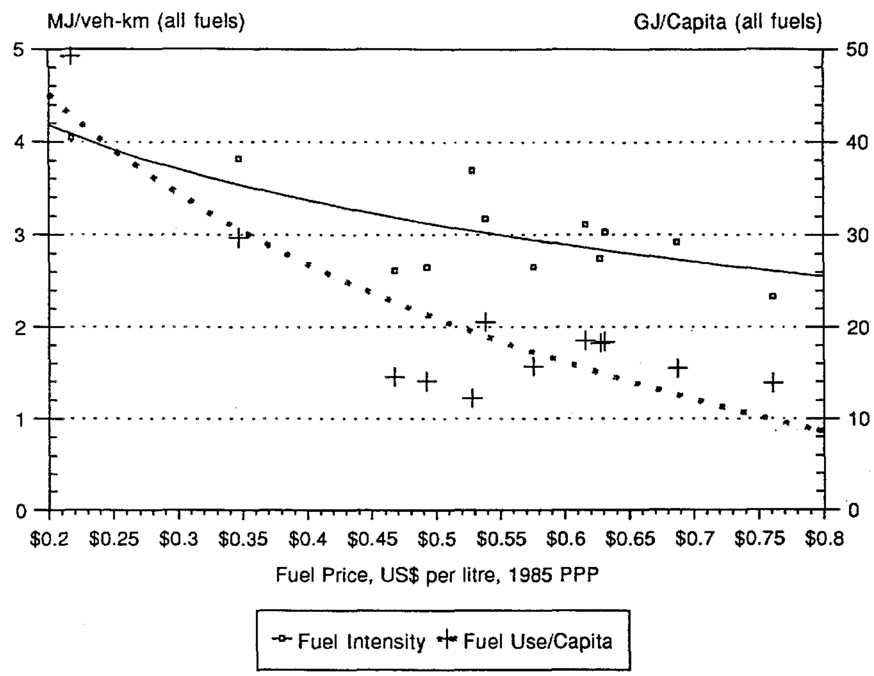
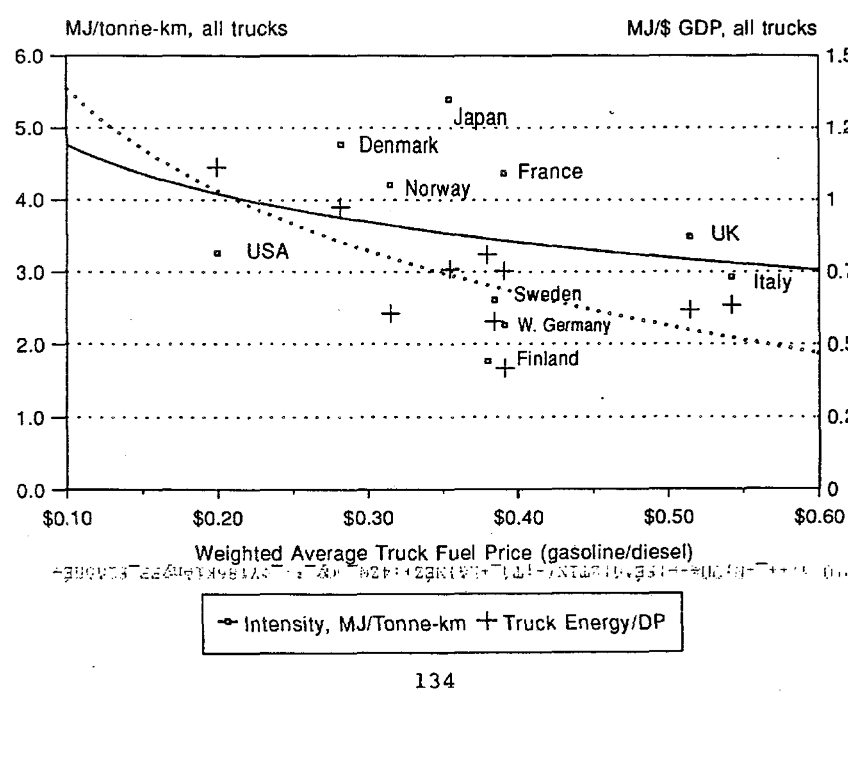


Figure 16: Truck Modal Energy Intensities and Fuel Prices
International Comparison, 1992



DISTANCE WORKING - MOTIVES AND BARRIERS: A SMALL CASE STUDY OF THE IMPACT OF DISTANCE WORKING ON TRANSPORTATION

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ABSTRACT

This paper is first of all concerned with unveiling the subtleties of the interplay between motives and barriers for introducing distance working into organizations and to discuss the impact of distance working on travel behavior. The paper is based on a comprehensive literature survey on distance working and transportation studies. Furthermore, the paper reports from our own ongoing experiment on distance working at the Danish Technological Institute: 'Save Transport, Time and Energy: Work at Home two to three Days a Week' (in the following referred to as the DTI case study). Based on qualitative data we discuss three major social-psychological aspects which have an impact on the potential for distance working: Social isolation, 'workoholism' and child-caring. In addition, we present some preliminary findings indicating that distance working has a marginal effect in terms of reducing commuting using cars.

1. INTRODUCTION TO DISTANCE WORKING

Distance working has existed for decades, cf. freelance journalists, employees working overtime at home, registered child-minders, and teachers preparing lessons at home. A new dimension of the term is the use of telecommunications-related technology to conduct work. This dimension is not direct derivable from the Scandinavian term 'distance working' contrary to its synonyms 'teleworking' and 'telecommuting'. While the term 'teleworking' is used mostly in British-European literature, 'telecommuting' is predominant in American literature.

At present, there is not a complete consensus on how to determine the term distance working. As such, the term allows of several research approaches (cf. Mokhtarian, 1991):

- The salaried employee or self-employed working at home instead of in the office.
- The salaried employee working overtime at home after a full day at the office (evenings or weekends).
- The salaried employee working from a center closer to home than the primary office (non-home-based), e.g. the satellite/local work center.

In the DTI case study our research approach focuses on distance working supported by telecommunication, carried out by persons with a traditional employment at a company, and in average working at home instead of in the office two to three days a week (this does not necessarily mean working at home two to three full days, but it should rather be understood as 16-24 hours spread over one week - some days working both at the office and at home). Thus, inspired by the Swedish researcher Forcebäck (1995), we define distance working as follows:

> 'Work voluntarily carried out at home, by a person employed at a public or a private company, within or outside normal working hours, and in average two to three days a week. The work must be supported by computers and telecommunication'.

The American term 'telecommuting' is often defined as the use of telecommunications-related technology to partially or completely replace the commute to and from work (cf. Mokhtarian, 1991; Niles, 1994). Socially seen, less transportation means energy savings. Furthermore, it will affect the environment positively because of decreased emission of polluting gases. Our research approach also covers this transportation-telecommunication-substitute perspective - meaning that we analyze whether digital traffic actual replaces vehicle traffic. This subject is discussed later in this paper.

Estimates of the number of existing and projected distance workers vary widely, often because the estimates are based on different definitions of the term (cf. Johnston & Culpin, 1995, who use a very broad definition, and Forcebäck, 1995, who uses a very narrow one). Thus it is extremely important to pay attention to the multiplicity of variations in the definitions of the term distance working when comparing literature and estimates of distance working.

2. MOTIVES AND BARRIERS FOR INTRODUCING DISTANCE WORKING

Considered from an overall point of view, distance working has been made possible by:

- Development of advanced computers and telecommunication facilities at decreasing costs.
- Growth in the linkage of computer networks, e.g. the Internet.
- Both employees as well as employers have become more open-minded towards new methods of working.
- Increasing pressure on enterprises to reduce costs and to heighten the level of service.
- Increasing consciousness of the environment.

- A general shift in work-related motivating factors - away from traditional parameters as career and wages towards a higher priority to have an independent, interesting and meaningful job.

As mentioned above, our research approach to distance working is closely related to the concepts of information technology, telecommunication and transportation. Current information and telecommunication technologies provide unique opportunities for introducing distance working in a massive scale into organizations. In spite of the fact that distance working is not a new phenomenon, we still have not seen the major breakthrough in the private as well as the public sectors.

According to results from the TELDET-project (Korte et al., 1994) approximately 1.25 million distance workers exist in the five largest European countries: England, France, Germany, Spain and Italy. The TELDET definition of distance working only differs slightly from the definition used in this paper:

'Work carried out at another place than the primary office, at least one day a week, supported by telecommunication and information technology'.

In comparison with the above figures, EU-commissioner Bangemann (High Level Group on the Information Society, 1994) recommends the total number of distance workers to be almost ten times higher in the year 2000.

Korte et al. (1994) estimate a theoretical distance working potential in Europe in the year 2000 at approximately 7% of the total labor force. Furthermore, they estimate that about one third of all jobs are suitable for distance working.

According to our definition, distance working in Denmark is estimated to cover about 0.4% of the total Danish labor force or 1.2% of all Danish white-collar workers (cf. Millard, 1996). Distance working supported by telecommunication is much less widespread in Denmark compared to the major European countries. On the basis of our survey we have arrived at the conclusion that it is plausible that the 7% estimate will apply to Denmark in the year 2000 - provided that differences between Denmark and her European neighbors exist, e.g. on subjects like national working culture, structure of labor market, the spread of information technology and transportation infrastructure.

We aim to be able to evaluate the figures and estimations related to the potential for distance working from a qualitative and multifactorial perspective. In the below table 1, we have listed barriers and motives for introducing distance working as a common method of working in organizations. It is these barriers and motives related to the totality of working life we wish to examine in through experimenting with distance working. In the next section we will present the approach of the DTI case study and discuss some preliminary results based on quantitative as well as qualitative methods.

Barriers for distance working	*Motives for distance working*
Tradition: • We go to work because of demand of the employer. Thus the employer is the key to introducing distance working. **Confidence and Self-confidence:** • The employer's confidence in the employee. • The employee should have common goals with the company and have an interest in fulfilling these goals. • Independent work. **Organization and Content of Work:** • Not all kinds of jobs are suitable to be carried out at home. • The content of work must be well-defined and have a character which makes it possible to delimit it compared to other job assignments. • To estimate the work on output rather than on consumption of working hours. **Homework and Private/Family Life:** • Social life at the workplace. • Teamwork at the workplace. • Inspiration from colleagues. • Constructive criticism from colleagues. • The employee as a balanced person. • Informal information exchange. **Demands for Residence:** • Room for home office. • Placement of the home office. • Environment of the local community. **Unsolved Legal Matters:** • Security and insurance at home. • Taxation, e.g. on computers at home. • Working environment.	**Motives of the Employees:** • Flexibility and job control. • Higher efficiency. • Better balance between work and family life. • Opportunity to take care of sick children (important in Denmark where both parents normally are working full time). • Higher emphasis on job content. • Less transportation expenses. • Less transportation time. **Motives of the Company:** • Greater flexibility to solve peak loads. • More customer service. • Flexible production. • Increased productivity. • Higher emphasis on 'Human Resource Development'. **Technology:** • Better tools and services. • Open networks - the Internet. • Telecommunication - ISDN. • Communication, E-mail, NetFAX, Video conferences, 'Virtual reality'.

Table 1. The table summaries push and pull factors influencing the spread of distance working as a method of working in a massive scale. Sources: The DTI case study, 1996; Mirchandani, 1995.

3. THE DTI CASE STUDY

At present, we are dealing with our own distance working experiment called 'Save Transport, Time and Energy: Work at Home Two to Three Days a Week'. 10 employees (engineers, architects etc.) from the DTI Energy VISION, a research and development unit at the Danish Technological Institute, participate in the experiment.

The overall aim of the experiment is to unravel the relation between distance working and transportation focusing on social, psychological, organizational and legal issues related to the introduction of distance work into organizations. It applies comprehensive semi-structured and open-ended qualitative forms of interviews, quantitative time-budget analysis techniques, and diary writings. The experiment started March, 1996 and ends July, 1997.

Our technological aim has been to provide the distance workers with the same telecommunication opportunities whether working at home or at work. By means of an ISDN telecommunication line, the home offices of the above 10 employees and the primary office at the DTI Energy VISION have been connected. Thus telecommunication facilities as e-mail, facsimile transmission, Internet, access to the local area network at the DTI as well as printing facilities have been placed at the distance workers' disposal both at home and at the DTI.

Monday May 27, 1996									
Time	*Working at home*	*Working at DTI*	*External Meetings*	*Means of transportation*					
				Bus	*Car*	*Bicycle*	*Plain*	*Train*	*Other*
6:00									
6:30									
7:00									
7:30									
8:00									
etc.									

Means of communication	*Working at home*	*Working at DTI*
Number of e-mails		
Number of facsimile transmissions		
Telephone (in minutes)		
Internet (in minutes)		

Table 2. An illustration of the schemes used for logging of quantitative data. 'DTI' is our company acronym.

The schemes shown above have been used to log the quantitative data. We have used a very simple scheme to reduce the participants' workload when logging their working, transportation, and communication behavior. We wanted to be able to distinguish between the means of transportation, the time used working at home, and the time used working at the company. Furthermore, we wanted to be able to analyze when the work is carried out. In addition, we wanted to be able to scrutinize any change in the communication behavior during the experiment. We have collected data through random samplings. The duration of a single sample is three weeks. The data presented below is based on two samples.

So far we have observed that three variants of distance working have been used by turns:

1. Working at home full days.
2. Working at home a few hours on Saturdays, Sundays, and other non-working days.
3. Working at home a couple of hours before or after working at the office.

An analysis of our preliminary data have shown that the employees participating in the experiment have:

- Worked at home 24% of all working days (including Saturdays and Sundays).
- Combined working at home with working at the office in 32% of all working days.
- Worked at the office for 44% of all working days.
- Used distance working in about 30% of normal working hours (37 hours a week in Denmark).

In a transportation perspective, the 10 employees together saved the below commuting time per week:

- More than 5 hours of transportation in car.
- Just below 4 hours of transportation in public transportation (bus and train).
- Just below 2 hours of transportation on bicycle.

These figures should be compared with the relatively low average commuting time per employee (about one hour in car, about two hours in bus/train or about 1½ hour on bicycle per day). The figures should also be related to the fact that no transportation is saved on the days where distance workers work both at home and at the office.

Even though technical problems in connection with the implementation of computers and other telecommunication facilities could explain the present relatively low frequency of days working at home, it seems that two to three days may be a too high estimate for the average of distance working at DTI. But at present, further data is needed to support this finding. Currently, we are using qualitative techniques to explore the impact of the motives and barriers mentioned in the above section further. Due to limited space we have chosen only to discuss results related to three major social-psychological aspects of distance working: Social isolation, 'workoholism' and child-caring.

One of the main drawbacks of distance working claimed has been in relation to the notion of 'social isolation'. One claim is that it can be difficult for the distance worker to keep up to date in what is going on at the office in regard to social interactions of working life. At work it is possible easier to get to know your colleagues - what their interests and preoccupations are. In addition, distance workers are often excluded from engaging in informal social activities like 'birthday cake get-togethers' and canteen gossips and chats. As one of the employee told us:

> "I don't think I'm going to use the opportunity to work at home in a massive scale. I like to be together with my colleagues. I kind enjoy it working with all these people around me. Being at home to much I think I'll get bored".

Being isolated from work can be a major problem to some people. As humans we are in fact social animals. Being at work with our colleagues is often essential for maintaining self-confidence. If we lose confidence in ourselves, it is most likely that motivation for doing our job as well as our work performance will decrease. This could be the beginning of a vicious circle. One way to avoid the feeling of social isolation is to have regular meetings at the workplace to ensure formal as well as more informal discussions about work, family life, project initiatives, the latest movie, changes in office policies, etc.

For the time being we, at the DTI Energy VISION, do not have regular meetings. This could be another reason why we have not used the opportunity to work from home as much as expected. On the other hand, as discussed in relation to the definition of distance working, the participants of the experiment are free to commute to work whenever they want. So far, our experience is that voluntariness is an important part of distance working so no one is forced into social isolation. In fact our findings indicate a work pattern where people work some early hours at home, travel to work and stay until mid-afternoon whereupon they travel back to home and finally work an hour or two during the evening.

Another major drawback often mentioned in relation to distance working is the notion of 'workoholism'. In some ways 'workoholism' forms a contrast to the notion of social isolation. 'Workoholism' is not a new phenomenon arisen with the opportunities to work at distance. But the immediate access to work through the information and communication technologies within an 'arm's length' at home seems to play a certain role in creating 'workoholics'.

Our observations show that one of the major strengths of distance working is flexibility according to when you want to work and when you do not. On the other hand, it can be difficult to distinguish between work and leisure. The problem is that the workplace is moved to your home and the computer with all its e-mail, facsimiles, Internet and other opportunities for carrying out work exactly as if you where at the traditional workplace is only a few seconds away. To some people it has been difficult to stay away from the computer - some times only to check for any new e-mail. As one of the participants of the experiment told us:

> "It was not because I wanted to do any work at home, but I just wanted see if there was any e-mail for me. But having turned on the computer and received some new e-mails you might as well go on answering them. Now, in answering the mail you just need to get hold on some information in a document you have been working on lately. In doing so you find that some of the calculations included in the document need some refinements.....and suddenly you have spend hours working and your wife starts grumbling about."

Another of our findings related to 'workoholism' is that some people tend to work round the clock. That is, they tend to spread their working hours throughout day and night. ' here is no doubt that 'workoholism' in the long term could contribute to so-called 'burn-outs' and other related sufferings. In the short term there is no reason to think that 'workoholism' could be harmful. At present, we need more data to conclude if 'workoholism' is a de facto work pattern within our experimental group.

The last social-psychological point we will discuss is the relation between family life, children, child-care, and distance working. One of the authors of this paper has been interviewed a number of times in relation to distance working. The journalists often want a photograph to go with their writings showing a cheerfully playing baby just next to the hard-working distance worker in front of his or hers personal computer. If there is no babies around the photograph should at least include some toys scattered around in the home office. The journalists try to sum the wildly held view that distance working is particularly suitable for those with children to look after. Work and family-life can be reintegrated and the responsibilities of child-care reconciled with the needs and pleasures of work. There is no doubt that the possibility offers greater flexibility to those with child-care responsibilities. It is for example possible to take care of children when they are feeling ill. You can stay at home and look after the child during daytime and then when your spouse arrives from his or her work you can work through the late afternoon and the evening. Families with small children often mourn about the fact that they do not have enough time with their children. Using the opportunity of distance working it is possible to spend more hours with the children throughout the day.

Our study shows that it is of great advantage to be able to take care of your sick children during daytime and then 'pay for it' by having to work in the evening. On the other hand we have findings indicating that it is difficult to assume working full-time at home while caring for a young child at the same time. The problem is that you are at home physically, but not mentally. It can be difficult to take care of or play with a child while being deeply involved in solving intricate problems concerned with your work. So the possibility of working at home does not necessarily remove the need for other types of child-care arrangements.

The preliminary findings we have presented in this section based on both quantitative and qualitative data indicate that there is a reduction of commuting time. To reduce travel time to and from work is one of the main motives for distance working for the employees involved in our experiment. Another finding is that the frequency of distance working tends to be lower than expected. The barriers presented in table 1 seem to be stronger than we predicted. Currently we have only looked at some of the social-psychological factors. In our experiment social isolation has a clearly negative effect on the frequency of distance working. The possibility of combining distance working with child-caring in case of childrens' illnesses has a positive effect. It is still too early to predict the influence of 'workoholism'. We certainly need to make further research into these intricate and often contradictory social-psychological motives and barriers for distance working.

In addition, further research into the following conditions is needed as they have not yet been sufficiently clarified. Therefore one of the next, and new, steps within our study of distance working is to shed light on legal matters as working environment, security and insurance at home, taxation e.g. on computers and other telecommunication facilities at the distance worker's disposal at home. The overall thesis is that distance workers should have the same rights guaranteed by the company compared with employees who work full time at the company (this is for instance claimed by a Danish labor union).

The findings presented indicate that distance working reduces transportation though in a minor scale. In the next section we will put the findings into perspective. First we will take a look at international studies of the impact of distance working on transportation and the environment. After that we will discuss the potential for distance working in Denmark and relate it to the findings presented in this section.

4. I NFLUENCE ON TRANSPORTATION AND THE ENVIRONMENT

Distance working is often seen as means for travel substitution in replacing commuting between home and work with telecommunication. A common hypothesis within transportation studies of distance working is that the combination of information technology and telecommunication is a natural substitute for passenger transportation: Digital traffic can replace vehicle traffic on the streets and highways of the transportation infrastructure (e.g. Niles, 1994). As mentioned many American researchers use this transportation-telecommunication-substitute approach when dealing with distance working. This is reflected in the term 'telecommuting' and some definitions of the term - cf. Mokhtarian's (1991) definition:

"The use of telecommunication to partially or completely replace the commute to and from work".

In a case study of 280 distance workers carried out by the Washington State government (cf. CADDET, 1995) it is concluded that distance working impacts energy consumption in three major areas: It generally saves transportation and office energy use, but increases home energy use. The estimated net energy savings were about 5,000 MJ (about 1,400 kWh) annually per distance worker - primarily due to a reduction in transportation (gasoline). All distance workers in the case study taken together saved about 6,460 round trips (30% reduction per distance worker compared with a non-distance worker), 372,970 kilometers (75% reduction), and about 35,200 liters of gas (50-60% reduction of the outlet of pollutants) per year.

Another hypothesis contrary to the above is that distance working in reality does not reduce transportation as much as claimed. American studies show that even though distance working actually reduces commuting between home and work, the use of other kinds of transportation (e.g. trips between home and shops) increases in stead. In a case study from California it was estimated that 6% of the labor force used distance working on average 1.2 days a week. Scaled to the whole of California this only resulted in 0.5% net transportation energy savings (cf. Mokhtarian, 1996). The U.S. Department of Transportation (1993) estimates that distance working in the year 2002 will reduce the total annual vehicle miles traveled by only approximately 1% below the level expected to be seen if there were no such thing as distance working. The U.S. Department of Energy (cf. Niles, 1994) calculates that the reduction in mileage is likely to be even less because of commuters moving further away from work and other travelers taking the road space vacated by distance workers.

Many surveys and estimations point to savings related to transportation as a result of introduction of distance working, but disagreement exists between researchers about to what extent these savings turn out to be. We find it important to point out that if we look upon one single distance worker, a big potential of savings exists on an average day, but when this saving is related to a total transportation energy saving, the potential is reduced considerably. In the below table, we have grouped arguments for the two above perspectives on the impact of distance working on transportation behavior.

Main hypothesis: Information technology and telecommunication is a natural substitute for passenger transportation	***Circumstances claimed to work against the hypothesis***
• Digital traffic replaces vehicle traffic as distance workers do not need to commute to work on those days they work at home. • A number of studies have proved actual reductions in passenger transportation as a result of the introduction of distance working. • One of the main motives for working at home among the DTI distance workers is to avoid transportation time/commuting.	• Distance workers will move further away from work - commuting as much as they did before (traveling fewer days, but at a longer distance). • Distance workers may reduce commuting, but at the same time increase other kinds of transportation (e.g. trips to shops, friends/family, and sport activities). • Some days distance workers work both at home and at the primary office. • Other travelers will take the road space vacated by distance workers, e.g. when the wife (normally using her bike, the bus etc.) uses the car in stead of her home working husband. • Researchers claim that even proven results concerning reductions in passenger transportation have been misinterpreted and abused for commercials purposes (e.g. telecommunications corporations have a great interest in proving the public utility of distance working).

Table 3. The table summaries arguments for two different perspectives on how much distance working will impact transportation behavior/commuting. Sources: E.g. The DTI case study, 1996; U.S. Department of Transportation, 1993; Mokhtarian, 1996; Nilles, 1996; Telecommuting, 1992.

Now, it is not likely that the above American estimates can be directly transformed into European and Danish conditions among others because the average commuting distance in kilometers is much longer in the U.S. compared with Europe and especially Denmark.

Our calculations of the impact of distance working on transportation behavior in Denmark are based on information on transportation in 'car as driver' due to the fact that the majority (60%) of all kinds of transportation in Denmark can be traced back to this category and that transportation is not reduced if distance workers commute by public transport or in 'car as passenger'. The Danish Ministry of Transport (Trafikministeriet, 1996) estimates that the total commuting kilometers on an average day in Denmark totals 39.7 million kilometers, of which 23.3 million kilometers can be traced back to transportation in 'car as driver'. This corresponds to 36 commuting kilometers 'in car as driver' per Dane on an average day.

On the basis of the above information and definitions (7% of all potential distance workers working at home two to three days a week as an average), we have worked out that in the year 2000 the total reduction of commuting in cars on a single distance working day accounts for about 595,000 kilometers. This corresponds to a reduction of 1.5% of the total annual commuting in cars in Denmark. Seen from another perspective the 1.5% totals 5½ days of total commuting in the year 2000.

Based on our preliminary findings we support the view that distance working does reduce transportation and saves energy, but the reduction of transportation consumption and energy savings will only be of minor importance. It is important to pay attention to the fact that the rapid development of telecommunication and information technology is not the only parameter to be taken into account when estimating the future spread of distance working. In the DTI case study we aim to analyze multifactorial parameters concerning working life which will influence the expansion of distance working in future. These multifactorial parameters will not only be examined by means of statistics - in stead we attach great importance to the use of qualitative analyses. At the end of our case study we aim to be able to evaluate the above figures and estimations from a more qualitative perspective.

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LAND USE AND TRANSPORT PLANNING AND ECONOMICS

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1 INTRODUCTION

The Norwegian government has a few years beck made a resolution about «National Guidelines for Coordinated Landuse and Transport Planning». The background for these guidelines and planning principles is the need for developing our cities in an ecological sound way, compatible to sustainable development. In brief, the thinking is that it is compelling to reduce the private car use in order to reduce the CO_2 pollution, traffic accidents, traffic noise etc. To achieve that it is necessary to enforce **a coordinated landuse and transport planning**, so that the city development is based on a diversified transport system where public transport plays an increasingly more important role, and that the landuse is geared at being supportive to the public transport system.

The mentioned national guidelines are aiming at:

«Landuse and transportation systems are to be developed so that they promote efficient use of the resources, with environmentally sound solutions; shielded communities and living environments; good road safety and effective flow of traffic. A long-term, sustainable perspective is to be the basis for the planning. Emphasis is to be put on achieving good regional solutions that cross the municipality boundaries.»

Furthermore, the guidelines says:

«The planning in the counties and municipalities shall be performed in such a way that the decisions are made on basis of analyses of alternative solutions for landuse and transport system. The possibilities for an efficient public transport system shall be clarified. The impacts of the various solutions on the environment, natural resources

and welfare economic situation should be described, including a cost/benefit calculation.»

Introducing these planning principles, the goverment finds that the planning by the municipalities are taking these guidelines into practice to a rather dissatisfactory level. The government, i.e. the Ministry of Environment, is therefore trying to find ways and means to improve the practice.

One major issue has been to show that these planning principles in effect are economically sound, not only arguing on a global level (CO_2 reduction etc.), but also on a regional and local level. Therefore the Ministry of Environment initiated a study, which is the background for this presentation today, a preliminary study to explore how the cost/benefit analysis should be carried out, taking due considerations to the positive environmental and landuse benefits which this coordinated planning should achieve contrary to traditional planning principle where the private car accessibility is dominant.

The frustration, so to speak, by the Ministry of Environment is that the Ministry of Communication is proving roadprojects to be economically beneficial, calculating nicely the net present value and the cost/benefit ratio to prove their case. Now the Ministry of Environment wants to make sure that all relevant benefits due to the coordinated landuse and transport planning are included in the calculation so that other solutions may compete in economical terms.

So the aim of the preliminary study has been to structure a method where the economic significance of coordinated landuse and transport planning can be documented.

2 ISSUES OF CONCERN

To get an efficient use of resources, we need to take into account all the costs and impacts implied by utilizing the resources. This means that the individuals have to consider both the internal and the external costs. The problem is that the external costs most often are not being taken into account,

An example related to transport, is the matter of traffic congestion. The individual cardriver is **not** taking into account other travellers additional time consumption due to his choice of using the car. Another example is that by developing high density residential areas, the traffic volume will be less, implying environmental positive effects, and these effects are not taken into account by the individuals.

In general, there are two options at hand for the government to influence the individuals to act according to what is welfare economically beneficial:

1. To introduce taxes on utilizing natural resources so that the costs are internalized (like extra gas tax)

2. Calculate both internal and external costs

Regarding no. 2, there is at present no wide concensus about pricing of external costs. Therefore a number of impacts in practice cannot be calculated in monetary terms, only described in qualitative terms. These impacts are then to be weighed against the net present value deriving from the cost/benefit calculation. The weighing should be carried out as a verbal discussion.

A major obstacle to welfare economically sound decisions is the fact that the landuse planning and dicisions are the prerogative of the municipality, while the transport planning is the responsibility of the county og state level. In a region with a common housing and job market, the decision process becomes complex and unpredictable, and with a result which is not welfare economically optimal. Two major dilemmas occur:

1. **Dilemma in local planning**
   One dilemma for a municipality occurs when facing a choice between 1) infill development in existing residential areas higher densities, or 2) new areas to be developed.

   The welfare economically optimal solution is likely to be to utilize existing residential areas. The traffic volume may be lower than in other alternatives. On the other hand, the developing of new residential areas is more costly as it requires roadconstruction and extension of the public transport system.

   Seen from the municipality point of view, infill development takes time and is dependened on the landowners acceptance to sell. Hence this strategy may imply that the housing demand is not met in the municipality in question, and the risk is that the neighbouring municipality provides the necessary housing plots and is «steeling» taxpayers. Developing a new residential area is, on the contrary, instrumental to meet the demand as the construction can be speeded up and the housing supplies can be more predictable.

Hence, despite that the most welfare economically beneficial solution is to make more condense residential areas, the municipality is likely to rather develop new residential areas.

2. **Dilemma in transport planning**

For the transport authorities on county and state level the choice is between road construction or expanding the public transport system.

In a situation described above the authorities do not know whether the municipality is to go for a new residential area or higher density in the existing areas. To minimize the economic risk, the authorities tend to choose the road construction alternative.

The effect of this is that neither the municipality nor the county/state authorities will end up with the optimal welfare economic solution, but rather the poorest solution. These two dilemmas are supposed to be discussed in a principal agent context in the next paper.

Another major issue of concern is that the simple cost/benefit analysis often used for road projects, is giving meaningless results when there is a transfer from cars to public transport, the «engineer syndrome»!

The situation is that the road engineers are calculating the time costs for both car drivers/passengers and public transport passengers, before and after a measure has been implemented. Since those shifting from car to bus will have a longer travelling time, the measure is calculated not to be economically beneficial. Which is nonsense, as those shifting from car to bus have found this beneficial to themselves.

Hence there is a need to redirect the cost/benefit analysis to fit a more complex planning situation than traditionally has been the case for planners in Norway.

3 CASE STUDIES

In order not to be theoretical but «down to earth», 5 different case studies have been carried out. These case studies are examplifying some relevant planning situations where the options are to make decisions in line with the national guidelines or the opposite.

The case studies have been:

1. Infill development in existing residential areas or establishing new residential areas (as a satelite)
2. Alternative density in residential areas
3. Landuse and traffic restrictions in innercity area
4. Improved public transport or a new bridge to an island township
5. Moving a business out of the innecity area or not

The aim of the casestudies was both to test which cost/benefit components may be relevant to include (more components than in ordinary transport analyses), and to get an indication on which components may be of particular importance.

Without going into details, the case studies revealed that when alternative landuse measures are to be assessed, it is relevant to include at least costs and benefits due to differences in land consumption, construction costs of houses, and energy consumption (stationary, not mobile).

Furthermore, in general the differences in house construction costs may be particularly significant, but also land consumption and energy consumption. As for transport related costs, the time costs are most significant.

4 METHODOLOGICAL APPROACH

At the outset, it is seen as instrumental to base the methodological approach on the same approach as in the «Handbook 140 Impact analysis» issued by the Norwegian Road Administration.

Hence, an impact analysis approach is poposed to be adopted as the framework which is combining the impacts in monetary as well as non-monetary terms. The main sequences are:

1. Carry out a cost/benefit analysis, calculating the net present value

2. Weighing systematically the non-monetary impacts up against the net present value

3. Compare the various alternatives up against the reference alternative

4. Systematic discussion of the major arguments, including the distribution effects.

The impacts to be included and assessed is proposed to be (m=in monetary terms; nm=not in monetary terms):

Regional impacts	Land consumption for dwellings (m) Land consumption for industry (m) Land consumption for public buildings (m) Energy consumption (m) Operation/maintenance of buildings (m)
Environmental impacts	Living environment (m, nm) Leisure activities (nm) Natural environment (nm) Cultural heritage (nm) Landscape (nm)
Natural ressources	Farming and fishing (nm) Geo ressurces, ground water resources (nm)
Traffic safety	Accident costs (m)
Accessibility	Time costs (m) Vehicle operational costs (m) Benefit of new generated traffic (m) Inconvenience costs (m)

	Transport quality (nm)
	Bicycle accessibility (nm)
Investments/operations	Investments in transport system (m)
	Investments in housing development costs (m)
	Operation/maintenance of public service and infrastructure(m)
	Operation costs of road network (m)
	Operation costs of public transport (m)
	Ferry/boat costs (m)
	Toll collection costs (roadpricing) (m)

To the extent the components, fully or partly, can be calculated in monetary terms, these are to be included in the net present value. Those which cannot be calculated in monetary terms, are to be described and weighed against the net present value.

Some components can be calculated in monetary terms, but shall **not** to be part of the cost/benefit analysis, namely the distribution effects. Such effects implies that what somebody is gaining. somebody else is loosing, which in the cost/benefot analysis is balanced out. These effects are for instance:

Distribution effects	Tax income
	Employment and side effects
	Ticket costs
	Environmental damage costs (partly)

5 METHODOLOGICAL CHALLENGES

The case studies revealed a number of issues to be looked into in order to develope a method which in a consistent way includes both landuse impacts and transport impacts in a common framework. The major issues are:

Double counting

There is an immanent danger of double counting. For instance, double counting may occur when noise on the one hand is calculated in monetary terms and on the other hand in addition is described and weighed as a major disadvantage to the living environment.

Reference alternative
Ordinarily in cost/benefit analyses a «doing nothing alternative» is defined. This is instrumental and fully relevant when assessing roadprojects etc. But when landuse is taken into consideration a longer term perspective is called for and it is necessary to make a choice between the one or the other directions of development regarding population growth, working places, where to develope residential areas etc. Hence, a «doing nothing alternative» is in a way non-existent. But a reference alternative is needed for a systematic comparison between alternatives, and this alternative should possibly reflect a trend alternative.

Cause - effect chain
The question is how far in the cause - effect chain the assessments should go in practical planning. For instance, if a business moves out of city center to the periphery, the immediate effect is related to the impacts of this decision. But subsequently some other private or public activity is likely to take over the land and buildings in the city center, and the question is what is the impact of this. And so on. The key issue is that the analysis is to clarify the **differences** between two situations or alternatives, and therefore in principle we are searhing for the **end impacts**.

Premises regarding land consumption per dwelling, number of dwellings and number of persons
To make comparisons between alternatives, it is important to set identical premises for the alternatives. In ordinary transportation plans the above premises can be set identical. But taking landuse measures into consideration, the planning issue in focus is often to alter for instance the land consumption per dwelling, and hence it is meaningless to set identical premises. Hence, the alternatives will not include the same number of dwellings or the same number of persons, and this is rather awkard in a planning situation.

Calculating the net present value
As mentioned above, to calculate the benefits by calculating the differences between the before and the after situation is methologically wrong if for instance cardrivers voluntarily transfer to public transport. In coordinated landuse and transport planning in cities this transfer is a key and main aim. To keep track of the cost/benefit components becomes more complicated and there is a need for standarized calculations.

Calculation of cost/benefit ratio
In economic analyses there is a discussion what figure to be put as denominator in the equation. Taking landuse masures into consideration the investment and operation costs shall include dwellings, industrial buildings etc., and in that case the private sector

investments and operation costs will far exceed the public sector costs. The question becomes whether or not, and in case how, the private sector costs shall be included in the denominator.

Time costs for pedestrians and cyclists

Time costs for pedestrians and cyclists are not included in monetary terms in the Handbook from the Road Administration. If a measure leads to more pedestrians and cyclists, and these travellers experience a reduction in time consumption, this benefit should be added as well as the benefits for new pedestrians/cyclists.

Pricing of land

The coordinated landuse and transport planning implies that the planners and decision makers to a greater extent have to assess the utilization of the land. In this situation the pricing of land becomes important to sort out since this cost component may be quite significant.

Consensus on pricing

In principle all types of impacts can be priced and a lot of studies are dealing with this. But in decisionmaking processes and for the sake of consistency in planning, it is important to have a consensus on which components to be in monetary terms and to which prices.

Long term assessments and the calculation interest rate

The calculation interest rate is standardized to 7 %. This means that the long term benefits has comparatively low value. The question is whether or not this is giving a fair weight to the long term impacts. For instance, how can the exhaustible natural resources be given proper weight when the problems arise in the next generation? In this context the extreme position could be to use 0 %. Something in between is maybe more relevant.

Distributional effects

Assessing the impacts of landuse and transport measures, some impacts do not have a welfare economic impact, but only a distributional effect. But nevertheless, this distributional effect is **politically** very important and will in many cases override the results from the cost/benefit analysis.

Some main examples are:

- A realignment of a road may imply that the shops along the old road have to close while new shops will be established along the new road, maybe in the neighbouring municipality
- The neighbouring municipalities may gain or loose taxpayers depending on the landuse decisions and hence on where the major development actually is coming about
- In public transport the ticket costs and the income for the transport company is balanced out. But to the decisionmakers it is of importance to know who is benefitting and who is not.

So, although these elements are not to be calculated as part of the cost/benefit analysis, the weight of the argument in decisionmaking processes is not to be forgotten.

6 CONCLUSIVE REMARKS

The overall objective of coordinated landuse and transport planning is to contribute to a global reduction of pollution and energy consumption.

The preliminary study indicates clearly that if landuse impacts are properly included in the cost/benefit calculation, the assessments may bring forward overwhelming and heavy arguments in favour of coordinated landuse and transport planning and the planning principles inherent. This is particularly so if the long term perspective is applied.

Yet, the decision makers may override the conclusions from the cost/benefit analysis and the impact assessments, because some crucial points may not be properly argued and given weight. In Norway the following arguments tend to be given heavy weight among decision makers:

- The distribution effects
- The standard of dwellings
- The conservation of agricultural land

So a major challenge seems to be: How can the decision makers of today give proper weight to the benefits of the future generations?

Session 4. Megacities: Solutions to the transport and air pollution problems as a precondition for economic development

Chairman:
Tore Nilsson, Saga Petroleum, Norway

URBAN AIR POLLUTION, STUDY OF MEXICO CITY

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1 INTRODUCTION

The Metropolitan Area of Mexico City (MAMC) is an outstanding case of a fast urban development with lagging, and thus insufficient, massive transportation facilities. This has given rise to a distorted transportation system that accounts for most of the air pollution problem of the city and constitutes a drag on economic development.

In this paper, we first describe the MAMC geographical conditions, its growth in physical and economic terms, its transportation system, the ensuing air pollution problems together with some of the mitigation actions undertaken (this has been described in more detail in Bauer 1995a and Bauer 1995b, although here some of the information has been updated). Afterwards the results of a survey of the displacements of individuals within the city and the time spent on these are presented, to then draw some considerations on the negative economic impact it represents.

2 THE METROPOLITAN AREA OF MEXICO CITY

The very rapid economic and population growth of the MAMC concur with special geographic and climatic conditions to give rise to a serious air pollution problem, both of organic and inorganic origin. It is the country's urban area where the environmental impact from the use of hydrocarbon derived products is most critical.

The city is situated in the southern part of a plateau at an altitude of 2 240 m above sea level, surrounded by over 3 000 m high mountains on all sides except the north, which is the direction from where the usually moderate winds (less than 5 m/s) predominantly blow. Its climate is temperate. Winter is characterized by the absence of winds, stationary masses of cold air and almost daily thermal inversions. Over the year there occur on the average 18 thermal inversions per month, that break after 7 a.m. in the summer and after 10 a.m. in winter.

The MAMC extends politically over the Federal District (D.F. for the name in Spanish) and 28 municipalities of the State of Mexico (E.M.), that account for an area of 4605 km^2. The city itself covers a continuos surface of over 1 400 km^2, many previously separated towns having been engulfed by its expansion. Indeed, its population has grown from 1.7 million in 1947 to over 16 million at present (over 8 million in D.F. and about 9 million in E.M.), which is close to 20 percent of the country's total. This is the result of both a high birth rate and the rural to urban migration. Another contributing factor is the fact that the Federal Government is located there, in an effectively very centralized structure for the country, both politically and administratively.

The MAMC accounts for 36 percent of the country's gross domestic product (GDP). It houses 37 000 industries, equivalent to 26.4 percent of the total; in terms of heavy and medium industries the percentage is 31 percent.

The consumption of commercial energy reaches 25 percent of the national total, and is constituted of oil products and natural gas (82%) and electricity (18%). Figure 1 exhibits the distribution by sector and fuels of the mid 1993-mid 1994 average daily 43.8 million liters hydrocarbons consumption, given in equivalent liters of gasoline. It is seen that transport is the main consumer, with 56 percent of the total. Gasolines, leaded and unleaded, account for 75 percent of the transport fuels, followed by regular (0.5% sulphur) and desulfurated (less than 0.05% sulphur) diesel, and a minimal amount of LPG.

Because of the altitude, the air oxygen content is 23 percent less than at sea level, making the internal combustion processes less efficient and thus emitting more pollutants. Also, been located at a northern latitude of 19 degrees, the MAMC receives a considerable amount of solar radiation that favours the formation of ozone.

3 TRANSPORT AND THE ENVIRONMENT IN THE MAMC

A survey carried by INEGI (the National Institute for Statistics, Geography and Informatics) in 1994, of the origin-destination of the displacements of people in the MAMC, gave a total of 20.6 million trips per day, defined as the trip for going either to work, or to school, or to shop, etc. and the trip back home. As many of these displacements employ more than one means of transportation, the number of trip segments was estimated at about 30 million by the Commission of Urban Transit that convened in 1995 to propose a new law of transportation for the Federal District (other estimates put this figure as high as 40 million; these attempt to take into account, for example, that subway riders may use several lines in one trip). According to INEGI 1994, the distribution by carrier mode of these trip segments was as follows: small buses called "microbus" and vans, 55 percent; private automobiles, 16.7 percent; Metro, 13.6 percent; D.F. municipal buses, 6.8 percent; suburban buses (State of Mexico), 3.4 percent; taxis, 2.5 percent; trolleybus, 0.7 percent; bicycles, 0.7 percent; motorcycles, 0.1 percent. Thus, 85 percent of the trip segments imply the use of an internal combustion vehicle.

The vehicle fleet is around three million, of which private automobiles account for 71 percent, or equivalently, 95 percent of the passenger vehicles. These, however, account for only 16.7 percent of the estimated 30 million trip segments per day, up from 19 million in 1982. The average occupation is barely two persons per trip segment.

On the other hand, the 61 000 microbuses and vans that supply 55 percent of the transportation needs, although serving along fixed routes agreed with the city government, tend to circulate all day independently of the demand. Being privately owned, they compete for passengers increasing considerably the circulation problems. The same applies to the 51 000 taxis as very few operate from taxi stands. The municipal bus service, --that had about 2 800 units and is currently in the process of being privatized-- contributes also, as well as the 2'900 suburban buses. Consequently, the average speed of the motor vehicles in most of the city is low, 36 km/h at best but very often as low as 13 km/h during peak hours.

The average age of the internal combustion vehicle fleet is about ten years. Thus a considerable fraction of the vehicles does not have catalytic converters.

The subway system --the Metro--, initiated in 1966, consists at present of ten lines for a total length of 178 km with 154 stations. It is intensively used, transporting 4.5 million passengers on work days, but still handles only 13.6 percent of the trip segments. It is however confined to the D.F. portion of the MAMC.

As a consequence of the above, transport is the main responsible for air pollution in the MAMC, as can be seen from Table 1 and Figure 2 (SEMARNAP 1996). In summary, this is due mainly to a constantly increasing demand for transport of people and goods, to a deficit in massive transportation facilities (Metro), to a disorganised bus and taxi service, and to the excessive and inefficient use of private automobiles. Transport of goods -predominantly with trucks and vans- includes not only the supplies to the city, the exports from it and the internal deliveries, but also the transport of goods between other regions that cross Mexico City as there are no complete by-passes available yet.

4 AIR POLLUTION: THE POLICIES

In 1990, a Comprehensive Urban Air Pollution Control Plan was issued, with 42 concrete actions aimed at:

- cleaner fuels;
- expansion of the public transportation system;
- control of vehicular emissions;
- control of industrial emissions including power plants;
- reforestation;
- research, education and communication.

a) Cleaner fuels

The need for cleaner fuels was reinforced by legislation that established limits on the emissions of SO_2, NO_x, CO and particulates from the use of fossil fuels. These limits vary according to the classification of the different geographical regions as "critical", "of socio-political sensitivity" or "of potential restriction". Preliminary levels are in effect, with more strict ones being mandatory from 1998 on. The MAMC is considered critical.

Consequently PEMEX, the state oil company that by law is the sole supplier of oil products, directed its investment policy to modify its refining processes towards the production of better quality fuels, rather than to increase its capacity. A so called "ecological package" was structured in 1990, involving twenty plants, with an initial investment of 1 200 million dollars. The priorities have centered on reducing the sulphur content, on producing increasing amounts of unleaded gasoline and on reformulating with the addition of oxygenate compounds. In addition the lead content in leaded gasoline has been reduced by 92 percent.

At present 46% of the gasoline marketed is unleaded. Leaded gasoline is expected to be phased out by the year 2000. PEMEX started providing the MAMC with oxygenated gasolines, especially in the winter, on the basis of imports of MTBE. Manufacturing plants of MTBE and TAME, with a capacity of 90 thousand barrels per year, are scheduled to begin production shortly.

Beginning in 1990, diesel with a 0.5 percent sulphur content was provided to the MAMC's industry and transport; since 1993, diesel for transport has less than 0.05 percent.

b) Control of vehicular emissions

Catalytic converters in the exhaust system were made compulsory in all new vehicles sold from 1991 on; concurrently, unleaded gasoline was introduced into the market.

As can be seen in Figure 3, which gives the results of two compaigns (Frebuary 1991 and October 1994) of remote sensing of emissions from cars in several locations in the city, the effect of catalytic converters is striking. However, approximately 45 percent of the vehicle park is over ten years old (SEMARNAP 1996). The phasing out of models prior to 1991 will take some years yet.

A twice a year compulsory smog check verification of the level of CO, unburnt HC, $CO+CO_2$ and O_2 (dilution factor) exhaust emissions -using BAR-90 analysers- has been enforced, and can be considered successful in spite of some technical and administrative control problems. Currently it is estimated that the remaining problem is non exhaust HC leaks.

A one day per week restriction to circulate programme was instituted in 1991, intended to reduce by 20 percent the circulation of private automobiles on work days. Announced as a temporary measure, it was however made permanent and therefor induced the acquisition by many of a second car, usually an older one. Thus the impact of this measure is questionable. No change in the overall trend in gasoline consumption was noticed.

Finally, the use of LPG was promoted in public transport and delivery trucks; an estimated 17 000 vehicles were converted. However, the programme is now on hold due to several severe accidents with unsupervised converted units by individuals who wanted to profit from the subsidized low price of LPG for household consumption.

c) Expansion of the public transportation system

Construction of subway lines within the D.F. continues. A new 20 km line was completed in 1994. The current projects will add 52 km by the year 2003. Nevertheless, the system lags considerably behind its original plan of 600 km by the year 2000, or the revised one of 315 km by the year 2010. There are in addition two elevated train projects, that however have encountered public opposition.

During the past administration, the number of licenses granted for privately owned microbuses and taxis was increased considerably, conditioned to operate with recent models equipped with catalytic converters. This was seen as a measure to attract private capital into collective urban transportation, relieving the chronic shortage and encouraging its use, in addition to providing (self-) employment in a period of economic crisis. This it achieved. However, no reduction in private automobile use was noticed, but there was certainly an increase in traffic congestion with a negative impact on air pollution. A very strong growth in the consumption of gasoline was noticed. As pointed above, these independently owned vehicles tend to circulate all day, whatever the demand; they cannot be managed as a bus line, that can be programmed to field more buses during rush hours than in the rest of the day and on weekends.

d) The Federal District municipal bus service is been reorganized, and the private sector will be able to participate. One of the purposes is to substitute the microbuses with larger capacity vehicles. It is estimated that 10 000 regular buses could provide the same transportation as 40 000 microbuses.

e) Research: the Mexico City Air Quality Research Initiative (MARI)

Although not the first research effort, MARI has been the largest, systematic, interdisciplinary project instituted to deal with the air pollution in the MAMC. As a joint project of the Instituto Mexicano del Petróleo (Mexican Petroleum Institute) and the Los Alamos National Laboratory, with the collaboration of over twenty institutions in Mexico and the US, it involves the areas of modelling and simulation, measurements and characterizations and evaluation of strategies, to integrate a systems approach to the problem.

The modelling and simulation task focused primarily on adapting existing codes for meteorology and dispersion --provided by LANL--, and air chemistry to the unique conditions existing in Mexico City. Dispersion and meteorological codes were used to describe from first principles daily wind patterns and dispersion of pollutants. Detailed 3-D airshed modelling of ozone formation was done using the most advanced model. The applicability of the modified codes was verified by comparing the codes' results with extensive data obtained during specific MARI measuring campaigns and the information from the existing network of meteorological and pollutant monitoring stations in Mexico City, that also provided the initial and boundary conditions.

The measurement task included three field campaigns. The largest ever carried in the city for environmental purposes took place in February 1991 over three weeks and fourteen locations. Fourteen different measurement techniques were applied to observe the atmosphere during that period. One of them remotely measured the emissions from vehicles circulating in the streets, recording also the make and model year (Figure 3). It was used by the strategies' evaluation group to determine the effect of removing the worst polluting vehicles from circulation and for estimating the effect of requiring catalytic converters on new vehicles.

Indeed, the strategic evaluation task was intended to provide the link between modelling and the people responsible for developing the policies to combat air pollution in the MAMC. It involved developing a methodology of analysis of different strategies. In particular, the utility of the entire simulation and decision analysis system created by MARI, was demonstrated by developing, modelling and ranking air quality control strategies defined as different subsets chosen from thirty seven control options, involving control or modification of stationary, mobile and natural emission sources. They ranged from gasoline reformulation to reforestation, from improving power plants to control of evaporative emissions in solvent applications (IMP/LA 1994).

Perhaps one of the most illustrative applications of the modelling tool was to analyse the often stated proposal to cut a notch in the mountains in the Southwest corner of the valley as a means to improve the ventilation of the city air. The computer model allowed to do this by simply modifying the corresponding database file until a significant air flow change is gained. It showed that at least a 250 m high and one kilometer wide notch would have to be opened. The cost of removing the tons of earth and rocks was exhibited to be beyond the very limited potential benefit derived, without even taking into account the pollution that would arise from dust and the unforeseen impact on the local ecology.

Also by modelling the scenario in which no pollution control measures are taken, MARI provided the Mexican authorities with a picture of how much more acute the situation might have been, had they not implemented the regulatory measures taken to date.

The bilateral technical team of MARI is already involved in another large scale project addressing the second largest problem in the MAMC, that is, the suspended particulate matter, in particular PM10, and secondary aerosols, well known threat to human health and the main cause of the visibility impairment associated with smog in urban areas.

5 AIR POLLUTION: THE EVOLUTION

Under the impact of policies and actions implemented since 1990, air pollution in the MAMC has evolved from a third world type pollution (i.e. SO_2, CO, Pb and particulate matter from dirty combustion processes and fuels) to one more characteristic of a developed country, namely photochemical pollution.

This evolution is substantiated by an extensive monitoring network. The detection of total suspended particles (TSP) and heavy metals in the atmosphere was initiated in 1976 with stations operated manually. In 1986 an automatic network of 25 stations started registering throughout the city levels of ozone, CO, NO_2 and SO_2, and TSP, in addition to the following meteorological parameters: wind velocity and direction, temperature, humidity, height of the inversion layer. In 1993, seven new complete stations were added, mainly to monitor suburban areas not covered by the previous network. Also some automatic monitors for particles with diameters below 10 micrometers, or PM10, have been added; they take readings every hour.

Table 2 shows the standards for each pollutant, the number of monitors that detect them and their operating principle. Particle sampling is carried out during a 24 hour period every six days, or every three days in the winter.

Lead, SO_2, NO_2 and CO have been brought down to international accepted levels, as can be seen in Figures 4 and 5. On the other hand, ozone has been increasing, although the introduction of reformulated unleaded gasoline seems to moderate the trend (Figure 6).

6 ECONOMIC IMPACT OF DISPLACEMENT PATTERNS

The air pollution problem of the MAMC, due to a large extent to the transport sector, has already claimed large expenditures, diverting resources from other development needs. An example of this is the closure of the refinery that had been engulfed by the growing city, at a cost of 500 million dollars. Another is the ecological package of PEMEX that has postponed the increase of its refining capacity, which may mean a necessity to import significant quantities of fuels if the economic recovery is stronger than currently anticipated (Bauer 1996).

The deficiency of the transport system has additional economic impacts, deriving from the displacement patterns of individuals and the time employed in the displacements. The survey quoted above (INEGI 1994) provides detailed information on these subjects.

Going to work is the main reason for displacement (40.5%), followed by going to school (26.1%). It is found also that the work trips take longer in general than the rest: 34.7 percent up to 30 minutes, 37.5 percent from 30 to 60 minutes, 17.2 percent from 60 to 90 minutes and the remaining 10.5 percent, over 90 minutes. Table 3 shows the average durations of the diverse trips according to destination. The average value is 42.67 minutes.

Table 4 shows the average duration of trips according to transport mode. Displacement on public transports takes on average 43.5 percent more time than on private automobile. If the displacement uses both means of transportation, the time increase is 127 percent.

In general, the average transportation time in the MAMC exceeds the 35 minute optimal top benchmark (Navarro 1996). This implies a loss of productive time of about 2.6 million work hours per day. Using the value of 3.5 times the minimum salary of three dollars per day as average income of the work force, the economic cost of the waisted time amounts to US$ 6.2 million per day, or US$ 2 263 million per year. Ninety percent of this loss is associated with the displacements to work.

7 CONCLUSION

The transport of people and goods in the MAMC is the main source of air pollution in the MAMC, as it is done almost completely on internal combustion vehicles. The production of cleaner reformulated fuels, the implementing of compulsory emission verifications and the introduction of catalytic converters have already had positive impacts, as undoubtively has the existence of a subway system. On the other hand, economic and politically expedient measures like the promotion of microbuses and taxis, have counteracted to a certain extent the benefits obtained. The MAMC still has a serious air pollution problem in terms of aerosols and ozone.

The delay in providing a clean massive transportation system, especially extending the Metro to the heavily populated sections of the MAMC in the State of Mexico, results in an excessive use of automobiles and buses. The vehicular traffic is thus slow, with considerable congestions during peak hours. A crude estimate of the economic cost of this has been provided. However there are many other externalities that are just beginning to be assessed and quantified, such as health effects. The road to a clean city is long and costly, but is been taken.

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Table 1

1994 MAMC Emission Inventory
(tonne/year)

Sector	PST	SO_2	CO	NOx	HC	Total	%
	Tonne/year						
Industry	6 358	26 051	8 696	31 520	33 099	105 724	3
Services	1 077	7 217	948	5 339	398 433	413 014	10
Transport	18 842	12 200	2 348 497	91 787	555 319	3 026 645	75
Vegetation & soils	425 337	0	0	0	38 909	464 246	12
Total	451 614	45 468	2 358 141	128 646	1 025 760	4 009 629	100

Source: SEMARNAP 1996

Table 2

The MCMA atmospheric monitoring network

Pollutant/ Standard	Monitors	Operating principle
Ozone (O3) 0.11 ppm hourly average	19	UV photometry
Carbon mnoxide (CO) 13 ppm eight hour average	26	non-dispersive infrared (NDIR)
Sulphur dioxide 0.13 ppm 24 hour average	26	pulsating fluorescence
Nitrogen oxides 0.21 ppm hourly average	19	chemilumuniscence
PM10 150 ug/m3 24 hour average	15	gravimetry
PST 150 ug/m3 24 hour average	18	gravimetry
Lead 1.5 ug/m3 3 month average	10	atomic absortion spectrophotometry

Table 3

Average duration of trips by residents in the MAMC according to purpose
(minutes)

Purpose	MAMC	D. F.	E. M.
Home-work	51.12	50.66	54.80
Home-school	36093	36.72	37.31
Home-other	35.67	34.59	37.88
With origin and destination other than home	35.63	35.06	38.83
Total	42.67	41.50	45.06

Source: Elaborated on the basis of INEGI 1994.

Table 4

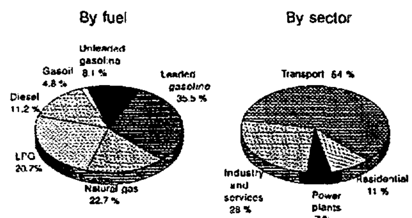
Average duration of trips according to transport mode
(minutes)

Transport mode	MAMC	D. F.	E. M.
Total	46.0	40.6	53.5
Public	49.8	43.9	57.4
Privated	34.7	32.0	39.4
Mixed	78.7	74.4	84.7

Note: Does not include trips by minors (< 6 years)
Source: INEGI 1995.

Figure 1

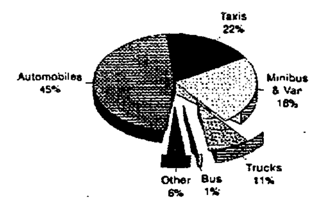
Fuel Consumption in the Valley of Mexico (1994)



Source: PEMEX 1995

Figure 2

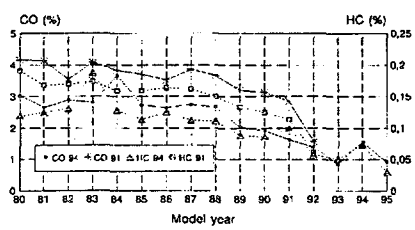
1994 MAMC Emissions' Inventory
- contribution of transport by type of vehicle -



Source: SEMARNAP 1996

Figure 3

Tailpipe emissions in mexico City



Source: IMP: remote sensing campaigns on February 1991 and October 1994

Figure 4

Lead emissions and concentrations

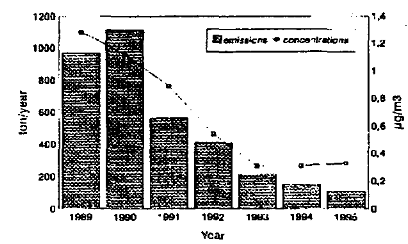
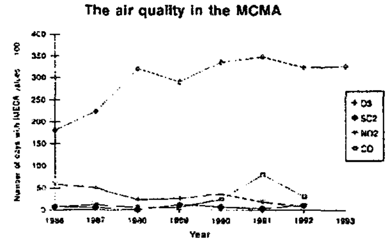


Figure 5

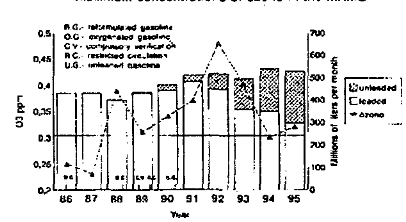
The air quality in the MCMA



Note: IMECA (Mexican Air Quality Index) = 100 corresponds to the acceptable standard

Figure 6

Average monthly gasoline consumption and maximum concentrations of ozone in the MAMC



TRANSPORTATION IN MEGACITIES: GROWING DEMAND AND EMISSIONS - A COMPARATIVE ANALYSIS OF SUSTAINABILITY IN DEVELOPED AND DEVELOPING ECONOMIES

By Ranjan Kumar Bose, Tata Energy Research Institute, India

1 INTRODUCTION

The urban transport problem is fundamentally similar in all large cities. The basic causes are the same and so are many of the consequences, although there are some differences in degree between cities in developed and developing economies. Transport systems in large cities of the developing economies as compared to the developed economies are characterized by: (a) much lower level of motorization[1] of transport and travel requirement, (b) more rapid rates of economic growth, population growth, and the growth in number of motor vehicles, (c) higher population densities, (d) much lower per capita energy consumption and emissions of carbon dioxide, (e) reduced access to capital and to advanced environmental technologies. Despite greater level of vehicle ownership, higher rate of trip generation and increased use of energy on a per capita basis in cities of developed countries, it is the large cities in the developing countries that, in general suffer most from growing traffic congestion, road accidents, energy use and emissions, overcrowding of public transport, and poor conditions for pedestrians and cyclists.

2 CROSS PERSPECTIVE

Unfortunately, no comparative studies are available between cities in developed and developing countries with respect to transportation energy demand and emissions. Whatever research is done in this area, looks at either comparison of cities among developed countries or among developing countries. The most comprehensive study by *Newman and Kenworthy* examines 60 cities from over 30 developed countries patterns of urban land use, travel pattern, and transport energy use (*1989*).[2] In developing countries, a new approach to planning called integrated transport planning was carried out in 4 Asian cities by *Zegras and Birk* (*1994*).[3] *Walsh* has summarized motorization and its adverse impact on air pollution based on 7 cities case study all in developing countries (*1994*).[4] *Shimazaki, Hokao and Mohammed* developed a graphical model that analyzes the modal choice pattern in 19 Asian cities (*1994*).[5]

In this paper, the efforts underway in developed and developing country cities to bring about sustainable transportation system is illustrated, through the use of case studies of two megacities -- Los Angeles and Delhi. Such a cross-comparative study would facilitate formulating a set of policy measures and implementing mechanisms on the basis of experience gathered from these cities, and for megacities in general. The goal of this comparative assessment is to identify options for cities of various levels of infrastructure development that would enable them to meet transport needs while minimizing environmental degradation, oil consumption, and traffic congestion. But more than that the study is expected to find out what implications the international comparisons have for future urban transport policy in developed and developing countries. Finally, the paper analyzes the sustainability issue of transport policy for developed and developing economies, by drawing lessons learned from the two cases.

3 LOS ANGELES

The Los Angeles (LA) region has over 15 million residents, covering approximately 97,280 square kilometre, encompassing six counties (LA, Orange, Riverside, San Bernardino, Ventura and Imperial) and 188 incorporated cities in Southern California. The region is the second largest in the United States behind the New York region and encompasses nearly half the State's (California) population. LA has two convenient metropolitan area definitions - the urbanized area and the LA/Long Beach Standard Metropolitan Statistical Area (SMSA), the latter of which corresponds to LA County. Unlike the other U.S. cities where the urbanized area and SMSA populations correspond reasonably well, there is quite a large difference (2 million people) between the Urbanized area and the SMSA of LA. The analysis of the data presented in this section is for the entire LA region in Southern California, with particular emphasis on the Los Angeles (LA) County.

3.1 Population

In 1990, there were 14.6 million inhabitants in the region, 3 million more than in 1980. Half of this increase was due to an influx of migrants, and half to babies born to residents of the region. Nearly 60% of the population in the region during 1990 was concentrated in the LA County (8.86 million). By 2015, the region is expected to contain 22 million inhabitants with about 54% of its people residing in the LA County.

3.2 Growth in motorisation

LA region is well known around the world as an automobile-oriented low density community. While the total number of vehicles registered in the LA County increased almost twice over the last four decades (from 3.1 million in 1960 to 6.1 million in 1990), the share of vehicles registered in the LA County with respect to the Southern California region, declined (from 79% in 1960 to 59% in 1990). This suggests that though the registration of motor vehicles in LA County increased in absolute value, but decreased in real value. During the last decade (1980-90) in the LA County, while the annual registration of passenger car and truck went up by 1.75% and 4.45% annually, that of motor cycle declined by 2.65%. The number of vehicles per inhabitant (vehicle ownership pattern) in LA have increased since 1960 and is now probably the highest in the United states. In 1990, for every 1000 people, there were 544 cars, 17 motor cycles and 690 total vehicles (which include trucks).

Currently, public transportation in the Southern California region is operated directly or under contract by about 17 separate public agencies. Regional public transportation improvements are currently directed toward the implementation of the rail programmes designed to create the infrastructure which supports service on high-and-medium capacity corridors.

3.3 Travel pattern

Approximately 49 million trips are generated daily (in a typical weekday) throughout the LA region. Over 96% of the travel demand is met by personal automobiles. The highest trip generating traffic subregion is the LA County (11.5 million trips daily).[6] Nearly 13 million trips daily (27%) are work related. People in the region relies on Single Occupancy Vehicles (SOVs) for a majority of all trips. In LA County, there has been an increasing use of SOVs between 1980 and 1990, while the share of commuters who depend on car pool and also on mass transit has declined.

3.4 Energy demand

Transport sector in the LA region currently consumes five types of energy. These include -- gasoline, diesel, M85,[7] CNG and electricity. Total energy demand in the region is expected to increase marginally from 20 million tonnes of oil equivalent (mtoe) in 1995 to 23 mtoe in 2010, indicating an annual growth rate of 0.94% (Figure 1).[8]

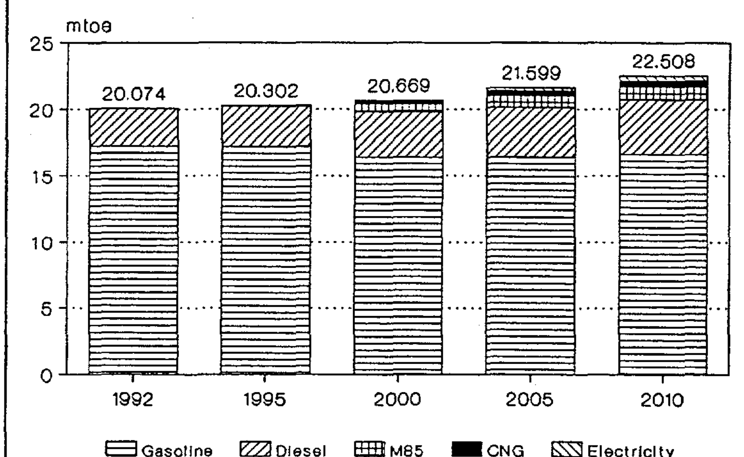


Fig.1. Transportation energy demand in the Los Angeles region

During the next fifteen year period (1995-2010), gasoline demand is expected to go down by 3.2% (from 17.22 million tonnes of oil equivalent (mtoe) to 16.66 mtoe), while demand for all other fuels is likely to increase. Diesel demand is likely to go up by 35% (from 2.99 mtoe to 4.04 mtoe); M85 by over 15 times (from 0.06 mtoe to 0.98 mtoe); CNG demand by nearly 23 times (from 0.02 mtoe to 0.47 mtoe) and electricity demand by 90 times -- from 46 gWh (or 0.004 mtoe) to 4239 gWh (or 0.36 mtoe). This clearly indicates, in the forthcoming years, the LA region will have more and more penetration of new and alternate clean fuel vehicles. Also, the usage of mass transit run on diesel is expected to increase.

3.5 Emissions and air quality

LA suffers the worst air pollution in the United States, and the primary source is automobiles.[9] Technological gains have been partially offset by population growth and by increases in vehicle miles travelled (VMT).

Contrary to popular belief, air quality is not getting worse in LA, it is getting better. The most significant automobile emissions in the LA region are Reactive Organic Gases (ROG), NO_x, and CO. Table 1 presents the change in emission of principal pollutants in the region between 1987 and 2010 under two cases -- with and without the Air Quality Management Plan (AQMP) in the LA basin.[10]

In 1987, autos accounted for nearly 44% of ROG, 61% NO_x, 88% CO. In the absence of Air Quality Management Plan (AQMP) in the LA basin, emissions of these pollutants fell after 1979 and will continue to fall through 2010 (by 18.2% for ROG from 1987, by 20.6% for NO_x, and by 45.7% for CO). This reflects the effectiveness of emission controls already in place. This trend is not observed, however, for pollutants little caused by automobiles (5%) like PM_{10} (particulate matter with a diameter of ten micrometers or less). PM_{10} emissions is expected to increase by 46.6%, while SO_2 emissions is likely to decline by only 6.5%, between 1987 and 2010 (Table 1).

In the absence of AQMP, current NO_x emissions are little higher than the federal standard (for NO_2, the federal standard is 100 $\mu g/m^3$, yearly average) and is expected to be within limits by 2010; the region would remain in compliance with respect to SO_x (for SO_2 the federal standard is 365 $\mu g/m^3$, daily average). O_3 remains the major problem with maximum concentrations about 2.7 times the federal standard and with little improvement by 2010. CO, now more than double the federal standard (10 milligrams/m^3, 8 hourly average) improves through to 2010, particularly with the adoption of stricter California Air Resources Board regulations in June 1990. The PM_{10} situation actually deteriorates from 1.8 times the federal standard (50 $\mu g/m^3$, daily average) now to 2.7 times the standard, but it is not affected much by transportation, except indirectly through road construction. These considerations suggest that there is a need for AQMP if the region is ever going to comply with federal standards.

Table 1 also gives the projected emissions in presence of AQMP. As can be noted from the same table, if fully implemented, AQMP would bring about a dramatic reduction in emissions, ranging from 46% to 84%.

Table 1. Baseline emissions and emissions under AQMP, total and mobile on-road vehicles, 1987 and 2010 (tons/day)

	ROG	NO_x	SO_x	CO	PM_{10}
Total emissions, 1987 (t/d)	1379	1098	124	4972	1072
Transport emissions share, 1987 (%)	43.9	60.5	25.8	87.8	4.9
Baseline emissions, 2010					
Total emissions, 2010 (t/d)	1128	872	116	2698	1572
Emissions share by on-road, 2010 (%)	26.2	56.7	25.0	67.9	3.6
Change in emission share, 1987-2010 (%)					
• total emissions	-18.2	-20.6	-6.5	-45.7	46.6
• transport emissions	-51.1	-25.6	-9.4	-58.0	5.7
Emissions with AQMP, 2010					
Total emissions, 2010 (t/d)	178	335	36	1301	854
Total emissions reductions w.r.t baseline emissions, 2010 (t/d)	950	537	80	1397	718
Change in total emissions w.r.t baseline emissions, 2010 (%)	-84.2	-61.6	-69.0	-51.8	-45.7
Total emissions from mobile on-road vehicles, 2010	219	287	10	1083	18
Change in emissions w.r.t baseline emissions, 2010 (%)	-26.0	-41.9	-65.5	-40.9	-67.9

4 DELHI

Delhi, an ancient and historic city of India, is situated on the banks of the river Yamuna, with greatest east-west length being 51.9 km and north-south width, 48.48 km. The city with a total area of 635 square km, is located between latitude 28°24′17″N - 28°53′00″N and longitude 77°50′24″E - 77°20′37″E and at 216 metres above mean sea level. To the west of Delhi is the Great Indian Desert (Thar Desert of Rajasthan), to the south, the Central hot plains and to the north and east, cooler hilly region.

4.1 Population

Delhi, the third largest city of India, has witnessed phenomenal population growth during the past few decades. From a population of 0.4 million in 1901, its population has grown to 9.4 million in 1991. During the 1981-91 decade, its population grew by 3.2 million. If this growth rate continues in the present decade (1991-2001), Delhi will have 14.1 million people by the year 2001.

4.2 Growth in motorisation

The city of Delhi has been experiencing an exponential growth in motorized vehicles - with an average growth rate of 18.1% per annum between 1985 and 1989. The growth of vehicles in Delhi has been faster than the population. Its urban population which was 3.65 million in 1971 increased to 5.73 million in 1981 and 8.47 million in 1991 indicating a more than two folds increase in the last two decades. While the corresponding figures of the increase in vehicle population accounts for 0.21 million, 0.57 million and 2 million respectively, which indicates more than nine times increase in the last two decades.

Vehicle ownership per thousand population shows that the two wheelers have increased by more than three and a half times from 1973 to 1989 (35 to 128), while during the same period cars and jeeps have gone up almost double (17 to 32).

There has been a sharp change in vehicle composition in Delhi in the last two decades. The two wheelers have become the most popular mode of personal transport and their number is rising rapidly. Of the total vehicles in 1971, nearly 53% were two wheelers, and this rose to 68% in 1993. The corresponding figures for car and jeep were 30% and 22% respectively. The change in vehicle mix was more gradual between 1988 and 1993. Among the public transport vehicles, there are over 20,000 buses, 70,000 autorickshaws (or three-wheelers), and 10,500 taxis. In addition to these passenger vehicles, Delhi has about 0.11 million goods vehicles like, trucks and vans.

4.3 Travel pattern

While an estimated 12.7 million trips were made daily in 1990, the annual growth rate of urban travel demand is 9.5% in Delhi.[11] About 43% of all trips were for work related and 31% for educational during 1981.[12] About 75% of the educational trips, 25% of the work trips and about 50% of the total person trips in Delhi are walk trips.[13] Bus caters to over 32.5% of the total trips in Delhi, while 15.4% is catered by private vehicles, which include cars and motorcycles/scooters. Over 2% of trips are catered by autorickshaws and bicycles.

4.4 Energy demand

The two major fuels used for the propulsion of motor vehicles in Delhi are gasoline and diesel. Over 90% of the registered vehicles in Delhi (2.2 million in 1995) run on gasoline.[14]

The Long Range Energy Alternatives Planning (LEAP) system model is used to estimate energy demand in the transport sector for the next fifteen years (1995-2010).[15] The LEAP model is run under four alternative scenarios to study the impact of different urban transport policy initiatives that would reduce total energy requirement and emissions in the transport sector of Delhi.[16] A brief description of each scenario is given below:

Business-as-usual scenario (BAU): This scenario assumes, the present trends of vehicular growth in Delhi will continue, and fuel efficiency norms, modal split pattern and occupancy levels will remain unchanged till 2009/10 from 1990/91 (base year) observations. BAU is also referred here as "present trends" scenario.

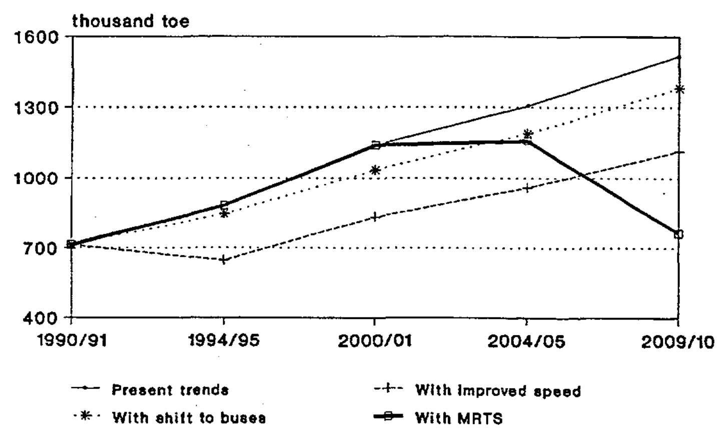
Improvement in the vehicular speed: This scenario assumes, through appropriate traffic management measures, travel speed on Delhi roads will increase from an average present speed of 20 km/h to 40 km/h (energy efficient speed) by 1994/95 for all types of vehicles. With this, fuel efficiency will improve for each mode of passenger vehicles.

Increase the share of buses: This scenario assumes, through appropriate transport policy interventions, there will be an increase in the share of buses during 2000/10 to the level observed in 1981/82. In other words, modal split during 2000/01 will be brought to the same level as was the case in Delhi during 1981/82. This would mean, a large portion of the passenger travel demand in Delhi will be met by bus services thereby it would bring overall efficiency of passenger movement. The extent of total petroleum demand will therefore reduce in this scenario along with reductions in emission levels.

Introduce mass rapid transit system (MRTS): This scenario assumes, the integrated multi-modal MRTS is introduced in this scenario by 2004/05 and continues to grow further in phases till the full capacity of MRTS is achieved in 2009/10.[17] It is estimated that the per cent share between roadways and railways for 2005 and 2010 would be 87.60:12.40 and 74.56:25.44 respectively.[18] This would mean that by 2004/05, a portion of passenger road transport will be substituted by railway and would save petroleum demand over future years.

Figure 2 summarizes the result. Consumption of gasoline and diesel together to meet passenger travel requirement in Delhi is estimated to go up more than double over the next fifteen year period -- from 0.71 mtoe in 1990/91 to 0.88 mtoe in 1994/95 to 1.52 mtoe in 2009/10 -- under BAU scenario. In all other scenarios energy demand is expected to decline in future, with maximum reduction in energy demand is observed with introduction of MRTS in Delhi.

Fig 2. Transport energy demand in Delhi for passenger travel



4.5 Emissions and air quality

Vehicular emissions of CO, HC, Pb, NO_x, SO_2, and TSP (Total Suspended Particulate) are also estimated by the LEAP model under alternative scenarios described earlier (Table 2). The loading of various pollutants in Delhi during 1990/91 is estimated to be CO (179,590 t); HC (73,000 t); Pb (100 t); NO_x (16,120 t); SO_2 (2,270 t) and TSP (360 t) respectively. Gasoline driven vehicles are responsible for as much as 97% of CO and HC loading while the diesel driven vehicles produce the remaining 3%. Gasoline driven vehicles also contribute 32% of the total NO_x emission, and 15% of SO_2 emission. Also, only gasoline vehicles contribute Pb emission. On the other hand, diesel vehicles only contribute TSP (diesel smoke) emission. Considerable reduction in emissions of all pollutants considered is observed during 2009/10, if MRTS gets introduced in Delhi.

Table 2. Annual emissions (in thousand tonnes)

Alternative scenarios	1990/91	1994/95	2000/01	2004/05	2009/10
Present trends					
CO	179.59	222.28	286.33	329.05	382.42
HC	73.00	90.35	116.39	133.75	155.44
Pb	0.10	0.13	0.17	0.19	0.22
NO_x	16.12	19.95	25.70	29.53	34.32
SO_2	2.27	2.81	3.63	4.17	4.84
TSP	0.36	0.45	0.58	0.67	0.77
With improved speed					
CO	179.59	184.21	237.29	272.69	316.92
HC	73.00	76.58	98.64	113.35	131.74
Pb	0.10	0.11	0.14	0.16	0.18
NO_x	16.12	12.88	16.59	19.06	22.16
SO_2	2.27	1.73	2.22	2.55	2.97
TSP	0.36	0.26	0.33	0.38	0.44
With shift to buses					
CO	179.59	203.22	268.22	268.01	311.48
HC	73.00	82.88	94.72	108.85	126.51
Pb	0.10	0.12	0.13	0.15	0.18
NO_x	16.12	19.86	25.42	29.22	33.95
SO_2	2.27	2.86	3.74	4.30	5.00
TSP	0.36	0.46	0.62	0.72	0.83
With MRTS					
CO	179.59	222.28	286.33	288.24	191.62
HC	73.00	90.35	116.39	117.16	79.55
Pb	0.10	0.13	0.17	0.17	0.11
NO_x	16.12	19.95	25.70	25.87	15.99
SO_2	2.27	2.81	3.63	3.65	2.25
TSP	0.36	0.45	0.58	0.58	0.35

5 COMPARATIVE CITY PROFILE

A comparative profile of demography, transportation systems, energy use and emissions of the two megacities -- Los Angeles and Delhi -- during 1990 is presented below:

1) Delhi with nearly 9 million residents is experiencing a rapid growth of population as compared to LA with 15 million people during 1990. The average annual growth rate of population between 1980 and 1990 is 2.4% in LA and 4.7% in Delhi. With the fast growing population in both the cities, the transport needs have also been rising, resulting in an increased demand for public transportation facilities and personal vehicles. Total registered motorized vehicles in LA was 10.5 million in 1990, over five times compared to Delhi. The average annual growth rate of vehicles in both the cities are much faster than population growth (2.7% for LA and 14.4% in Delhi between 1984 and 1990).

2) LA is an automobile oriented low density (149 persons/sq.km in 1990) community with more than 87% of the daily commuters (6.8 million) travel by car. Delhi has over 95 times higher density of population (14313 persons/sq.km in 1990) with 15% of the daily commuters (9.6 million) travel by personalized modes, mainly scooters and motorcycles. The city of Delhi solely depends on buses for mass transport needs.

3) LA has 17 times more cars per 1000 people than Delhi (32 cars per 1000 people). But, ownership of motorized two-wheelers in Delhi (128 scooters/ motorcycles per 1000 people) is 7.5 times higher than in LA. In Delhi, in recent years, the motor vehicle fleet grew by an average 14.4% per year. In contrast, vehicle fleet growth rate in LA in recent years have averaged only 2.7%. This suggests that the high relative growth registered in Delhi is likely continue as a result of currently low levels of per capita vehicle ownership, rising per capita incomes, and growing domestic motor vehicle manufacturing industries.

4) Total per capita vehicle kilometers is nearly 1.8 times higher in LA. In 1990 total per capita motorized travel demand was 16875 kms, whereas in Delhi it was 9234 kms. Over 96% of the travel demand in LA is catered by personal vehicles (86% by cars and 10% by motorcycles). In contrast, more than 72% of the motorized travel is met by bus, and the share of personal vehicles is 25% (9% by cars and 16% by two-wheelers). Hence, LA has a far lower level of dependence on public transport service (825 bus km per person per year). This is over one-eighth the level provided in Delhi (6661 bus km per person).

5) Nearly 49 million trips are generated daily (i.e., each person makes 3.4 trips) in LA, as against 12.7 million trips (i.e., 1.5 per capita daily trip rate) in Delhi. Only 27% of total daily trips are associated with commuting to and from work place in LA, of which over 72% of the trips are on Single Occupancy Vehicles (SOVs), 15% depend on car pool and only 5% use mass transport. In the case of Delhi, about 43% of the total trips are for commuting to and from work place and 31% for education purposes. Over 50% of travel in Delhi is by walking, 32.5% by buses, 9.5% by scooters/motorcycles, 6% by cars and remaining 2% by autorickshaw and bicycles.

6) Transport energy and in particular gasoline use, is a powerful reflection of how much automobile dependence there is in a city. In 1990 the per capita gasoline consumption in LA was 1176 kgoe compared to only 52 kgoe in Delhi. In terms of total per capita energy use (i.e. including diesel) the corresponding figures are 1367 kgoe and 84 kgoe respectively. Such large difference in per capita transport energy consumption is in conformity with the strong negative correlation of urban density with gasoline consumption demonstrated in a research study of thirty-two principal cities of the world.[19]

7) Annual emissions of CO, SO_x, NO_x, and SPM are very large in the LA basin as compared to Delhi. Despite the strict controls in the LA basin, maximum hourly O_3

concentration was 660 μg/m³ in 1990 as against the federal standard of 235 μg/m³ (value not to exceed more than once in a year). But, the local impacts of CO, SPM, lead and SO_2 on health and welfare are the most serious aspect of motor vehicle pollution in Delhi. This is due to a far larger population density and larger percentage of population moves and lives in the open air and is thus exposed to these automotive pollutants. Also, relatively high levels of lead (0.58 gm/litre) and sulfur (0.25%) in Indian gasoline and relatively poor levels of vehicle technology and maintenance, have deteriorated the air quality in Delhi.

8) On a per capita basis, the LA region burnt (1.02t C per capita during 1987) nearly 15 times as much carbon than Delhi (0.07t C per capita annually during 1990).

6 SUSTAINABILITY AS THE NEW FOCUS OF TRANSPORT POLICY

Achieving sustainable transportation strategies is likely to mean different things in the context of developed and developing countries. In developed countries, absolute reductions in emissions of various pollutants from "on-road" vehicles in the face of growing vehicle travel, by using advanced pollution control technology, is a realistic goal. However in developing countries, the state-of-the-art technological solutions to deal with manifested environmental problems are expensive and difficult to afford given the limited financial and economic resources available in developing countries. They should adopt cost-effective solutions to problems which vary by locality. Interventions therefore, must be selective, enforceable and affordable. In particular, the developing countries need to complement supply side interventions with demand management measures. These can be regulatory interventions. But given the need to finance the development and improvement of transportation alternatives, pricing mechanisms need to be explored more actively.

6.1 Increasing reliance on demand management measures

The current air quality strategy in developed economies is based primarily on a search for a technological fix. For this the developed countries are working towards zero emission or very low emission motor vehicles. In the meantime the polluting fleet is large and growing and the focus is appropriately on a reduction in emission factors (pollutants per unit of transport activity) through enhanced fuel quality and improved vehicle engines. However, the growth in motor vehicle fleet, plus the increased average number of miles driven by more fuel efficient vehicles can partially or fully offset the improvements obtained from the increase in energy efficiency and the reduction in emissions output of individual vehicles. Thus, there are limitations to a strategy focused primarily on affecting automotive technology.

Demand management is critical for the current air pollution strategy, and needs to be more vigorously used than at present, having usually failed due to: (i) lack of public transport alternatives; (ii) lack of staff for design and enforcement; and (iii) political unwillingness to implement and enforce. To be most effective a range of restraint instruments need to be planned as part of a comprehensive transport strategy. It is desirable, therefore, to complement the supply-side interventions with demand management measures if the ultimate objective is to secure improved levels of air quality. Measures directed at encouraging the development of alternatives to polluting, motorized transportation, reducing the need for travel or creating disincentives to excessive automobile use, are policy options that need to be considered and pricing has a critical role to play.

6.2 Emission control measures

Vehicle Inspection and Maintenance (I/M) programmes have been an integral element of air pollution control programmes in many industrialized countries, but special care is required in designing the inspection and enforcement mechanisms of I/M programmes in developing countries. Available data suggest that a well-run I/M programme can bring about very significant emissions reductions -- about 25% for HC and CO and 10% for NO_x.[20] Although I/M programmes can reduce emissions from the worst vehicles in the existing fleet, emissions are nonetheless likely to remain unacceptably high because of the large number of uncontrolled vehicles already in existence. Where the severity of the air quality problem warrants it, therefore, it may be appropriate to consider vehicle retrofit and replacement programmes.

6.3 Policy and institutional reform

The key to improvement in the transport sector remains the availability of a basic infrastructure. The main infrastructure networks -- particularly road and rail networks - remain in the public sector and will continue to make demands for resources. Beyond that, however, there are new policy implications and the need to ensure transport provision which is economically, environmentally and socially sustainable. The core infrastructure must be properly maintained; low cost public transport services of adequate quality must be provided for those dependent on them; the adverse environmental impacts of transport must be contained.

Past failure to meet these requirements has been partly a human resource problem, as governments do not possess adequate skills to perform the planning and control tasks required of them. But it is also institutional in so far as governments continue to rely on mechanisms making unrealistic demands on human resources and motivations. The general strategy involves a complex institutional agenda containing the following elements: (a) deregulation to create the framework for a competitive market, and associated supervision of market behavior to maintain user responsiveness; (b) increased private sector participation in supply within those markets; (c) commercialization of many remaining public sector functions, including increased user participation in objective setting and management; (d) environmental management to avoid adverse impacts of markets; and (e) targeted poverty reduction to contain adverse distributional effects.

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Session 5.a. Effectiveness of public policies, transport and energy sector

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HOW CONFLICTING GOALS CONCERNING ENVIRONMENT AND TRANSPORT INFLUENCE THE POLICY PROCESS

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1 INTRODUCTION

Making freight transport more environmentally desirable is a challenging task. Traditionally, transport policy is traditionally oriented towards increasing capacity of the infrastructure. This goal is very far from the environmental goal related to transport policy: Less local and global pollution. The concept *integration* describes how the two policies relate. This paper will make an apprisal of the *integration of the environmental dimension in freight transport policy* in the EU and six European countries – and suggest ways for improvements. The presentation is based on results from an international project with participants from Switzerland, Italy, Germany, Great Britain, the Netherlands and Denmark (Hey et al., 1996).

2 MOTIVATION FOR THE STUDY

Conflicts among policy areas are common. The core of policy is the process of weighting different interests against each other. While interest organizations, like hauliers organizations or environmental grass roots, work for a specific area, the role of politicians and administrative institutions is to weight pros and cons and to make decisions. Often basic information on the relation between cause and effect is missing and many important factors are impossible to control. Incremental policies are often preferred (Weale, 1994).

This study describes and analyses the conflicts between transport policy and environmental policy. The core of *transport* policy is the development and maintenance of the infrastructure. New motorways, new bridges, and new railways are built as a response to the increasing traffic. Traditional transport policy includes the optimal use of limited resources under various frame conditions, e.g. the interest of preventing accidents, the interest of preserving and developing cities. The concept of integration could also be applied in relation to other frame conditions. Here we concentrate on the environment.

The *environmental* consequences of transport are numerous: Noise, visual effects, barrier effects and local and global pollution. The conflict between conventional transport policy and environmental policy is clear in relation to the plans to reduce CO_2-emissions from transport. With continued growth in transport volume it will be very difficult to realize zero-growth or even reduction in CO_2-emissions from transport. Although potentials for improved efficiency exist it will be difficult to achieve ambitious CO_2-goals only by technical solutions.

We define integration in the following way:

Integration is the process of mutually adjusting the objectives of transport policies and environmental policies. It requires political decisions on priorities. Its objective is to achieve compatibility between environmental and sectoral targets.

A high degree of integration requires that the traditional hierarchy – economic growth, transport policy, environmental policy – is broken, and a more equal balance is achieved. Our definition of integration is far stricter than *"integrating environmental considerations in the decision-making processes"* (Miljøministeriet, 1994), which typically means that the environmental consequences must be described. The Brundtland report mentions "*to make well-informed choices*". Information on the environmental consequences can be included in the decision-making processes without affecting the outcome. It is important to notice that integration is not only a question of the environment being protected it concerns the way in which it is done. The degree of integration can be judged on how deeply the transport policy is influenced. If core areas such as transport demands are not influenced then the level of integration is low.

The relevance of integration is high if ambitious environmental goals are pursued. Sustainability can be difficult and expensive to reach exclusively by means of "end-of-pipe solutions" without integration. The issue of integration is clearly pointed out in the Brundtland report:

The challenges are both interdependent and integrated, requiring comprehensive approaches and popular participation. Yet most of the institutions facing those challenges tend to be independent, fragmented, working to relatively narrow mandates with closed decision processes. Those responsible for managing natural resources and protecting the environment are institutionally separate from those responsible for managing the economy. The real world of interlocked economic and ecological systems will not change; the policies and institutions concerned must.

Ambitious goals for improving the environmental quality can be found in many official plans, e.g. in the Danish *Trafik 2005* (Trafikministeriet, 1993). The EU also uses the concept of sustainability. EU Commissioner of Transport, Neil Kinnock:

... the Common Transport Policy calls for the establishment of transport systems capable of providing sustainable mobility so that goods and people may travel, throughout the Community, efficiently, safely, under the best possible social conditions and fully respecting the objectives of the Community's environment policy. (Cordis, 1996)

The Danish Ministry of Environment and Energy has supplied a strong statement for the need of integration:

It is not realistic to fulfil the CO_2 goals only with the use of technical measures, and it can therefore be necessary to address the demand for transport and the increase in this. The demand for transport is guided by a number of factors, some with physical characteristics and depending on the organization of society and other related to habits and life style. Therefore, in the long term these factors must be influenced and changed (Miljø- og Energiministeriet, 1995, our translation).

These statements support the idea of integration. There is a raising environmental awareness. We find it relevant to investigate whether this need for integration is just talk or it has led to actions and true integration.

3 STATUS OF INTEGRATION

In general, the integration of the environmental dimension in transport policy is judged to be moderate in all the countries studied. In plans and statements the wish to include basic aspects like reduction in the need for transport and sustainable mobility is expressed, but in practise only little is seen. Defensive integration – like "end-of-pipe solutions" – can be found in many cases, but active integration – where the need for transport is evaluated together with the environmental consequences – is seldom. Defensive integration can also be described as actions to reduce the negative consequences, without affecting the core of transport policy. With active integration environmental and transport goals are put on an equal footing from the beginning.

Policy instruments like Strategic Environmental Impact Assessment (SEIA) and diesel tax are regarded as instruments for active integration. SEIA can be seen as an attempt to incorporate the environmental dimensions at an early stage when plans and policies are discussed. The background is the experience that prevention is better, i.e. cheaper and easier, than cure.

In the study the six countries and the EU have been grouped into three categories according to their environmental profile. The three groups are presented in the following sections.

3.1 Good Intentions, but Weak Implementation

Ambitious policy plans exist and sustainability is often underlined. These countries are very concerned about the environment. This has resulted in legislative regulation of environmental protection and ambitious comprehensive policy plans for reduction of environmental impact (both transport and environment) containing both quantitative and strategic targets. But the implementation of these plans and targets are slow and incremental. One reason is the culture of consultation and consensus in the political system resulting in harmonization of the plans through the policy process. Sudden changes are seldom. Instead, politics and changes are taking place step by step. Denmark, the Netherlands and to some degree the European Union match this profile (Hey et al., 1996).

Denmark: Active integration of the environmental dimension in transport politics is limited, while defensive integration is found in many areas of the transport policy. Transport policy is capacity oriented with investments in new motorways and bridges for road and rail. In the recent decade some steps have been taken towards integration. Until 1991, the haulage contractors did not pay diesel tax. Today, the diesel tax is above the EU minimum level, corresponding to 125 percent of the fuel price before tax. Additional increases in the tax are passed for 1997 and 1998. Denmark is a small, trade depending country with an open economy. Industrial interests dominate environmental interests in the policy process. The consensus-oriented system makes it difficult to decide on an active environmental policy.

Inspired by the EU, the Danish Prime Minister's Department issued a new circular in 1993 on explanatory notes with a Strategic Environmental Impact Assessment (SEIA) of bills etc. The circular requires all ministries to carry out an assessment of the economic consequences and the environmental consequences of the bills etc to be introduced if the consequences are deemed to be serious. However, it is also stated in the circular that the scope and depth of a strategic environmental assessment should be limited when needed for administrative reasons and the availability of data. The ministry responsible for the bill has the task of preparing the strategic environmental assessment. The Ministry of Environment and Energy acts as an advisory capacity. Consultation is recommended in the case of a bill which is deemed to have serious environmental consequences (Miljøministeriet, 1994). An SEIA involves an assessment of positive and negative changes in pollution and health, possible consequences for resources and for natural and cultural amenities. The assessment should form part of the preparatory work on legislation and be available to politicians and the public from the date on which the bill is tabled.

In 1993-94, 261 government bills were passed and 35 of them were accompanied by a strategic environmental assessment in the explanatory notes. In 1993-94, there were four bills concerning the transport sector deemed to have environmental consequences. The four bills were subjected to a strategic environmental assessment the results of which appear in the explanatory notes to the bills. Two of the bills were on motorways, and one was on periodical inspection of cars, and one on cooperation among road authorities.

In February 1994, within a common EU framework Benelux, Germany and Denmark agreed on a joint vignette tax for the five countries – the "Euro Vignette". In October 1994, the vignette is decided on by the Danish Parliament together with other changes and compensations. Before the decision an SEIA was developed. In short, the yield from the total parcel (the vignette tax and the changes in the weight duty, insurance charges and diesel duty) is practically unchanged and - according to the SEIA – the environmental effect is close to zero. At the bottom of this, essential aspects are hidden. The parcel contains elements that are positive in relation to the environment and other elements that are negative. Technically the different elements could be carried through one at a time. By presenting the different proposals as a package solution the environmental differences are blurred.

The Ministry of the Environment did only become involved very late in the process being asked to go through the environmental statement. A government official in the Ministry of the Environment thinks (surprisingly?) that too much has been made of the environmental statement. He emphasises that the basis of the calculations is too slender. In a draft for the environmental statement a price elasticity for diesel of 0.3 was used. After a discussion with the National Environmental Research Institute the elasticity was reduced to 0.15. In the valuation was mentioned that maybe the value should be even smaller because it is a question of a national price change. Maintaining the original value would lead to a negative environmental valuation. It does not appear whether it is a question of a long or short-term price elasticity (Togeby et al., 1996).

SEIA can be seen as an attempt of active integration of the environmental dimension in the legislative process, but as practised at present it can only be described as a weak form of integration. One problem is that the requirements concerning both procedure and content are too lax. It is left to the ministry responsible for the bill to decide whether a strategic environmental assessment is needed, and in making that decision the ministry has to consider the need of a smooth legislative process, administrative needs and the availability of data.

A strategic environmental assessment does not in itself constitute an environmental guarantee. It is more in the nature of broadening the basis for decisions. This is illustrated in the case study of the introduction of a vignette tax. In some cases SEIA can be seen as a symbolic integration of the environmental dimensions.

SEIA is a way to secure that *informed* decisions can be taken. It is very possible to decide on a solution or policy not being environmental friendly, but the decision makers must know the consequences. SEIA can be regarded as an informative policy instrument (decided by politicians and directed towards politicians).

3.2 Concrete Steps, but no Overall Plan

The concern of the environment is playing a major part in these countries, the population expressing willingness to give priority to a healthy environment. The decision-making process is dependent on the will of the political majority. The policy is fragmented into elements with little continuity. General policy plans for transport and environment are lacking in these countries. The environment is not given top priority even when the environmental dimension is included in government organization and procedure. The problems with the fragmented politics are augmented by the complex vertical coordination between the administrative levels due to a federal structure. Germany and Switzerland match this profile (Hey et al., 1996).

Positive examples on integration can be found in Switzerland. The Alps make up a bottleneck for the traffic and this puts considerable environmental pressure on certain Swiss cantons. This combined with the Swiss electoral system and the general wealth has led to several environmental oriented decisions.

Switzerland is characterised by a mixed transport strategy containing both top-down elements (derived from the Swiss Integral Concept of Transport – a large 1977-study) and bottom-up elements. The regulation is using a variety of instruments. The following will in short describe the most important ones.

Weight limits and time-regulation of lorries. Switzerland has a 28-tonne limit for trucks, in contrast to the EU regulation of 40 tonnes. The 28-tonne limit creates a comparative advantage for rail and combined transport. There is a ban on lorries on Sundays, public holidays and at nighttime. These restrictions send many trucks on a detour through Austria or France. It is primarily the transit traffic that is affected by these limits.

The Swiss public has the right to call for a referendum. This was done in the *Alpine Initiative*, which was adopted in 1994. This is an example of a strategic decision. The target is in ten years to reduce the transit traffic. Originally, it required a total mode shift from road to rail for all transit freight traffic. The change must take place within ten years. The focus has shifted in the implementation phase mainly because of the influence of the EU. The target of the EU is to be non-discriminating by including all transalpine freight traffic and achieving the shift through market-based instruments. The implementation process is actually ongoing depending on bilateral negotiations between Switzerland and the EU.

Taxation: The Swiss taxation system is extensive and consists of various elements. Diesel fuel is charged a 75-centime tax per litre, in total corresponding to 195% of fuel price before tax. Since 1995, the tax on trucks has been earmarked for road construction and investment in combined transport. A referendum in 1994 confirmed a distance and weight dependant tax for trucks. Within 10 years such a tax must be introduced. This is another example of a strategic decision (Maibach and Hess, 1996).

3.3 Environmental Policy in its Initial Phase

Some countries have little concern about the environmental impact of traffic. The existing interest in the quality of the environment is more based on historical reasons than environmental awareness. The administration is primarily problem solving and much less planning. The government style is more defensive than active. Little integration of the environmental dimension exists in government organizations. Acute environmental problems will be solved by concrete actions. Italy and to some extent the United Kingdom match this profile (Hey et al., 1996).

The UK's diesel tax is high. It corresponds to 230% of the price before tax. Furthermore, it has been decided that the tax will be increased by 5% per year in real prices.

The liberalisation of railways in the UK is under way. The liberalisation can be seen as a contrast to the positive environmental effect of the high diesel tax. So far it seems that no environmental consideration has been taken (Fergusson, 1996).

4 BOTTOM-UP MEASURES

Sofar we have placed politicians and administration in the centre as decision-makers. However, the top-down approach is seriously limited. Competition among countries and EU restrictions on national regulation constrain the room for action. For open economies it is difficult to regulate much harder than the neighbouring countries. This means that the top-down instruments like taxes and environmental regulation with an impact on the competitiveness are difficult to use without international coordination.

Buyers of transport (including companies) might have more power and more potential for introducing new solutions than politicians. While politicians are limited in many ways – as this study shows – consumers can ask for new products and sooner or later, e.g. hauliers will respond. The role of politicians can to be to support this bottom-up development.

4.1 Green Consumers

Consumers – in a broad sense – can decide on more environmental transport or the opposite. Just-in-time concepts and high speed ferries will increase the energy use. On the other hand, companies with quality management systems or environmental systems might include the environmental practise of hauliers in their system who transport their goods.

The transport buyers have begun to demand green transport. The motivation can be a concern about a green image. Interviews with organizations representing Danish transport buyers and suppliers, respectively, show that environmental considerations are expected to be a competitive factor in the near future. The tendency is promising because it is a market development, and not influenced by the restrictions on traditional politics. The government should support this tendency. Examples of support are:

- Authorities could act as green consumers and use environmental friendly transport and work for solutions with less transport. This can include demands on vehicles (Euro I and II norms) and on fuel (e.g. low sulphur diesel)
- The Ministry of the Environment could establish an environmental label scheme for transport
- Authorities could encourage companies to publish environmental accounts and to include transport in these
- Support to the *bottom-up movement* through subsidy for research, development and demonstration projects.

Together the combined demands from the transport buyers can develop into a positive spiral. The environmental strategy of the largest Danish public transport company, HT (Metropolitan Public Transport) can serve as an example of the bottom-up tendency.

HT covers Copenhagen and the outskirts. The company is the planning and contracting company of the area coordinating public transport by bus in the area. HT does not own the buses, but signs contracts concerning 1,000 buses. HT is owned by the municipalities and counties in the region. As contractor HT has power (within some economic liberty of action) to define which demands the bus companies must meet to get the contract on the bus routes. Since 1995, the aim of the environmental strategy has been to reduce the negative environmental consequences of the buses. The strategy has been to exchange old buses with new and less polluting ones and to allocate the least polluting buses to the most densely populated areas.

The instrument has been to give the environment economic priority by rewarding low emissions through a better bus-hour price, e.g. 3 DKK extra per hour for a Euro II bus. Minimum environmental standards have also been set. Buses in central Copenhagen should at minimum be Euro I. In the next round this demand is raised to Euro II. The result from the fifth contract round has been that 161 standard buses have been exchanged with 150 Euro II and 11 Euro I buses, the calculated emissions have been reduced by 39-58 per cent and the economic savings have been 13 per cent compared to the contract round before. It is not possible to isolate the effect of the environmental reward (Møller, 1996).

Summing up this means that not only economic, but also environmental consequences have begun playing a part when bus contracts are established. It is a stepwise development which leaves time for the bus companies to react to the new demands. The result will in the long run be greener buses and a greener image for the HT.

The example could be transferred to other transport areas. The public sector as transport buyer could use similar demands when inviting tenders concerning transport tasks.

4.2 Local Authorities

In Denmark, congestion is relatively low and environmental problems in relation to transport are perceived as few. However, in the cities congestion problems and the negative impacts from transport are more obvious in the form of through noise, accidents and local pollution. The problems are often serious during rush hours. Many cities also wish to develop their inner city with pedestrian streets, public squares etc. Therefore, there might be a possibility for local regulation centred around the cities. Examples are:

- Establishment of restrictions in the cities where the regulations of freight transport can be strengthened without any effect on competition among haulage contractors from different countries. The regulation can be defined from a local maximum imission level.
- Establishment of city terminals.
- Time limited access to cities for haulages combined with special permits (all day) for green haulages, green drivers, green receivers etc.

5 CONCLUSION

The concept of *integration* is a way to label and analyse the politics. In practise, incorporation of the environmental dimension in transport policy is moderate in the studied countries. The integration is high to medium in the early phases in the policy cycle (initiation and estimation), but is then decreasing to low or no integration in later phases (selection, implementation and practise). This tendency of falling integration through the policy circle is found in all countries.

Conflict between transport and environment can have various results:

- The transport interests win – no consideration for the environment
- A compromise could be the result: Adding a noise wall to the motorway, or changing the route for a new motorway is called defensive integration in this study. Compromises can take the form of a de luxe solution, e.g. extension of both rails and roads. Such solutions have the potential for creating even more transport.
- Experience from conflicts can change the future policy process. A typical example is that decisions shall be made on a well-informed basis: Before a decision is taken consequences for the environment must be studied consultation processes with the public must take place.
- Symbolic actions are frequent in politics. Conflicts can be solved by environmental friendly *talk* and a little action. Strategic Environmental Impact Assessment (SEIA) can under certain conditions be an example of symbolic integration. The environmental consequences are described, and the involved interests are heard, but there is no change in the environmental outcome.

Our study suggests that many restrictions exist on traditional top-down policy instruments: international competition, different perception of environmental threats and powerful actors. Other informative instruments like SEIA have only limited impacts on practical politics.

Industrial companies and authorities seems – to an increasing extent – to act as green consumers. This bottom-up tendency should be supported by transport and environment policy.

A potential for local initiatives based on maximum imission levels seems to exist. In cities the negative impacts of transport are visible. Local authorities may on this background introduce restrictions on traditional freight transport and may offer new alternatives. Central authorities need to provide a common framework for such initiatives.

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INFRASTRUCTURE AND PRODUCTIVITY

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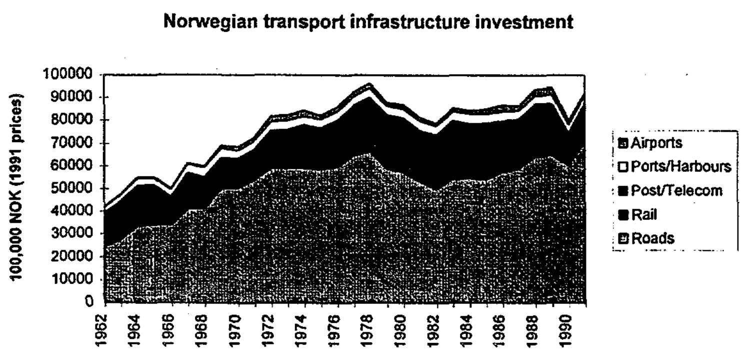
1. Introduction

One issue of major concern to economists and politicians today is whether public infrastructure investments, such as those in roads and airports, lead to gains in private sector productivity. Beginning in the mid 1970s, nearly all OECD countries experienced a sustained decline both in public infrastructure investment and in private sector output. This led many to conclude that underinvestment in infrastructure was largely responsible for the low growth rates in output and productivity which were experienced by these countries. This paper is a first attempt to address the question of how publicly owned transport infrastructure capital enters into the private production process and whether there is a discernible link between this particular type of public infrastructure and private production costs in Norway.

In contrast to the analytical studies performed in the literature thus far, most of which look at the impact of aggregate public infrastructure investment (i.e. which also includes utilities, sewers, schools, etc) on the manufacturing sector, we are interested in the effects of transport infrastructure on both aggregate and sectoral production. By transport infrastructure, we mean the real fixed public capital stock in air, rail, road, sea, and communication activities. This variable is particularly interesting to focus on because it is reasonable to assume, for example, that expenditure on a better highway system will have more of a direct effect on the economy than, say, building a hospital will. Public transport infrastructure capital is also arguably an important type of public infrastructure to study because it accounts for such a large part of the total public capital public investment in most OECD countries. In 1991, total investment in Norwegian public transportation infrastructure was NOK 9.2 billion (1991 prices), which was approximately 1.3% of GNP or about 7% of total national gross fixed capital formation (Statistics Norway, 1994). The most dramatic *change* in transport infrastructure investment levels occurred in the post/telecommunications sector, as figure 1 shows.

However, by far the majority of all public transport infrastructure investment went to the road sector. For instance, road investment accounted for 73% of total public investment in transport infrastructure in 1991. This means that, for Norway, when we analyze the effects of public transport infrastructure investment on the private production process, we are primarily talking about the impact of spending on roads (including tunnels and bridges).

Figure 1



Norway stands out as an interesting case study for two main reasons. First, Norway was one of the only OECD countries which did not experience a sustained decline in its public transport infrastructure investment after 1975 (OECD, 1960-1990). Both Norwegian GDP and public transport infrastructure investment rose steadily between 1962 and 1991. This then raises the question: is there a connection between Norway's steadily increasing investment in transport infrastructure and its similarly even GDP growth? A second interesting feature of Norway is its geography combined with its political objectives as a welfare state. Norway is a long, thin country which contains many small coastal islands and which is criss-crossed by fjords all up and down the coast. There is, therefore, a high demand by rural inhabitants for transport infrastructure, especially for bridges, tunnels, and roads, in these isolated regions.[1] While it seems clear that providing a better transportation infrastructure network to these people would increase their welfare, it is less clear whether connecting these regions is justifiable on economic grounds--that is, whether the construction of a better public transport infrastructure network results in a 'payoff' in the form of lower private production costs in the affected regions.

[1] However, this is not necessarily reflected by a high willingness of inhabitants to pay for the services from these types of transport capital.

The paper is further structured as follows: Section 2 presents a review of the literature and critiques some of the main approaches. Section 3 goes over the model and the main conclusions drawn from the estimations at both the aggregate and dissagregate level. Lastly, section 4 concludes with some final comments.

2. A review of the literature

A brief review of the literature demonstrates that economists are widely divided over whether or not public infrastructure investment generates economic returns, in terms of higher output or increased productivity. The controversy is not about *if* public capital belongs in the production (or cost) function, but rather *how* the function should be estimated. Important issues to consider are which functional form is appropriate and whether the data used are stationary, i.e. give reliable results.

It should be noted at this point that there is an important distinction between the *stock* of infrastructure capital and the *flow* of services from that stock. It is the amount of *services* which a firm receives from the infrastructure stock which influences a firm's cost structure, rather than the total infrastructure capital network which exists. Unfortunately, it is impossible to accurately measure the amount of infrastructure services which a firm uses. For example, it is hard to measure which parts of a national highway system a firm actually uses, how intensely it uses these routes, and how to account for variations in road quality or congestion levels. To account for this, the public infrastructure capital stock is often multiplied by a capacity utilization index (see, for instance, Nadiri and Mamuneas (1991)).

Some studies find a clear link between infrastructure investment and productivity. For example, assuming Cobb Douglas production technology, constant returns to scale over all inputs, and using time series data, Aschauer (1989) performs a straightforward least squares regression of total private business economy value-added per unit of private capital on the private labor-capital ratio, the net (of depreciation) public capital (nonmilitary) stock to private capital stock ratio, capacity utilization in the manufacturing sector,[2] and on time as a proxy for technological change. Using annual US data from 1949-1985, he finds that the elasticity of output with respect to 'core infrastructure', is .24 and is highly significant.[3] The estimated elasticity of output with respect to private capital is .26. Therefore, in Aschauer's model, public 'core' infrastructure capital appears to have almost the same impact on private sector output as private capital does. He concludes that the government should take advantage of this large stimulative effect by increasing public investment in infrastructure.

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[2] Here, in Aschauer's production function approach, capacity utilization is used to capture short-run business cycles.

[3] Aschauer defines 'core' public infrastructure as highways, mass transit, airports, utility (electric, gas, water) systems, and sewers. So defined, 'core public infrastructure' comprises 55% of the total nonmilitary public capital stock.

Several studies have reestimated Aschauer's model and obtained opposing results. For example, when Hulten and Schwab (1994) reestimate Aschauer's equations using first differenced data instead of the levels, they also find that the coefficient on public capital becomes statistically insignificant. They note that, "with slightly different statistical approaches (i.e. whether or not the data are first differenced), the same data could lead us to conclude that additional investment in infrastructure could have either a dramatic impact or virtually no impact on the private economy." This underscores the importance of checking data for stationarity prior to estimation. Tatom (1991) also does not find any evidence of an infrastructure-productivity link at the aggregate business sector level.

Economists are not only divided over econometric issues concerning data stationarity, they are also divided on how to model the link between infrastructure public capital and output. Most studies of the effects of infrastructure capital on output use the Cobb Douglas single equation aggregate production function specification. This is probably due to its simplicity, especially with relatively few inputs, and to the fact that current research is often compared to earlier work, which usually employed Cobb Douglas aggregate production functions.

The main problem with the Cobb Douglas production function is the relationships that it presupposes between the inputs. The elasticities of substitution between the different inputs are constant and equal to one which means *ex ante* that private capital, public capital and labor are all assumed to be substitutes, which controverts much of the empirical evidence.[4] By choosing this form, then, one has already decided beforehand that higher investment in public infrastructure leads to higher marginal and average productivity of the private inputs.

Previous studies which use a cost function approach include Lynde and Richmond (1992,1993a), which find a strong connection between infrastructure investment and private sector productivity.

3. Estimations

Like Lynde and Richmond, we use a cost function approach in this paper. According to Meade (1952), public capital affects output in two ways. One way is as an environmental variable which can boost private input productivity. The other way public capital affects output is more directly as an input which contributes independently to a private firm's production. Public capital can stand in its own right in the production function, even though it is not a 'choice' variable of the firm. The important distinction is that public infrastructure capital is different from traditional inputs because it is not purchased by the firm like private inputs are. Instead, changes to

[4] Private and public capital are found to be complements in most of the literature, especially in the manufacturing sector. See, for example, Seitz (1994), and Berndt and Hansson (1991).

the stock are usually determined externally, via the political process. Assuming that the individual firm has no influence in this process, public infrastructure capital should be considered as an exogenous, unpaid factor of production which affects the firm's variable costs.

Suppose that, in a perfectly competitive market, each industry has a simple, (variable) private cost function which depends on private input prices (p_K,p_L, p_M), gross output level (Y), the amount of public transport infrastructure capital services freely provided by the government (G), and a time index (t) used to capture technological change. The three private input quantities- services of capital (K), labor (L), and intermediates (M) - are determined conditional on the predetermined (by the government) free (to the firms) public input, namely public transport infrastructure capital services. G is thus modeled as an exogenous unpaid factor of production which can indirectly influence the cost function by altering the production environment. Total cost is defined by

$$(2.1) \qquad C(p_K, p_L, p_M, Y, G, t) = \min_{K,L,M} p_L L + p_K K + p_M M \qquad s.t.\ \mathrm{Y} = \mathrm{f(K, L, M, G, t)}$$

where f(.) is a production function. We assume that $f_K > 0$, $f_L > 0$, $f_M > 0$, $f_t > 0$. In order for infrastructure services to be considered as a production input, $f_G \geq 0$ must be found to hold. This is equivalent to saying that the cost function is non-increasing in G, which is known as the free disposal assumption (see below).

We approximate the cost function using the translog form and estimate a set of cost share equations, making sure to use stationary data. The production and cost functions contain the same information according to duality principles, but we use the latter specification because it allows us to explicitly include input price effects and their impact on factor utilization. After obtaining results for the aggregate Norwegian economy, we re-run the regressions at the sectoral level, to examine the impact of public transport infrastructure capital on sectoral production.

We use a cost function of the form

$$(2.2) \qquad \begin{aligned} \ln C = {} & \beta_0 + \sum_i \beta_i \ln p_i + .5 \sum_i \sum_j \beta_{ij} \ln p_i \ln p_j + \beta_Y \ln Y + .5\beta_{YY} (\ln Y)^2 + \sum_i \beta_{Yi} \ln p_i \ln Y \\ & + \beta_G \ln G + .5\beta_{GG} (\ln G)^2 + \sum_i \beta_{iG} \ln p_i \ln G + \beta_{YG} \ln Y \ln G + \beta_t t + .5\beta_{tt} t^2 \\ & + \sum_i \beta_{it} (\ln p_i) t + \beta_{Yt} (\ln Y) t + \beta_{Gt} (\ln G) t \qquad\qquad i, j = K, L, M \end{aligned}$$

To ensure that the cost function is consistent with economic theory, some conditions must be imposed on the parameters. Neo-classical theory maintains that the second partials of the cost function must be symmetric and that the cost function is linearly homogeneous in input prices. Once the model is estimated, it should also be checked that monotonicity and concavity of the cost function hold.

In order for infrastructure to be cost reducing (i.e. for it to have a positive marginal product) in this translog framework we must find that:

(2.3) $$\frac{\partial \ln C}{\partial \ln G} = \beta_G + \beta_{KG} \ln p_K + \beta_{LG} \ln p_L + \beta_{MG} \ln p_M + \beta_{YG} \ln Y + \beta_{GG} \ln G + \beta_{Gt} t \leq 0,$$

or in other words, that the 'cost share' of infrastructure is negative.

Shephard's Lemma allows us easily to find the input cost share equations (s_K,s_L,s_M):

(2.4) $$s_i = \frac{\partial \ln C}{\partial \ln p_i} = \beta_i + \beta_{iK} \ln p_K + \beta_{iL} \ln p_L + \beta_{iM} \ln p_M + \beta_{iY} \ln Y + \beta_{Ki} \ln G + \beta_{it} t \quad i = K, L, M$$

Only two of the three private input share equations need be used since the private factor cost share equations must sum to one. The producer's choice of inputs determines the cost level at the same time, and therefore equations (2.2) and (any) two from (2.4) comprise a set of simultaneous equations. Full Information Maximum Likelihood (FIML) estimation is used. In our first-round estimations, only the two cost share equations are estimated.[5]

An alternative way of expressing the shadow price of public transport infrastructure capital is in terms of the adjustment costs of labor, private capital, and intermediates:

(2.5) $$\frac{\partial C}{\partial G} = p_L\left(\frac{\partial L^*}{\partial G}\right) + p_K\left(\frac{\partial K^*}{\partial G}\right) + p_M\left(\frac{\partial M^*}{\partial G}\right) \leq 0.$$

This shows that an exogenous change in the *transport* infrastructure capital stock can affect the private production costs by altering both the productivity of and the cost minimizing conditional demands for the private factors. Only if these effects go in the "right" direction (for example, if all private inputs were substitutes with respect to public transport infrastructure capital), will an increase in public capital services unambiguously reduce private production costs.

The Data

To test for stationarity, we use Augmented Dickey-Fuller (ADF) t-tests to check for unit roots in the levels variables. A unit root here corresponds to a zero coefficient on the lagged levels variable and indicates a non stationary data series. We find that all of the aggregate variables are stationary after first differencing.

[5] As mentioned in the conclusion, it is better to estimate the two share equations with the cost function in order to check that the latter is well defined. This will be done at the next stage of investigation.

In accordance with the literature,[6] the price of private capital is constructed using the user cost of capital formula:

$$(2.6) \qquad p_K = p_J(r+\delta)$$

where p_J is the price index of new investment, r the interest rate, and δ the physical capital depreciation rate, which is assumed to be .05.[7]

Aggregate Estimation Results

To summarize, our preliminary aggregate estimation yields the following main results about the Norwegian economy during the sample period 1971-1991:

1. Constant returns to scale (over K, L, M, G) at the aggregate level is not consistent with the data at the 95% significance level.
2. No significant productivity effect or bias effects from transport infrastructure capital are found.

Our results controvert those studies which conclude that public infrastructure capital plays an important role in private production.[8] This difference in findings could be due to our focus on the aggregate level,[9] or our use of a specific type of public infrastructure variable (transport). However, there are several other studies which find, as we do, no significant link between infrastructure and output growth at the aggregate level.[10] Having found no evidence of productivity-public transport infrastructure capital link at the aggregate level, we now turn towards sectoral estimations in the hope that they may provide more insight as to how/whether public transport infrastructure capital affects private production costs.

Disaggregated Estimation Results

Oil production contributes an increasing share to Norwegian GDP (aggregate) after the late 70s. Whereas oil revenues were negligible in 1971, by 1991 they accounted for 14.5% of GDP. However, the petroleum sector, as well as several other sectors, does not depend to a great degree on public transport infrastructure capital. Conversely, it is reasonable to expect that the road transport sector, for instance, would be heavily dependent upon the provision of a good highway system. Therefore, it was our aim that by disaggregating the data, we might be able to uncover the various degrees to which

[6] For example, Seitz (1994), Nadiri and Mamuneas (1991), and Lynde and Richmond (1992) all use this type of specification for the user cost of capital.
[7] At the next stage, a unique depreciation rate for each sector will be calculated.
[8] For example, Nadiri and Mamuneas (1991) for the US manufacturing economy.
[9] Most other studies analyze only the manufacturing sector.
[10] See, for example, Hulten and Schwab (1991) and Tatom (1991).

public transport infrastructure capital services can affect private sectoral costs. By dividing the economy into six major production sectors, we hope to find sector-specific infrastructure effects which were not revealed at the aggregate level. This is particularly important since different industries require different kinds and amounts of public transport infrastructure capital in the production process.[11] We first divide the economy as follows into six major sectors, based on our *a priori* beliefs as to their relative dependence upon transport infrastructure capital:

Sector A *(a priori belief about G dependency level: medium)*
Construction (excluding oil well drilling),Central and Local Govt.: Education and Research, Healthcare and Veterinary Services, Finance and Insurance, Wholesale and Retail Trade, Other private services, Other Central and Local Govt. services

Sector B *(a priori belief about G dependency level: low)*
Agriculture, Ocean Transport, Fishing and Fisheries, Production and Pipeline Transport of Oil and Gas, Forestry, Dwelling Services, Oil and Gas Exploration and Drilling

Sector C *(a priori belief about G dependency level: medium-high)*
Manufacture of Pulp and Paper Products, Metals, Industrial Chemicals, Metal Products and Equipment, Petroleum Refining, Consumer Goods, Wood, Chemical, and Mineral Products, Building of Ship and Oil Platforms

Sector D *(a priori belief about G dependency level: low)*
Production of Electricity and Gas

Sector E *(a priori belief about G dependency level: high)*
Road Transport

Sector NV *(a priori belief about G dependency level: high)*
Air Transport, Rail Transport, Sea Transport, Post and Telecommunications

Again, before estimating we check and find that the sectoral data are also stationary after first differencing. The hypothesis of constant returns to scale is consistent with the data in only one of the six sectors: the manufacturing sector (sector C). Thus, only for this sector is the restriction imposed on the parameters. For the other four sectors, the data reject this hypothesis and no CRTS restrictions are imposed on the equations.

We use the same set of simultaneous equations as before. The LHS variables, therefore, are now the sectoral cost shares, instead of their aggregate counterparts. As for the exogenous variables, the input prices are now sectoral, as is (gross) output level. Public transport infrastructure capital services, however, is not a sectoral variable because we assume that all of the available infrastructure services are at the disposal of any

[11] While we have not disaggregated public transport infrastructure capital by type in this analysis, we hope to do so at the next stage of investigation.

industries which want to use them (i.e. G is a pure public good such that consumption of services are non-rival and non excludable).

Interestingly, the public capital coefficient estimates in the s_K equation (B_{KG}) are significant in all sectors except B (agriculture/oil), which we had anticipated would not be heavily dependent upon G. In the other five sectors, this bias effect of public capital is positive, which means that increasing the availability of public transport infrastructure capital services raises the cost share of private capital. For the intermediate sectoral input cost share equations, the public transport infrastructure capital coefficient estimates are significant in two sectors--A and C (services and manufacturing). Contrary to our aggregate results, here we find that increasing the availability of public transport infrastructure capital services significantly reduces the cost share of intermediate inputs.

We can calculate the total elasticity of the (conditional) demand for private inputs with respect to the public input (ξ_{iG}) as the sum of a productivity effect (s_G) and a factor bias effect, according to (2.6).

$$(2.6) \qquad \xi_{iG} = s_G + \frac{\beta_{Gi}}{s_i} \qquad i = K, L, M.$$

Table 1 - Summary Statistics from Sectoral Regressions

Sector	s_G	$Bias_{LG}$	$Bias_{KG}$	$Bias_{MG}$	ξ_{LG}	ξ_{KG}	ξ_{MG}	Conclusions
A-Svcs.	0	-.306	.966	-.286	-.306	.966	-.286	L,G substitutes K,G complements M,G substitutes
B-Agric. /Oil	0	0	0	0	0	0	0	no effect of G on pvt. factor demand or productivity
C-Manuf.	-.04	-.165	.506	-.111	-.205	.466	-.151	L,G substitutes K,G complements M,G substitutes
D-Electr. /Gas	0	-.005	.679	-.528	-.005	.679	-.528	L,G substitutes K,G complements M,G substitutes
E-Road Transp.	-.02	-.691	.873	0	-.711	.853	-.02	L,G substitutes K,G complements M,G substitutes
NV-Non-Road Tr.	-.013	-.328	1.14	0	-.341	1.13	-.013	L,G substitutes K,G complements M,G substitutes

Examination of the table 1 estimates reveals some interesting information about the relationships between the private and public variables. Most striking is that public transport infrastructure capital has no measurable impact whatsoever in the agriculture and oil sector (B). For all of the other sectors, we find a complementary relationship between private capital and public transport infrastructure. The other two private inputs, labor and intermediates, are found to be substitutes with the public input in all of these sectors. The productivity effect of public transport infrastructure capital is negative (i.e. cost reducing) in the manufacturing, road and non-road transport sectors (C, E, and NV). We estimate that a 1% increase in public transport infrastructure capital services reduces manufacturing (variable) costs by .04%, road transport costs by .02%, and non-road transport sector costs by .01%. Thus, in these sectors the mean marginal product of public transport infrastructure capital services is positive. In the other three sectors, where no significant productivity effect was found, the total impact of G on private factor demand is just the bias effect. Note that in all cases, the bias effects are much stronger than the productivity effects.

Conclusions from Sectoral Estimations

The most important findings at the sectoral level are:

1. The hypothesis of constant returns to scale is rejected for all sectors except manufacturing (C). This is consistent with the literature, where many of the econometric studies which focus solely on the manufacturing sector find constant returns to scale (for example, Lynde and Richmond (1992)).
2. Public transport infrastructure capital is not estimated to have any effect on the agriculture/oil sector (B). This is consistent with our *a priori* expectations.
3. Public transport infrastructure capital and private capital are found to be complements in all sectors (except sector B). Labor and intermediates are estimated to substitute for public transport infrastructure capital in all sectors (except B). These production relationships findings are basically undisputed in the literature, except for Nadiri and Mamuneas (1991).
4. Public transport infrastructure capital is found to be slightly cost reducing in 3 sectors: manufacturing, road, and non-road transport, with this productivity effect being strongest in manufacturing.
5. In all sectors (except B), the bias effect is much greater than the productivity effect, indicating that the main influence of public transport infrastructure capital comes via its effect on private factor demand.

4. Conclusions

In conclusion, our results indicate that during the sample period public transport infrastructure investment reduced costs slightly in three sectors and significantly altered the demand for private inputs (except in the oil/agriculture sector). The influence of public transport infrastructure investment appears to come primarily through a bias effect, rather than through a productivity effect. It appears that the sectoral effects cancel each other out, which may explain why no effects are detected at the aggregate level.

While we feel confident that the cost function/cost share is the best approach to the question of returns to public capital, there still remains possible econometric problems to grapple with such as endogeneity of public capital, omitted variables, and reverse causation. Furthermore, due to infrastructure's unique nature, accurate measurement of its services will always be difficult. In particular, we need a better way to measure the flows of services from the infrastructure stocks, in order that the degree of utilization efficiency of the infrastructure network can be taken into account. In the next stage, we need to go back and estimate the cost share equations simultaneously with the cost function to check that the cost function is well-defined (and particularly whether the Hessian matrix is negative semidefinite). We also should check whether the ADF test of stationarity was powerful enough given the small sample size. If not, a good deal of LR information may have been lost via first differencing and our results may not be robust.

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COST BENEFIT ANALYSIS OF POLICY MEASURES IN THE TRANSPORT SECTOR

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Introduction

The Government has introduced a national target for the reduction of CO_2 emissions from the transport sector, which aims to stabilised emissions at the 1988 level, by the year 2005. This target was first formalised in the Government's 1990 transport action plan, and later repeated in "Traffic 2005", published in December 1993. The latter document also makes reference to six discrete strategies, which the Government proposed in order to attain the national target. Most recently, these strategies, together with the national target, were repeated by the Danish Ministry of Transport, in the form of "The Government's Action Plan for Reduction of the CO_2 Emissions from the Transport Sector", which formed part of an overall strategy plan (E21) in 1996.

The majority of the transport policy measures will impact on CO_2 emissions from the sector, even if they are targeted at different objectives, e.g. road safety, air pollution, time savings, etc. A long-list of potential measures, which might be adopted with the primary purpose is to reduce CO_2 emissions, has been identified from the six overall strategies.

The measures identified have been subjected to detailed analyses, to ascertain all the potential impacts. The main emphasis has been on clarifying the potential efficacy of each of the measures in reducing CO_2 emissions, and the social costs in a wide sense.

The analyses assumes that each policy measure is implemented separately. A methodology is developed that presents the respective consequences in commensurate terms. Similar calculations are undertaken for two different combinations of policy measures.

Methodology

A key concept in the analyses is the *CO_2 shadow price* of the policy measure. The shadow price shows the relationship between the costs and the generated CO_2 reduction measured in DKK per ton CO_2. Thus, it can be interpreted as measure of the cost-effectiveness of each of the policy measures in this area. This interpretation allows comparative assessment of the individual measures, or groups of measures.

The costs are calculated as total (discounted) net costs, i.e. with the deduction of possible benefits apart from the non-priced CO_2 reduction. Costs and CO_2-reductions are calculated for all policy measures and compared, to a 'do-nothing' scenario, where present policy is assumed to remain unchanged.

The calculated CO_2 shadow prices are not comparable with the shadow prices, which the Danish Energy Agency applies in similar analyses of the energy sector. They have been modified and extended for two reasons; firstly, to reflect the desire to analyse the social costs related to the utilisation of tax instruments. And secondly, to reflect a series of problems which are particularly pertinent in any attempt to estimate costs in the transport sector. These differences, to the approach used by the Danish Energy Agency, generally result in higher shadow prices, and may also impact upon the rankings of the individual policy measures.

The theory of welfare economics has been employed to divide the cost estimates into three areas, where benefits in each of the categories are counted as negative costs:

i) *A measure of the consumers'/road-users' welfare change*, comprising both increased transport costs and lost 'consumer surplus' due to behavioural responses;
ii) *The lost tax revenues* reflecting the change in taxation revenue for the state, engendered by the introduction of new policy measures, e.g. a loss caused by a reduced demand for fuel and vehicles or vice versa;
iii) *Increased externalities* from the traffic, based on an estimate of the marginal external costs per km for different types of vehicles.

The inclusion of the third category, the external costs, is an explicit attempt to provide a monetary value for the negative effects that are imposed on society, by road users. However, some of these externalities lend themselves to monetary valuation more than others. Thus, only five of the most important are included in this analysis:

* Accidents * Noise * Air pollution * Infrastructure use * Congestion

while effects like the barrier effect and insecurity, water and soil pollution, visual nuisance, and the consumption of depletable resources have been excluded. Thus, it is acknowledged that the estimates could be interpreted as incomplete. However, it is estimated that the most important effects are included.

The following figure illustrates the relevant inputs; the marginal external costs per km by type of vehicle. Any interpretation, and use, of these figures should recognise and acknowledge the implicit rough assumptions and the high level of uncertainty that surrounds these estimates. However, the figures are indicative of the scale of the external costs, and as such are valuable for policy appraisal.

The figure indicates that, generally, the external costs per km driven increase with the weight of the vehicle. The costs of accidents, infrastructure use and congestion constitute the most important components of the external costs.

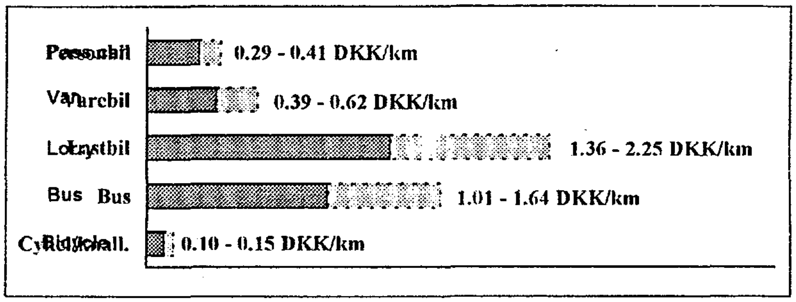


Figure 1 The Marginal External Costs of Transport Modes

It should also be noted that the scope of the social cost calculation is limited, in the sense that only the effects produced in the transport sector are included. Thus, derived CO_2 effects, welfare effects in the rest of the economy, e.g. changes in employment, the balance of payments are not taken into account and, more generally, the distributional consequences or the political feasibility of the analysed measures are not considered.

The Individual Policy Measures

Few of the policy measures are expected to produce a significant effect on the total emissions from the transport sector. The likely measures to be effective include; initiatives to improve energy efficiency, mileage related taxes (fuel taxes or road pricing) or use of biofuels. The remaining measures are each expected to produce an independent reduction in CO_2, of less than 1% of the total emissions from the transport sector.

The individual policy measures display a high variation in the estimated shadow prices, although this depends, at least partially, on whether a high or low estimate is employed for the calculation of the external costs. The most cost-effective CO_2 reduction is engendered by an increase in those taxes that are directly related to the distance covered, i.e. fuel taxes and road pricing. This reflects the fact that the costs, and thereby also the incentives to change transport behaviour, increase most for those trips which produce the highest CO_2 emissions. Hence, these policy measures are directly targeted towards the problem in question; a reduction of the CO_2 emissions.

A comparative assessment of the different policy measures is presented in Table 1. The main types of measures are classified into four groups, according to the size of the CO_2 effect and the shadow price.

Table 1 Classification of Policy Measures according to CO_2 Effect and the Shadow Price

	Low Shadow Price	High Shadow Price
High CO_2 effect	• Road pricing (goods[1]) • Increased fuel taxes	• Standards for energy efficiency • Tax relief on biofuels
Low CO_2 effect	• Packing rationalisation • Environmental labelling	• Increased fixed vehicle taxes • Differentiation of fixed vehicle taxes • Combined transport (domestic)

1) Road pricing for passenger cars is analysed in relation to a combination of measures (see below) and results in a lower shadow price.

In addition to the above, a number of other measures have also been subjected to analysis. However, the presentation of an acceptable cost calculation is more difficult, as each results in a reduction totalling less than 1% of the total CO_2 emissions from the transport sector.

The analysis of the social costs suggests that the existing Danish tax structure in the transport sector implies higher welfare losses in relation to the reduction of CO_2 emissions, than would result if the taxes were targeted more directly towards the external costs of the traffic. The following boxes offer a number of possible conclusions as to how combinations of policy measures can produce lower costs, than unilateral use of individual measures.

Initiatives to improve the energy efficiency of vehicles should be accompanied by increased fuel taxes. For the measure "Energy Efficiency Standards for New Passenger Cars" the external costs constitute a very important part of the calculated shadow price. The reduced costs per km increase the volume of transport, thus generating bigger external costs, as these are primarily related to the distance covered and not to fuel consumption. However, as the fuel consumption per km decreases, the tax per km decreases accordingly. An accompanying increase in the fuel taxes makes it possible to maintain the balance between taxes and external costs per km. In this way, the social costs measured per ton CO_2 (the shadow price) are reduced, as the major part of the increase in the distance covered, and thereby the increased external costs, will be eliminated.

A restructuring of tax system, shifting from fixed to variable taxes will markedly lower the costs associated with the CO_2-reducing measures. The high Danish level of fixed vehicle taxes gives rise to high social costs in terms of the welfare loss. This results from the fact that high fixed taxes prevent part of the population from owning a car. The fixed taxes, in contrast to the taxes related to the distance covered, are only indirectly oriented towards the externality of the traffic, and therefore do not directly reduce the distortions, as accidents, air pollution, etc. which are primarily connected with distance driven and not with the car ownership as such.

Thus, CO_2 measures that result in the further reduction of the car fleet have high costs, as the welfare loss per car reduced is high, and is not directly accompanied by a reduction in the external costs from use. This welfare loss per car will be significantly smaller in a situation where the vehicle taxes are replaced by road pricing, sufficiently high to maintain the total distance covered at an unchanged level compared to today, in spite of a larger car fleet.

The effect of tax differentiation is probably modest. Model calculations based on comparisons between the countries indicate that with the existing tax structure, the effect of tax differentiation on the energy efficiency of the individual models will be modest, as the existing tax level already today highly encourages the population to choose small, energy-saving cars. The difficult point is that if the Government wishes to maintain the same tax revenue level, it has to reduce the tax on the energy-saving cars which, at the same time, typically are the less expensive This will lead to an increase in the car fleet followed by an increase in the total distance covered. Alternatively, the tax level may remain the same for the cheapest cars, but then the average tax will be increased, which will result in welfare losses similar to those described above. In connection with a tax differentiation the CO_2 shadow price will thus be considerably lower in a situation where the tax level for fixed taxes is low. The effect of differentiated vehicle taxes will increase, though, through the simultaneous introduction of environmental labelling.

Environmental labelling has probably only a little effect, but also very low costs. Environmental labelling will also increase the average energy efficiency of the cars by directing the potential new car owners' attention towards the fuel economy. The effect, however, is expected to be even more insignificant than from a marked differentiation of the registration fee. However, environmental labelling is considered as a policy measure which implies very low costs.

Fuel taxes are targeted towards CO_2 emissions, but only indirectly towards other externalities. From a theoretical point of view, fuel taxes are among the most cost-effective measures for reducing the CO_2 emissions. In practice, the shadow price for fuel taxes is in fact among the lowest, and significantly below the shadow price for the fixed taxes. However, considering the present tax structure, a separate increase in the fuel taxes will not result in a cost-minimising reduction strategy, as a reduction of the car fleet will take place concurrent with a decrease in the distance covered. This will result in welfare losses due to the high vehicle taxes as described above.
Seen from a welfare-economic point of view, the fuel tax level must not only be established with a view to reducing the CO_2 emissions. A portion of the fuel tax has to correspond to (internalise) the external costs, which depends primarily on the type of vehicle and the distance covered, and not on the energy consumption. As the fuel tax per km only depends on the energy efficiency and the type of fuel used, the fuel taxes cannot be determined so that the tax per km reflects the differences among the external costs of the individual vehicles.

Road pricing is suitable to pay for the other external costs. To ensure that improvements in energy efficiency do not make inroads into that portion of the tax, representing internalisation of the external costs related to the distance covered, the fuel taxes may be increased *pari passu* with the energy efficiency, as discussed in the first box. Alternatively and more targeted, part of the fuel taxes can be transformed to a road pricing tax that depends on the type of vehicle, as does the external costs. The advantage of the road pricing is the possibility of differentiating between the vehicles according to the estimates of the relative size of their external costs. Thus, the taxes are linked directly to the externalities instead of, as today, indirectly through the fuel consumption. The fuel taxes may then be designed as a proper CO_2 tax imposed on all modes of transport.

A large future potential for traffic information in connection with road pricing. A genuine road pricing system is only obtained through differentiating the user charges, to reflect the actual road section driven as well as the time of the day. The external costs are typically lower in the country than in the urban areas where also the time of the day is of importance, as the congestion costs are highest during rush hours. It is therefore estimated that there is an important potential welfare gain, if the road pricing system is differentiated according to the local conditions, as the most harmful traffic bears the highest costs and is thus limited the most. This requires, however, the utilisation of modern traffic information systems. In practice, could only be implemented in the long run, as the relevant technology is not yet fully developed.

Two Combinations of Policy Measures

It can be concluded that a cost-effective reduction in the CO_2 emissions from the transport sector is not feasible through the introduction of one single measure; it requires the simultaneous implementation of a combination of policy measures. To illustrate this conclusion two additional analyses have been made of combinations or "

It should be noted, however, that as for the analyses of the individual measures, no considerations have been made concerning the practical implementation of the parcel of measures, including possible conflicts with EU directives or other existing agreements. Likewise, no decisions have been made as to the political feasibility.

The following analysis, the "Parcel" Scenario, is closely related to the measures formulated in Annex 1 of the "Government's Action Plan for the Reduction of the CO_2 Emissions from the Transport Sector" prepared in 1996. A leading element is the significant improvement of the energy efficiency of new cars, realised through the introduction of standards combined with increased fuel taxes. In addition, environmental labelling of new cars has been included as well as a differentiation of the tax on motor vehicles according to weight in order to increase the incentive to choose energy-saving cars. In short, the parcel contains the following measures:

"Package" Scenario

I. **Introduction of energy efficiency standards for new cars,** resulting in an average increase of 20% from 15 km/l to 18 km/l by 2005.
II. **Reduction of the registration fee** of 14.000 DKK for all cars neutralising the increase in the car price as a result of technology costs totalling 4,000 DKK. Cars with fuel efficiency more than 20% below the average of new cars are levied a surcharge of 10.000 DKK on the registration fee.
III. **Introduction of environmental labelling and differentiation of the tax on motor vehicles according to weight** totalling 20 DKK/year/gram CO_2/km and maintaining an unchanged tax on the average car according to weight of 18 km/l.
IV. **Increase in fuel taxes** of 1.17 DKK/l and 0.93 DKK/l for petrol and diesel respectively, maintaining the fuel costs per km at the same level and the total distance covered remains unchanged compared to the base scenario.

In the light of the problems with the existing tax structure, the following sections outline what can be termed the 'Restructuring' scenario, a more radical restructuring of the whole tax structure for the transport sector, along with its consequences. Hence, the formulation of this scenario is based broadly on the overall targets for the transport sector, and not only with regard to a reduction of the CO_2 emissions. The purpose of the analysis is therefore to evaluate the overall consequences, including those of the CO_2 emissions, of such a radical change in the tax structure.

The removal of the "high" registration fee is envisaged, in addition to a reduction of the fuel taxes to a level of 300 DKK per ton CO_2. The introduction of road pricing is envisaged, corresponding to the external costs of the individual types of vehicles. These measures will, in aggregate, result in a significant increase in the variable taxes. Furthermore, the initiatives to improvement in the energy efficiency from the "Package" Scenario are maintained.

"Restructuring" Scenario

I **Introduction of energy efficiency standards for new cars,** resulting in an average increase of 20% from 15 km/l to 18 km/l by 2005.
II. **Removal of the registration fee for passenger cars and the present fuel taxes**, leaving only VAT on the producer price of all cars as well as on petrol and diesel.
III. **Introduction of environmental labelling and differentiation of the tax on motor vehicles according to weight** totalling 20 DKK/year/gram CO_2/km and maintaining an unchanged tax according to weight on the small 'economy' cars.
IV. **Introduction of a CO_2 tax on fossil fuels** totalling 300 DK per ton CO_2., which corresponds to 0.72 DKK/l and 0.81 DKK/l for petrol and diesel respectively.
V. **Introduction of road-pricing** corresponding to the high estimate for the external costs per km.

The main results of the analyses of the two scenarios are presented in Table 2.

Table 2 Annual Costs and CO_2 Effect by Use of the Two Combinations of Measures

(Mill. DKK)	**"Parcel Scenario"**	**"Restructuring" Scenario**
Road users' welfare loss	1,740	÷3,350
passenger cars	250	÷8,890
goods	1,490	5,540
The Government's loss of revenue	÷935	÷2,660
passenger cars	÷135	2,480
goods	÷800	÷5,140
External costs	÷520 - ÷320	÷1,940
passenger cars	0	÷1,520 [1]
goods	÷520 - ÷320	÷420 [1]
social costs, total	**290 - 590**	**÷7,940**
CO_2 reduction from the transport sector	**13%**	**10%**

1) Based on the high estimate for external costs corresponding to the road pricing.

The "Package" Scenario

The table *"Package" Scenario shows a reduction of approx. 13% in the CO_2 emissions from the transport sector* compared to the base scenario. The largest CO_2 reduction is recorded for passenger cars, where the total effect is obtained through improved energy efficiency, as the fuel taxes are adjusted in order to maintain the distance covered at the same level. Thus, in the case of passenger cars there is no benefit in terms of savings in external costs. For goods, however, a benefit is generated as a result of the increasing fuel prices, which also give rise to considerable costs for the carriers amounting to approx. 1.5 mill. DKK per year. However, seen from an overall socioeconomic perspective, the major part of this loss is counterbalanced by an increased tax revenue of approx. 1 mill. DKK and by a savings in external costs of 0.3 - 0.5 mill. DKK. Private motorists will experience a minor loss, due to a small increase in the fuel costs, which is partly counterbalanced by an increase in the Government revenues.

In total, the social costs associated with the "Package" Scenario are estimated to 300 - 600 mill. DKK per year producing, by means of the CO_2 reduction obtained, a *shadow price of between 200 and 300 DKK per ton CO_2.*.

The costs relate to a package of measures and are thus considerably lower than if the measures were implemented separately. An important reason is that the package comprises a partial restructuring from fixed to variable taxes, which counteracts the distorting effects and the related costs caused by the existing tax structure.

It is therefore natural to conclude that a more comprehensive restructuring from fixed to variable taxes will result in a social benefit. If the tax structure is targeted towards the externalities through the introduction of road pricing, at the expense of the existing distorting fixed taxes, the apparent result should be a welfare gain. However, it is uncertain whether the benefit, caused by an increase in the distance covered, will be generated at the expense of increasing external costs and CO_2 emissions.

The "Restructuring" Scenario

In the light of the above, an analysis of the consequences has been made covering the more radical version, the "Restructuring" scenario. By means of this analysis, a CO_2 reduction of approx. 10% of the total emissions from the sector has been obtained in relation to the base scenario. Hence, the CO_2 effect, which is also in this scenario related primarily to the technological improvements in energy efficiency, will be somewhat lower than for the "package" scenario. In return, the tax restructuring will generate a considerable *social benefit in the range of 8 billion DKK per year.*

This saving, however, covers extensive distributional effects, as the motorists gain a welfare benefit of approx. 9 billion DKK, primarily in terms of a larger and better car fleet. In return, the freight transportation sector, which experiences a loss of more than 5 billion DKK, will bear much larger costs than stated in the base scenario. The loss is mainly due to the payment for the external costs of the conveyance of goods in terms of increased taxes and is therefore counter-balanced by a state revenue in the same range. In total, the state obtains a revenue of between 2 and 3 billion DKK, as the increase in the conveyance of goods more than counterbalances a total loss in passenger cars. Finally, the fall in distance covered by passenger cars as well as by vans and lorries results in lower external costs totalling approx. 2 billion DKK per year.

As the price which the consumers have to pay for a new car falls drastically, it is expected that the car fleet will increase by approx. one fifth. The increased imports of cars have of course a negative effect on the balance of payments. However, this is to some extend counter-balanced by the lower fuel consumption. In total, a negative effect of approx. 2.5 billion DKK per year is expected.

In conclusion, it should be emphasised that there is a high degree of uncertainty related to the presented CO_2 reductions and costs. However, this cannot shake the two main conclusions, which can be drawn on the basis of the calculations of combined measures.

First, certain combinations of measures may result in considerably lower costs than can be obtained by implementing the measures separately.

Second, the existing tax structure produces heavily distorting effects. In the long run, a comprehensive tax restructuring may generate a considerable welfare benefit without resulting in increased CO_2 emissions. In the short run, however, the implementation of such a restructuring will be hampered by EU bindings, considerations regarding the balance of payment and the distributional concerns, and perhaps other political considerations.

PUBLIC TRANSPORT SUBSIDIES: THE IMPACTS OF REGIONAL BUS CARDS ON THE TRAVEL DEMAND AND ENERGY USE IN FINISH URBAN AREAS

By J. Dargay, University College London, UK and S. Pekkarinen, University of Oulu, Finland

ABSTRACT

This study is a part of a larger Finnish project financed by the Ministry of Transport and Communications concerned with evaluating the impacts of new integrated fare and ticket policies. The objective of the policy is to encourage a modal shift from cars to public transport, thereby reducing energy use and the harmful environmental effects of transport. The regional bus card systems (RBC) provide the opportunity to purchase a monthly ticket, at a substantial discount on normal fares, which is valid on all buses in an area covering a city centre and the smaller independent communities surrounding. RBC systems are subsidised by both Local Authorities and the state government and are currently operating in over ten urban areas in Finland.

The intention of the policy is that the integrated fare and ticket systems would improve the convenience, economic competitiveness and desirability of bus travel, thereby increasing the number of passengers. The likely success of the pricing policy, in terms of increasing bus use, will be determined by the price sensitivity of demand: the higher the price elasticity, the easier will be the use of such measures. The impact in terms of energy consumption will depend on the relative importance of the generation of new bus trips and the shift to bus from cars and other modes.

The objectives of this research project are: 1) to estimate the fare elasticities of the demand for bus services and the price elasticities of RBC demand, 2) to evaluate the effectiveness of the adopted subsidisation policy and 3) to assess the consequences of the fares policy on energy use in transport. This paper deals specifically with the latter two issues.

1 INTRODUCTION

The transport sector has become of increasing interest out of both energy and environmental concerns over the past decade, and numerous policy measures have been designed, examined and implemented. The primary motivation for such policies arises from concern over the impacts of transport on the environment, both locally in terms of air quality, urban congestion and noise pollution, and globally in terms of greenhouse gas emissions. In addition to this, the socio-economic costs of increasing congestion have been an impetus for the formation of policies to encourage the development of more efficient transport systems, particularly in urban areas. A principal objective of many such policies has been to reduce the reliance on car travel by encouraging the use of public transport alternatives, thus improving transport efficiency while reducing the environmental consequences. This, however, has not been an easy task: the reduction in real oil prices since the mid-eighties has reduced the cost of car use in many countries so that public transport has become a less attractive alternative compared with the higher comfort and flexibility of time use provided by car travel.

In Finland a number of different fare and ticketing policies have been implemented as measures for improving the quality of service and economic competitivity of bus travel. A sencondary objective of these policies is to encourage a shift from car use to public transport in order to reduce energy consumption and its harmful effects on the environment. The aim of this study is to evaluate the effectiveness of such policies, in particular, the subsidisation of bus travel through the regional bus card system.

The Regional Bus Card (RBC) System has been devised for lower density medium-size urban areas. The Regional Bus Card is generally a smart card valid for 30 days from first use, with unlimited travel in the whole area. The price of the RBC is based on the price of the 40 trips' ticket for the average trip length for each community with a discount varying across communities. The discounted price is further subsidised by the local and state governments. Subsidies are paid according to the number of cards sold and are distributed among bus operators on the basis of the number of trips made with the cards on their buses and the average trip length.

This study covers two areas - Oulu and Kuopio - where the regional bus card system has been in operation from August 1992 and April 1993, respectively. Since then, the system has been extended to over ten other urban areas. The Oulu and Kuopio regions, located in north-western and central Finland, respectively, have each about 170 000 inhabitants, and are comprised of one major city, Oulu city with a population of 105 000, and Kuopio city with 84 000, and a number of smaller surrounding communities. The major city in each region provides the majority of employment opportunities and is the centre for secondary and higher education, so that there is a high level of commuting from the smaller surrounding communities. Apart from the major cities - Oulu and Kuopio - the study includes 7 surrounding communities in the Oulu region and 11 communities in the Kuopio region. In both regions, the RBC system has been seen as a successful and welcome service improvement of bus transport. The market share of total bus travel is around 6 % in Oulu and slightly over 20 % in Kuopio.

The study presented in this paper is part of a larger project aimed at evaluating the RBC system. The objective of the research project is threefold. The first is to estimate the fare elasticities of the demand for bus services, conditional on regional economic development and socio-economic factors. The second is to evaluate the economic effectiveness of the adopted subsidisation policy in relation to other possible measures for providing services on unprofitable routes in rural and sparsely populated areas. The final objective is to assess the consequences of the fares policy on energy use in transport, i.e. to determine to what extent the aim of the policy of reducing energy use by encouraging a shift from car use has been realised.

The data collected for the project are from several sources: passenger counts and prices from operators, communal data of socio-economic factors from communal statistical databases, and some price variables from Statistical Office of Finland. In addition, survey data of RBC users are utilised.

In an earlier paper Dargay and Pekkarinen (1996) present estimates of own-price, cross-price and income and service elasticities for purchases of the RBC and trips made by the RBC. The objective of the present paper is to consider the cost-effectiveness of the subsidisation of the RBC system, and its consequences for energy use. The calculations and results presented in this paper must be considered as preliminary, due to the limitations of some of the data used. Further data collection, which is currently underway, will provide a basis for more comprehensive and reliable estimates of the energy benefits of the RBC system.

In Chapter 2 a short description of RBC demand is presented, and the results of the surveys of RBC users are discussed. Various measures of the cost-effectiveness of the subsidisation policy are considered in Chapter 3, and in Chapter 4 the changes in energy use are calculated and discussed.

2 RBC DEMAND AND MODAL SHIFTS

The number of cards (RBC) sold varies considerably in the different communities in each region, from around 10 per month to nearly 250 in Oulu area, and from 3 per month to over 400 per month in Kuopio area. Differences in population[1] among

[1] Population density is from 1 to 32 inhab./km^2 in the Oulu area, and from 0.8 to 10.7 in the Kuopio area. Urbanization rates vary between 20 and 90 % across communities.

communities and differences in average trip length (from 10 to 60 km) partially explain the variation in demand, but the level of subsidisation also has an influence on the success of the RBC system.

In the Oulu area there seems to be no discernible trend in card purchases over time (Aug. 92 - Aug. 95), with the exception of Ii, where the number of cards sold has increased since the year of introduction, and in two communities, where it has declined (Kempele, Oulunsalo). Two dominant communities in Kuopio (Kuopio city, Siilinjarvi) have had monthly purchases of between 220 - 310 and 250 - 440 cards over the period (March 93 - Aug. 95), while all other communities the number is well below 50. As opposed to the development in Oulu, the number of cards sold has increased continually in most communities.

The price difference of RBC between communities is substantial because of the differing levels of subsidisation provided by the Local Authorities. This is seen in Figures 1a and 1b, where the monthly observations of cards sold and trips taken with the RBC in each community form more-or-less vertical lines which are clearly distinguishable from each other due to the substantial price differences indicated on the horizontal axis. Amongst communities there is a clear negative relationship between the price of the RBC and the purchases of cards as well the number of trips.

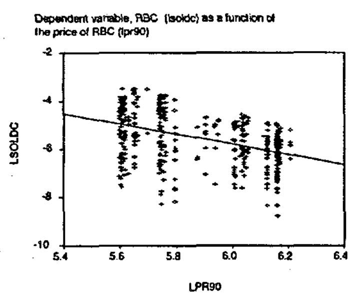


Figure 1a Scatter plot of RBC (cards) and the price of RBC

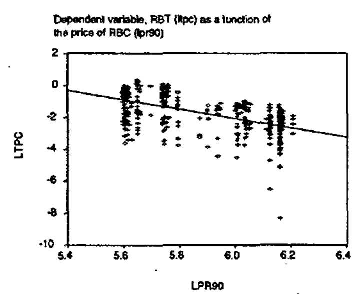


Figure 1b Scatter plot of RBT (trips) and the price of RBC

In an earlier phase of this project own- and cross-price elasticities as well as and income and service elasticities of RBC and RBT demand have been estimated for the two regions (Dargay and Pekkarinen 1996). The estimated own-price elasticity of the RBC varies from -0.5 to -0.9 (from -0.8 to -1.3) in the short (long) run depending on applied functional form[2]. The own-price sensitivity of the demand for trips (RBT) appears to be

[2] The log-log functional form produced slightly lower estimates.

slightly lower both in the short run (from -0.2 to -0.7) and in the long run (between -0.2 and -1.1). The income elasticities are negative for both RBC and RBT demand, indicating the 'inferior" nature of bus travel. The service elasticities[3] are positive in both cases, but lower for the demand for cards (0.1 - 0.4) than for trips (0.8 - 2.6), so that service supply seems not be very important for the decision of purchasing a card, but very essential for actual number of trips made by card. Regarding cross-price elasticities, the fuel price was found to influence the number of trips made, but not the number of cards sold. The elasticity of trips with respect to the petrol price was found to be 0.4 and 0.9 in the short and long run, respectively.

Although the introduction of the RBC has led to a reduction in the price of bus travel, it has not been possible to estimate the effect on total bus demand by econometric methods. The reason for this is that comparable information is not available in the areas covered by the RBC system. Neither has it been possible to estimate econometrically the effect of the introduction of the RBC system on the demand for other modes of transport, again due to the lack of suitable data[4] Thus in order to estimate the impact of the RBC system on total travel demand and mode choice - which is required for the computation of the effects on energy consumption - we are forced to rely on survey data obtained from RBC users. These surveys were not specifically carried out for the present study and the information contained is limited.

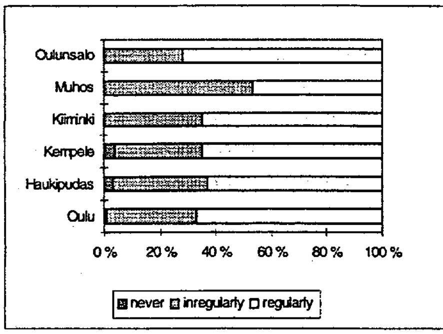
The Oulu area

In the Oulu area, the users of the RBC were surveyed in March 1993. The response rates for the individual communities varied from 14 % in Haukipudas to 43 % in Kempele. Of the respondents 70 - 80 % were women. The age structure of the respondents varies substantially in the different communities: in Muhos only 7 % were between 12 and 21 years old while in three communities this age group accounted for nearly 50 %. The proportion of travellers aged 31 - 50 years varied also from 22 5 to 60 % across communtiies. The age structure of the respondents implies that the trip purpose varies: in some communities the main group of users is commuters, while others it is school children and students.

About a half of the respondents (40 - 67 %) paid their trips by cash fare before the introduction of the RBC system. The regularity of bus use by the respondents prior to the RBC system is shown in Figure 2a. In most communities about one third of RBC travellers (28 - 35 %) used bus irregularly or seldom previously. In three communties, from 1 - 4 % of RBC travellers had never used the bus before. Since the RBC is only

[3] The service quality variable used is total veh-km of one dominant operator in each RBC system area.
[4] Estimation of the demand for total bus travel and the demand for car travel in the two RBC areas (and the relevant price and cross-price elasticities) will be carried out in the next phase of this project.

economic for regular bus use, the information on previous bus use implies that a significant proportion of the trips made by RBC where previously made by other modes.



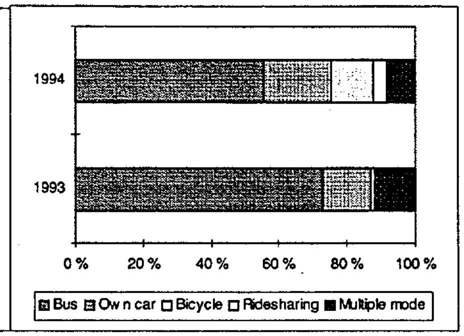


Figure 2a Regularity of bus use before RBC system in Oulu area

Figure 2b Previous main mode before RBC system in Kuopio area

The Kuopio area

In Kuopio, the passengers purchasing the RBC card were surveyed twice, once in October 1993 and once in October 1994, by providing a questionnaire along with the card. Questions more useful to our study were posed, particularly concerning mode used before the RBC. However, the response rates were rather low: 50 % in 1993 and 20 % in 1994. Of the respondents in 1993 survey, 73 % were women. About a half of all respondents were younger than 20 years of age and in the 1994 survey slightly more than a third were below 20 years old. However, of the male respondents, 76 % were below 20 years in 1993, and 70 % in 1994, suggesting that the RBC is relatively infrequently used for work trips among men. Apparently, the RBC system is very popular among students and school youth travelling daily from home to university, polytechnic/college, high-schools[5] and training schools. People of age from 31 - 50 years were the next largest user group: 28.5 % in 1993 and 46 % in 1994.

The main mode used by the respondents before the use of the RBC is shown in Figure 2b. Although most RBC users were also bus users previously, the proportions are rather different in the two surveys: 73 % in 1993 and 55 % in 1994. Both surveys indicate a substantial shift from car use: 14 % in 1993 and 20 % in 1994. Only the 1994 survey indicates a significant shift from bicycle, 12 %, while the comparable figure for 1993 is

[5] In the Kuopio area there are several small communities without their own high-school while in the Oulu area only Tyrnava is without a high-school.

less than 1 %. Car-pooling and use multiple/various modes[6] account for about 12 % in both surveys.

Although both the Oulu and Kuopio surveys are limited in information and the response rates rather low, they provide the only information currently available concerning the modes used previous to the introduction of the RBC. Given the uncertainty involved, in the calculations on energy savings that follow we will use upper and lower 'estimates' of a shift from car and bicycle use obtained on the basis of the surveys.

In Oulu, a 'high' estimate of trips previously not made by bus can be obtained by assuming that seldom or irregular bus travel means about 6 trips per month (of the average of 60 made by RBC), so that 10 % of RBC trips for this group could be allocated to bus as previous mode. This results in an 'estimate' of trips previously made by other modes of 30 %, assuming an equal trip rate for all passengers. A low 'estimate' is obtained by assuming seldom or irregular travel means about 20 trips per month, so that trips previously made by other modes would be 20 %. From the Kuopio surveys, we find that 27 % (1993) and 45 % (1994) were made by other modes. The response in the 1993 survey lies within the suggested 20 % to 30 % interval, and the low response rate of the 1994 survey makes us hesitant to use the results obtained.

It remains to split these trips into car and bicycle trips. The only available information is from the Kuopio surveys, but given the different rates of car (15 % and 24 %, including ride-sharing) and particularly bicycle use (0.05 % and 12%), it is difficult to arrive at any firm estimates. However, on the basis of these results, we will assume for the current study low and high estimates of the shift from car use of 15 % and 25 %, and a shift from bicycle use of 5 %.[7] In the ongoing work, new surveys will be carried out, and other information analysed in order to improve the 'estimates'.

3 COST-EFFECTIVENESS CALCULATIONS

Summary measures of RBC purchase and use, various types of bus fares and other background information are shown in Table 1. We see that the monthly average number of cards sold and the number of trips made per card is higher in Oulu than in Kuopio. The average distance per trip in the Kuopio area - 36 kms. - is more than twice that in Oulu. This is explained by the differences in population density in the two areas. The differences in average fares reflect the differences in average trip length between the

[6] These included the use of bus, private cars, bicycle, walking, and also train.
[7] In two other areas which have introduced the RBC system (Joensuu 1995, Upper-Savo 1996) the shift from car use is estimated to be about 15 % and the shift from cycle 4 % and 5 % respectively.

regions, but it is clear from comparison of the different fares that the level of subsidy for the RBC is also much higher in Kuopio.

Table 1 Summary of monthly passenger data in Oulu and Kuopio areas[8]

	Oulu area	Kuopio area	Two areas
Sold cards, RBC	99	85	92
Trips by cards, RBT	5,201	3,676	4,445
Trips per card, TCARD	60	45	53
Real price of RBC, PR90	328	417	372
Real price of 40 trips ticket, PS90	348	682	482
Real single fare, CASH90	12.05	21.60	16.80
Average trip lenght, DIST (km)	17	36	26
Passenger km by RBC, PKM	68,955	86,543	77,662
Total bus trips, ALL	560,172	436,786	499,087
Total vehicle kms, VKM	519,654	407,345	464,054
Total pass. kms, $PKMALL_1$	9,586,021	7,408,576	8,629,265
Average load factor, $LOAD_2$	18	18	18
No. of communities	8	12	20
No. of bus operators	3	8	11

$_1$ Average distance is approximated for Kuopio area by Kuopio city and Siilinjarvi only (21.5 km) because the company, Kuopion Liikenne, operates mostly within these two communities.
$_2$ The load factor is a ratio PKMALL/VKM, but a load factor of 16 is used for the calculations of energy use after discussion with operators

Measures of the cost-effectiveness of the subsidisation policy are calculated per card, per trip and per passenger kilometre. The real subsidy paid per a card (RBC) is calculated as:

For Oulu area: Subsidy90 = (tcard * cash90 * (100 - disc%)) - pr90
For Kuopio area: Subsidy90 = (tcard * cash90 * 0.75) - pr90

where *tcard* is the average number of trips made per card and month by community, *cash90* is the fare for a single trip of average trip length, *disc%* is the discount percentage depending on the magnitude of *tcard* (the more trips per card, the greater the discount), and *pr90* is the price of a RBC card for travellers. For the Kuopio area the discount is 25 % for all communities, because the number of trips per card does not vary significantly, but in Oulu it ranges from 25 % to 40 % (from below 40 to over 60 trips per a card).

The above formula is that used to determine the actual subsidies paid each month to bus operators by local and state governments on a 50-50 basis. The means of the monthly time series for all communties in each area are presented in Table 2, and the variation

[8] Information was not available from all operators with an exception of RBC. The figures presented in the table represent about 90 % of total supply and travel in Oulu, and only 50 % in Kuopio.

accross communities within each area is given by the Min - Max figures. In 1995, the yearly subsidy in nominal terms was 0.9 Million FIM in Oulu and 2.7 Million FIM in Kuopio, respectively.

Table 2 Monthly average subsidies paid for RBC in the Oulu and Kuopio areas, and the total monthly subsidy by community

	Oulu	Kuopio	Two areas[1]
Subsidy, FIM/card	105	343	223
Min - Max	42 - 309	124 - 724	42 - 724
Real subsidy, FIM/card	94	312	202
Min - Max (1990=100)	38 - 274	114 - 653	38 - 653
Real subsidy, FIM/trip	2.08	7.99	5
Min - Max	0.18 - 13.25	0 - 28.10	0 - 28.10
Real subsidy, FIM/pkm	0.12	0.22	0.17
Min - Max	0.02 - 0.54	0 - 0.67	0 - 0.67
Total monthly subsidy/comm.	7,846	18,611	13,175
Min - Max	110 - 32,200	0 - 113,769	0 - 113,769

[1] Figures are calculated as means of the sample consisting of both areas.

The variation across communities is great, especially in the Oulu area where the largest real subsidy per card (Ii) is over seven times the smallest (Kempele, Oulu, Oulunsalo). The subsidy per trip is slightly over 2 FIM in Oulu but almost 8 FIM in Kuopio on average. The enormous variation of subsidy per trip is due to different pricing policies and also differences in the number of trips per card. The subsidy actually paid correlates negatively with the number of cards sold, trips made, and number of trips per each card. The subsidy per passenger kilometre in Kuopio is only twice as high as in Oulu, which shows that trip lengths are longer in Kuopio than in Oulu.

These measures of cost-effectiveness will be used in another part of this project for comparison with similar measures for other policies designed to encourage public transport use. One of the prime concerns will be to compare the effectiveness of different subsidisation policies aimed at providing bus services on non-profitable routes in sparsely populated areas.

4 CONSEQUENCES OF THE FARES POLICY ON ENERGY USE IN TRANSPORT

The change in energy consumption resulting from a public transport subsidisation policy can be calculated as:

$$(1) \quad \Delta E = \Delta pkm_{car} \times (MJ/pkm_{car}) + \Delta pkm_{bus} \times (MJ/pkm_{bus}) + \Delta(MJ/pkm_{bus}) \times pkm_{bus},$$

where pkm_{car} and pkm_{bus} are passenger kilometres made by cars and bus, respectively, the terms in parentheses are energy use per passenger kilometre by each mode and Δ denotes the changes in each factor. The first two terms on the RHS of the equation give the changes in energy use for car and bus travel, respectively, assuming constant load factors, while the last term measures the change in energy consumption due to changes in bus load factors, which may also result from increasing bus use. The change in bus use Δpkm_{bus} can be further broken down into the shift from car use, the shift from non-motorised modes such as walking and cycling and generated trips so that

(2) $$\Delta pkm_{bus} = -\Delta pkm_{car} - \Delta pkm_{nm} + \Delta pkm_{gen}$$

so that equation 1 can be re-written as:

(3) $$\Delta E = \underbrace{\Delta pkm_{car} \times (MJ/pkm_{car} - MJ/pkm_{bus})}_{(1)} + \underbrace{(\Delta pkm_{gen} - \Delta pkm_{nm}) \times (MJ/pkm_{bus})}_{(2)} + \underbrace{\Delta(MJ/pkm_{bus}) \times pkm_{bus}}_{(3)}$$

The total change in energy use can be greater than, equal to or less than zero depending on the magnitudes of the three terms this equation:

(1) The decreased energy use per pkm because of shifts from car use (since $\Delta pkm_{car} \leq 0$ and pkm energy consumption is greater for car than bus at normal load factors).

(2) Increased energy use due to shifts from a) non-motorised modes (walking and cycling) and b) generated bus trips (since $\Delta pkm_{nm} \leq 0$ and $\Delta pkm_{gen} \geq 0$).

(3) Decreased energy use per pkm for bus trips due to the higher load factors resulting from increased passenger trips.

In this study, only (1) and (2a) are evaluated because of lack of sufficient data. Since (2b) and (3) have opposite effects on energy consumption, the estimates can either over- or under-estimate the actual changes. In order to calculate fuel consumption per passenger-kilometre it is necessary to have information on fuel consumption per vehicle-kilometre and average occupancy rates. From information received from bus operators, the estimated average fuel use employed for the calculations is 34 l/100 km[9].

Multiplying the average fuel use with the conversion factor 35.58 MJ/l[10] yields an energy use of 12.1 MJ/vkm. Assuming an average load factor of 16 passengers per

[9] Fuel use varied from 32 - 35 l/100 km in Kuopio and 32 - 39 l/100 km in Oulu.
[10] The converting factor used is 32.32 for petrol and 35.58 MJ/l for diesel respectively: Statistical Office.

vehicle results in a fuel consumption of 0.76 MJ/pkm. For cars, the comparable figure is 1.8 MJ/pkm, assuming an average fuel consumption of 8 l/100 km, a conversion factor of 32.32 MJ/km and an occupancy rate of 1.4[11].

The changes in the use of cars and non-motorised modes are calculated from the estimates of total passenger kilometres by RBC (*PKM* in Table 1), and the information on modes used before the introduction of the RBC system discussed in Section 3. The decrease in car passenger kilometres is calculated as $\Delta pkm_{car} = -s_c \times PKM$, where s_c is the proportion of trips shifted from car (15 % and 25 %). The decrease in the use of non-motorised modes is obtained as $\Delta pkm_{nm} = -s_{nm} \times PKM$, where s_{nm} is the proportion of trips previously made by cycle (5 %).

In the calculation of changes in energy efficiency (Table 3), both the shift from car use and from cycle have been taken into account. The former reduces energy use per passenger kilometre, while the latter increases it. Depending on the shift from car assumed, the RBC system has reduced energy use by between 98 and 184 thousand MJ per year in Oulu and between 123 and 231 MJ in Kuopio. The greater energy savings in Kuopio are the result of longer trip lengths and total kilometres by RBC in this area. However, according to our calculations, each MJ saved in Kuopio cost twice as much as in Oulu (see Table 2).

Table 3 Energy use benefits (and losses) of shifts from car (bicycle) use to the use of the RBC system in Oulu and Kuopio areas

	Oulu	Oulu	Kuopio	Kuopio	Both areas	Both areas
Shift from car use to RBC (%)	15	25	15	25	15	25
Fuel efficieny by bus, MJ/vkm	12.1	12.1	12.1	12.1	12.1	12.1
Fuel efficiency by bus, MJ/pkm	0.76	0.76	0.76	0.76	0.76	0.76
Change in fuel efficiency, MJ/month (Shift from car use)	10,757	17,928	13,501	22,501	12,115	20,192
Change if fuel efficiency, MJ/month (Shift from cycle)	-2,620	-2,620	-3,289	-3,289	-2,951	-2,951
Annual change in fuel efficiency MJ/year	97,644	183,696	122,544	230,544	109,968	206,892
Energy savings/subsidy unit MJ/FIM/month[1]	1.04	1.95	0.55	1.03	0.70	1.31

[1] For 'both areas' the monthly total subsidy is taken as the sum of the total subsidy in both regions.

Unfortunately, we know of no other studies with which we can compare our results concerning the energy savings of public transport subsidies. There are, however, a few sudies dealing with the energy savings of a shift from cars to buses. Schipper et al.

[11] The occupancy rate for private cars for commuting is 1.4 but is higher for other trip purposes.

(1992) concluded in a study of eight OECD countries in 1987 that one pkm transferring from cars to buses reduced energy use from 0.40 (Norway) - 1.81 (US) MJ. Our figure for Oulu and Kuopio - 1.04 MJ - lies midway in this range. From these figures, equivalent subsidies per pkm would only be less than half as effective in terms of energy savings in Norway as in Finland and nearly twice as effective in the US. In the UK, the fuel consumption of bus travel (Stokes and Dargay 1993) is higher (1.29 MJ/pkm) than in Finland, as is the fuel consumption of private cars (2.03 MJ/pkm), so that the energy savings of a shift from car use to public transport (0.74 MJ/pkm) is lower than in Finland. In this case, equivalent subsidies per pkm would be less efficient in the UK.

CONCLUSIONS

The results presented in this paper show that the demand effects, the cost-effectiveness as well as the energy savings of subsidisation policies can be calculated and evaluated. The regional bus card systems studied here are one example of new ticket and pricing policies employed in many countries for encouraging travellers use public transport and leave private cars at home. The participants of the RBC systems, now nearly 20 different areas, are very satisfied with the short-run effects on demand. Only the increasing financial burden to communities and county governments creates a barrier for further extension of the systems.

The demand elasticities help the planners and financers set prices as optimally as possible at the communal level. The cost-effectiveness measures of the subsidies give information to financers about how much they have to pay for each new user, trip and passenger kilometre. The required subsidy has varied during 1992 - 1995 in the two areas studied from 12 to 22 (Finnish) pennies per passenger kilometre. The subsidy paid in these two areas is around 30 % in Oulu and about 50 % in Kuopio of the normal fare per pkm, based on the price of the 40 trips' ticket.

The energy benefits of the subsidies appear to be substantial, on average between 110 and 207 thousand MJ/year for both regions, depending on the assumptions made. The benefit per subsidy unit is between 0.7 and 1.3 MJ/FIM, that is an average cost of 1 FIM per MJ. Whether the RBC system is an economically efficient means of reducing energy use will depend on the costs of other energy saving measures.

ACKNOWLEDGEMENTS

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Session 5.b Methods, models and data

Chairman:
Knud Mosekjær, Assn. Danish Electric Utilities, Denmark

OPTIMAL LEVEL OF MULTIPLE TYPES OF TRANSPORTATION WITH SEVERAL EXTERNALITIES

By Jens Hauch, Danish Economic Council, Denmark

1 INTRODUCTION[1]

In recent years, the level of transportation has increased dramatically. This has, seen from a social point of view, both beneficial and damaging consequences. The possibility of transportation gives households larger freedom in choosing between commodities and in choosing address. Firms have increased possibilities of attracting qualified employees and compete in larger markets, which might reduce the deadweight loss from imperfect competition.

There exist several types of transportation, each of which creates several externalities. The transportation types analysed here are domestic transportation on land, e.g. transportation in buses, trains and trucks. Transportation has several costs, some of which are taken into account by the agent when deciding on transportation. The agent takes his private costs such as fuel costs, capital costs, ticket price etc. into account. Transportation also gives rise to several externalities that are not taken into account by the agent. These externalities include accidents, air pollution, noise etc. Furthermore, transportation increases wear and tear on the infrastructure. In Denmark, the agent does not pay such costs directly, and therefore they do not affect the transportation decision.

The transportation mode chosen by the agent therefore might differ from the choice made by a social planner who takes all effects of transportation i.e. private and social costs into account. Transportation regulation is necessary to achieve the socially optimal level.

Transportation can be regulated in several ways. In some cases, direct regulation can reduce externalities significantly. An example of this is technical standards such as catalytic converters on cars that reduce the level of nitrogen oxide. On the other hand, with present technology some externalities are harder to reduce without reducing the level of transportation, e.g. wear and tear and carbon dioxide. Carbon dioxide can only be reduced by increased fuel efficiency. The present transportation system already widely use technical standards, yet there might be further possibilities of using technical standards in regulation. In this paper, only reductions in transportation are considered as instruments for reducing externalities, and the present level of technical standards is implicitly assumed constant in the model.

The externalities might differ in cities and in the country as the level of transportation and the damage functions might be different. This means that an optimal regulation of

[1]The views posed in the paper are not necessarily shared by the Chairmanship of the Danish Economic Council. The author would like to thank Jan V. Hansen, Peter Brixen and Jørgen Birk Mortensen for many helpful comments and clarifying discussions. The author is however solely responsible for the paper and problems and mistakes it may contain.

transportation should implement different shadow values depending on geography. Such aspects will not be taken into account in this paper.

The benefits of transportation (or the costs of reducing transportation) will typically be reflected in the demand functions for transportation, and from a neoclassical point of view they will always be included in the demand for transportation. Public transportation is however heavily subsidized, which indicates that regulating authorities have preferences for public transportation. For example, for social reasons the government ensures that even people that cannot afford a car have the possibility of travelling on public transport routes that would not be provided without the subsidies. Another reason for the subsidies might be regional development. In the model, the public transportation subsidies are assumed to perfectly reflect the authorities value of supplying public transportation and are therefore added to demand functions for public transportation.

When it comes to private transportation, the model works under the assumption that all positive externalities are included in the demand functions. If there are positive external effects not reflected in demand functions, the model will obtain a suboptimal level of transportation.

The purpose of this paper is to analyse how far the present transportation system is from the optimum with todays technology. Necessary taxes and effects on emissions will be analysed together with the costs of different tax systems.

The model presented here is a partial equilibrium model for transportation markets which solves for optimality when negative externalities are taken into account. There might be significant effects on rest of the economy from large changes in transportation. In general, such macro effects depend on the possibility of substituting between transportation and other inputs in production/consumption. In the partial model presented here, these effects should be reflected in the demand for transportation. There might however be macro effects that are not reflected in the demand functions, especially in the short run. Another approach to this could be a general equilibrium model of the economy with a special focus on transportation. This will however need a much larger modelling tool.

The present model should not be interpreted as a policy tool, but rather as an example of how environmental effects can be included in a model which also includes economic effects of regulation. The model does not solve for optimality in a long run steady state, but shows in principle what should have been done in the base year for optimality to have been obtained through transportation reductions. The model represents work in progress and currently has several weaknesses. Use of its results in real world policy making is therefore, limited.

In section 2, the theoretical background for modelling this kind of problem is given, a model is put together and solved for optimality. In section 3, the data needs and calibration of the model are described. In section 4, results are presented, and in section 5, the paper is rounded off with conclusions.

2 THEORETICAL BACKGROUND

The optimization problem that should be solved simultaneously can be formulated in the following way.

Assume there exist J types of transportation and I externalities. Relation (1) defines the marginal damage MD_i of an externality as a function of the level of the externality, E_i. Note that it is implicitly assumed that the damage from one externality is not directly correlated with the level of other types of externalities. This assumption is not necessary in the theoretical model, but will make life a lot easier in the empirical work.

$$MD_i = MD_i(E_i) \qquad i = 1,.....,I \qquad (1)$$

(1) describes a normal marginal damage curve. One example is the damage in monetary terms of one extra kilo of sulfur dioxide as a function of the emission of sulfur dioxide.

Relation (2) defines the total damage of an externality as the area under the *MD* curve. The only reason for introducing this is notational convenience later on.

$$\int_{o}^{E_i} MD(E_i)dE_i = TD(E_i) \qquad i = 1,.....,I \tag{2}$$

Relation (3) gives the size of externality E_i in physical terms, as a function of the contribution to this externality from the different types of transportation, x_j. An example of this relationship is the emission of sulfur dioxide that is given by the sum of the emissions from each type of transportation, where those emissions are given by the amounts of transportation times the emission coefficients. In that case, (3) has a very simple linear functional form. In other cases, this relationship is not linear, e.g. the increase in the noise level from one extra car measured in decibels is dependent on the total level of noise, and the functional form is more complex.

$$E_i = E_i(x_1,.....,x_J) \qquad i = 1,...,I \tag{3}$$

Relation (1) and (3) can be written as (4)

$$MD_i = MD_i(E_i(x_1,.....,x_J)) \qquad i = 1,...,I \tag{4}$$

Relation (5) gives the demand for transportation type *j* as a function of the prices of all types of transportation $(p_1,...,p_J)$.

$$x_j = D_j(p_1,.....,p_J) \qquad j = 1,...,J \tag{5}$$

It can be shown that under nonrestrictive assumptions (5) gives functions P_j, $j = 1,...,J$ that decide the price p_j as a function of $x_1, ...x_J$. They are not the inverse of the *D* functions, as they would be in a one market case.

Relation (6) is the "supply" of transportation type *j*. This equals the marginal user costs MUC_j of x_j and the tax t_j on x_j. *MUC* is assumed to be independent of the level of transportation for each transportation mode. This assumption is again not necessary, but makes life a lot easier in the empirical work later on. Authorities are assumed to implement constant unit taxes. These two assumptions imply that the supply cure for each type of transportation is horizontal.

$$p_j = t_j + MUC_j, \qquad j = 1,...,J \tag{6}$$

Consumer private surplus of transportation x_j, (CPS_j), is defined in the following way:

$$CPS_j(x_1,...,x_J) = \int_0^{\hat{x}_j} [P_j(\hat{x}_1,...,x_j,...,\hat{x}_J)]dx_j - \hat{x}_j P_j(\hat{x}_1,...,\hat{x}_J) \qquad j = 1,...,J \tag{7}$$

Consumer private surplus equals the total private surplus of transportation since the *MUC* is horizontal, and the producer surplus therefore equals zero. Again note that *CPS* does not take the externalities into account, it only focuses on the private value of transportation. Because the supply curve for transportation is horizontal, producers surplus equals zero.

In order to find the optimal level of transportation, we need a criteria function that maximizes the total social surplus, *SS*, of transportation. The difference between *CPS* and *SS* is that the latter takes the existence of externalities into account, along with tax revenues. We look at J types of transportation and thereby have J instruments to regulate. There exist I externalities. It is not possible, if $I > J$, to achieve any combination of I externalities. It is therefore not possible, in general to ensure that the usual optimization criteria $MD(E_i) = MC(E_i)$ is achieved for $i = 1,...,I$. We instead maximize the total social surplus given by the sum of consumers surplus of all types of transportation plus tax revenue minus the sum of total damage from all the externalities. Define in (8) social benefit from transportation type j $SB_j(x_j)$.

$$SB_j(x_1,...,x_J) = CPS_j(x_1,...,x_J) + (P_j(x_1,...,x_J) - MUC_j)x_j \qquad j = 1,...,J \qquad (8)$$

We get the following criteria function (9).

$$\max_{x_1,...,x_J} \left[\sum_{j=1}^{J} SB_j(x_1,...,x_J) - \sum_{i=1}^{I} TD_i(E_i(x_1,...,x_J))\right] \qquad j = 1,...,J \qquad (9)$$

The problem is solved by finding the necessary first order conditions, which gives the following result, (10):

$$\sum_{j=1}^{J} \frac{\partial SB_j(x_1,...,x_J)}{\partial x_{\tilde{j}}} = \sum_{i=1}^{I} \frac{\partial TD_i(E_1,...,E_I)}{\partial E_i} \cdot \frac{\partial E(x_1,...,x_J)}{\partial x_{\tilde{j}}}, \qquad \tilde{j} = 1,...,J \qquad (10)$$

The result is the following: The change in the sum of social benefit by a marginal change in transportation type $\tilde{j}$ shall in optimum equal the change in the sum of the value of the externalities. Or to put it in another way, using (8): The sum of marginal consumers private benefits plus marginal tax revenue shall equal the sum of marginal damages for each type of transportation. It is not possible to solve (9) for one type of transportation without paying attention to the other types; Marginal damage from one type of transportation depends on the level of the other types of transportation, just as the marginal benefit of one type of transportation depends on the level of other types of transportation.

From (6) it is possible to get the resulting optimal tax for each transport type reflecting the shadow value of transportation in optimum. Those shadow values will only by coincidence be equal. If the optimal transportation level should be achieved by taxing transportation, it would therefore not be possible to use the same tax on all types of transportation. In reality, the loss from using only one tax might, however, be limited.

There are costs associated with administrating a complex set of tax rules. One way of introducing different taxes that are dependent on level of transportation would be road pricing that might be expensive due to high capital costs. One frequently used method to implement taxes on transportation is fuel taxes. Fuel taxes are relatively easy to administrate since they, in contrast to road pricing, do not demand any investment in physical capital. The problem with fuel taxes is that it is hard to discriminate between types of transportation if several types of transportation use the same fuel. It is also impossible to discriminate transportation geographically, which could be advantageous if externalities differ geographically, e.g. between cities and country.

In the existing system, there are some possibilities of discriminating between transportation types. It is possible for the regulating authorities to affect the price of public transportation since the state is by far the largest public transport supplier. In private transportation it is possible to differentiate between prices of petrol and diesel and thereby to discriminate between cars and trucks. There might still be problems in taxing vans optimally as they use petrol or diesel, but vans only make up a very small part of total transportation and the loss from an inoptimal regulation of vans will therefore probably be small. Therefore it might not be much more expensive to administrate a system with several taxes than a system with one tax. If road pricing is used, the costs will probably be high, but they will contain the possibility of geographic discrimination.

When several markets are introduced, the Marshallian method of using change in the sum of consumers and producers surplus over markets as an indicator of the change in welfare is not necessarily correct.[2] When there is more than one market in which prices are shifting, the use of changes in consumers surplus as an indicator of the change in welfare resulting from a shift in prices may be problematic, Auerbach (1985). The problem is that consumers surplus does not come from the underlying utility function. The consequence is path dependence in calculating *CS*: As more prices are changing the order in which the different consumers surpluses are calculated becomes important. This result is originally stated by Hotelling (1936). Auerbach demonstrates the result in a simple two market example.

There are conditions under which the problem is not present: All cross price derivatives should be equal, Hotelling (1938). This condition is restrictive and will not generally be satisfied. In the model presented here, the condition will be fulfilled by setting all cross price elasticities equal to zero[3].

3 MODEL CALIBRATION

The model is calibrated with 1993 as base year. It describes what would be optimal regulation with todays technology, income and other macro variables.

In a study like this a large number of data is needed. The data can be separated into two groups, data used for estimating the demand functions and the welfare functions in one group, and data used for damage functions in another group.

The demand functions are based on empirical work by Brixen (1996). The functional form in demand used is the following:

$$x_j(p_1,\dots,p_J) = \gamma_j p_1^{\alpha_{1j}} \cdot \dots \cdot p_J^{\alpha_{Jj}}, \qquad j = 1,\dots,J \tag{11}$$

[2]Also in the single market case this method rests on the assumption that the marginal utility of income is constant, which is typically not the case.

[3]Diewert (1992) describes a welfare indicator he calls the Fisher Welfare Change Indicator. This welfare change indicator is an approximation to the true change in welfare for a cost function with satisfying 2. order approximative qualities. This means it is equal to equivalent variation. This indicator should in principle be useable in the model described here, and could relax the condition on cross price derivatives. Further work on the model should be to implement this indicator as an objective function.

The demand depends on own price and cross prices. Own and cross price elasticities are given by the α's. γ's are level constants calibrated from 1993 data. All parameters other than transportation prices that might affect the demand for transportation are assumed constant at the base year level. They could be parameters such as the income level, change in comfort in transportation, technological changes etc. They are reflected in the calibration of the γ's.

A set of elasticities can be calculated from Brixen (1996). The assumption that all cross price derivatives should be equal could not be verified empirically, but it is the calibration assumed that all cross price elasticities equals zero. This assumption implies that the possibilities of substituting between types of transportation are more restricted in the model than they might be in reality. The objective function will attain a lower value, but it is not possible to say anything general about the effect on transportation or externality level. The estimated elasticities are reported in table 1.

Table 1. Transportation data, 1993

Transportation type	Transportation level, mill. person/ton kilometre	Tax, DKK pr. person/ton km.	Own price elasticity
Cars	57060[a]	0.16	-0.54
Buses	9502[a]	-0.19	-0.55
Person trains	4798[a]	-0.65	-0.55
Vans	480[b]	2.73	-0.42
Trucks	9047[b]	0.22	-0.92
Freight trains	502[b]	-0.70	-0.5[c]

[a] Person kilometre.
[b] Ton kilometre.
[c] Guesstimated.
Source: Brixen (1996), Danish Economic Council (1996, p. 142) and own calculations.

The reported elasticities are elasticities on the level of transportation when variable transportation costs are changing. For public transportation, such variable costs are the ticket prices/freight prices and Brixens estimated elasticities are used directly. For cars and vans, the elasticities are calculated using estimations from Brixen.

In the actual demand for transportation in Denmark a lot of taxes exist. They should be subtracted from user costs in the search for optimality[4]. Existing taxes are reported in table 1.

The seemingly high tax on vans is a result of the calibration of this composite transportation good. Vans only transport a very small amount of freight but are also used for person transportation. Calculating the tax as either on person transportation or freight transportation will always seem strange as the service from vans is a composite of these.

In order to include damages from externalities into an optimizing model, it is necessary not only to measure the damage in physical terms but also in monetary terms. The choice of valuation method and the actual valuation of external effects of transportation could be the subject for several articles in itself. Though very interesting, the choice between

[4] Subsidies of public transportation are, as previously mentioned, seen as reflecting regulating authorities preferences for public transportation and therefore are also added to demand curves.

valuation methods will only be dealt with very briefly here, a good overview can be gained by reading Freemann (1985). There should be no doubt that existing valuation methods contain serious problems that may or may not be solved in the future. These problems will also be present in a model based on those methods. Existing valuation methods give the best estimation one can use today in valuing external effects in monetary terms, and should be used in this light.

Estimation of the damage functions in this paper is based on work done by the Danish Economic Council (1996) and Larsen(1996). The valuation methods used are based on a number of different techniques but when possible direct methods have been used. Central data are shown in table 2.

For the emission of the air pollutants nitrogen oxides, particulate and hydro carbon oxide the marginal damage is assumed to be a linearly increasing function of the level of emission, passing through the origin and through the present level of emission and damage (basically a linear function is estimated on the background of two points). This is of course a very rough approximation that can only be seen as satisfying within a limited interval of changes in emission levels.

When it comes to carbon dioxide and sulphur dioxide, marginal damage is assumed to be constant at the present level. The reason for this is not a general assumption that the marginal damage is constant, but an anticipation that the damaging effects of carbon dioxide are a function of the global level of carbon dioxide and that Denmark only contributes marginally to global emissions. It is reasonable to assume that the damage from the Danish emissions is equal to the marginal global value, no matter what the change in the Danish emissions. It is, of course debatable whether it is possible to estimate the present value of a damage assumed to happen once in the future, but I will for the moment leave that discussion to other.

Table 2. Data on externalities, 1993

Externality type	Total costs, mill. DKK	Emissions, 1000 ton.
Accidents	13829	-
noise	4980	-
wear and tear	673	-
nitrogen oxide	9172	98
sulphur dioxide	495	9
particulate	399	4.3
hydro carbon oxide	2546	98
carbon dioxide	2020	10096

Source: Larsen (1996) and Danish Economic Council (1996).

A further assumption is that emission coefficients in air pollution are constant and therefore that the emissions of the different kinds of air pollutants are linearly increasing with the level of the different types of transportation. The marginal damage from noise is, like the damage from carbon dioxide and sulphur dioxide assumed to be constant at the present level. This assumption, though valid for small changes in the level of transportation, is not without problems and further work on this subject could concentrate on more advanced functional forms for noise damages. The marginal damage from wear and tear of roads is assumed to be a constant function of transportation at the present level. This is not an unreasonable assumption. The marginal damage from accidents is assumed to be constant as a function of the number of accidents, which is reasonable, but the number of accidents is not a linear function of the level of transportation. The Danish Economic Council finds, based on work by the Danish Road Directorate, that the total number of accidents is exponentially increasing with the level of transportation by a power of 0.6. Consequently, the marginal number of accidents is a decreasing function of the transportation level. This means that the marginal damage from accidents will be a decreasing function of the level of transportation. This could potentially create problems in finding a single optimum but it turns out to be no problem in the model.

4 RESULTS

Two scenarios are run. In one of them multiple taxes are used. In the other, the effect of using a uniform fuel tax is analysed. By comparing the value of the objective function in these two scenarios one can get an impression of the cost of restricting oneself to using only one tax. This cost gives the upper level of the administrative costs that should be used to avoid restricting one self to only one tax. The goal of introducing taxes in this model is not to raise revenue with least cost to society, but rather to solve an environmental problem with least costs to society. The tax revenue however enters the social benefit function.

It should once again be noted that the model, because of several theoretical and empirical reasons, only gives a very rough picture of the real world. This should be remembered when interpreting the results.

The first scenario analyses the effect of introducing an optimal regulation of transportation. Authorities can use one tax on each type of transportation. As previously described, it is impossible to use one tax for each type of externalities as the number of transportation types puts linear restrictions on the number of instruments. The results are summarized in table 3.

Table 3. Optimal transportation with multiple taxes, 1993, 1993 prices

Transportation type	Change in transportation level, %	Tax, DKK pr. person/ ton km.	Tax, DKK pr. l. fuel	Maximum tax[a], DKK pr. l. fuel
Cars	-20.1	0.42	10.0	11.00
Buses	-25.3	0.21	10.7	11.50
Person trains	-25.3	0.31	16.1	17.25
Vans	-18.2	8.70	4.6	5.25
Trucks	-7.2	0.52	7.9	8.50
Freight trains	-4.7	0.37	11.0	12.50

[a]Calculated by Danish Economic Council (1996).

It is seen that in optimum all tax rates are positive, and that all tax rates in the optimal case are higher than in the actual situation[5]. This means that existing taxes does not take external effects of transportation sufficiently into account. Vans seem to be heavily taxed, it should be noted though that the reason for this is a very low load factor, which is seen when the tax is measured in DKK/l fuel. Here vans are taxed at a rate similar to the other types of transportation.

In table 3 are also referred results if the instruments were multiple fuel taxes. Those taxes can be compared to "maximal taxes" calculated by the Danish Economic Council (1996). The maximal taxes are calculated as actual marginal damage from each type of transportation. If the aggregate marginal damages from externalities is an increasing function of the levels of transportation, then maximal taxes will represent an upper limit of taxes. If all marginal damages of transportation were constant, the maximal taxes would equal optimal taxes.

It can be seen that the optimal transport levels are slightly lower than the calculated maximal levels. One could not ex ante be sure that the optimal taxes should be lower than the maximal taxes because the marginal damages of accidents are a decreasing function of the level of transportation. However, this fact is dominated by increasing marginal damages of other externalities. The resulting effects on externalities are given in table 4.

Table 4. Optimal change in levels of externalities

Externality type	Change in externality damage, %
Accidents	-11.9
Noise[a]	-9.9
Wear	-15.2
Nitrogen oxide	-18.8
Sulphur oxide	-17.7
Particulate	-16.4
Hydro carbon oxide	-19.7
Carbon dioxide	-18.2

[a] The reported number is not the change in noise level, but change in damage from noise.

One can see that the levels of all externalities fall by at least 10%. It is also clear that the largest reductions should be in the damages from air pollution. All air pollutants are reduced by at least 16 %.

The uniform tax scenario gives the consequences of implementing *one* optimal tax on fuel. This scenario differs from the multiple tax scenario as authorities now have chosen not to use more than one tax. They have thereby reduced their number of instruments, and it should be expected that the outcome should be less efficient than when multiple taxes are

[5]Remember that public transportation in optimum is assumed to recieve a lump sum subsidy for social and regional reasons. The net result, calculating both social/regional subsidies and environmental taxes, is zero for buses and freight trains. For person trains there will be a net subsidy of 1.6 bill. DKK a year. These are, however, still higher net taxes than the present.

used. If the costs of implementing a single tax system are small relative to the difference in administrative costs, then a single tax system should be preferred to a multiple tax system.

The fuel tax scenario also differs from a scenario with uniform road pricing. The difference occurs because fuel intensive transportation types are taxed more heavily under a fuel tax than under uniform road pricing[6].

Table 5. Effects of one optimal fuel tax

Transportation type	Change in transportation level, %	Tax, DKK pr. person/ ton km.	Tax, DKK pr. l. fuel
Cars	-18.6	0.40	9.5
Buses	-23.3	0.18	9.5
Person trains	-17.4	0.18	9.5
Trucks	-9.6	0.62	9.5
Freight trains	-4.1	0.32	9.5

By comparing the first column in table 5 with the first columns in table 3 it is clear that the consequences on transportation level of only using one tax are minor. Note also that the optimal tax should be 9.5 DKKpr. l fuel in this scenario. This means that trucks will be more heavily taxed than under multiple taxes while the other transportation types will be taxed less than optimally. The small change in transportation levels when only one tax is used indicates that the costs of restricting oneself to one tax might be minor. In table 6 results are presented concerning costs of different kinds of tax systems.

Table 6. Costs of different tax systems relative to the case of optimal taxation

Tax system	Costs relative to optimum,[a] mill. DKK pr. year
Uniform fuel tax	38
No taxes	7677
Present taxes	2249

[a] Vans are not included

From the table we can see that an optimal system of taxes gives large welfare improvements compared to a situation without taxes, about 7.7 bill. DKK a year.

The present tax system for transportation is costly compared to the optimal taxation, amounting about 2 bill. DKK extra a year. This is about 2% of gross output in transportation. The present tax system can therefore in not be said to be optimal. Comparing the present system to a situation withouttransportation taxes it is seen, however, that the present taxes are no worse than a system with no taxes, and therefore represent a step in the right direction.

A uniform fuel tax on transportation, as expected, gives rise to additional costs relative to the optimal situation. Those costs are around 38 mill. DKK a year. When deciding

[6] Vans are excluded from the fuel tax scenario. This is due to analytical problems encountered with vans when a fuel tax is used as instrument.

on which of those systems should be preferred, it is important to take administrative costs into account. These are, as mentioned previously, not included in the model. If the administrative costs of running a system with multiple taxes are less than 38 mill. DKK more expensive to run a year than a system with a single fuel tax, then the multiple tax system should be preferred. Otherwise, a single tax should be preferred.

5 CONCLUSION

The presented model is representative of a group of models that explicitly takes the external effects into account when solving for optimality. A necessary condition for using such models is a valuation of the external effects. This is not without problems but represents the best estimation one can make with the present theoretical and empirical knowledge. Other empirical and theoretical problems also appear, and, therefore, results should be seen in this light and only be taken as very rough estimates.

The model shows that the optimal level of transportation is lower than the present level. One could not ex ante be sure to get this result as the present level is strongly affected by taxes that potentially could be inoptimally high. It can be concluded, however, that the present taxes are all inoptimally small. In optimum, public transportation should face positive taxes, though they should be lower than taxes on private transportation.

All externalities should be reduced significantly in optimum relative to the present situation. The largest reductions should be in air pollution.

There are welfare gains from reducing transportation to the optimal level compared to the level in a world without taxes on transportation. This result would be expected ex ante as externalities are not taken into account in the decision of transportation level in a situation without taxes. The existing tax system improves welfare relative to a system without taxes but is still inoptimal. There are therefore possibilities of improving the tax system.

It is shown that the efficiency costs of reducing the number of taxes are significant, but the major part of the welfare gain can be achieved with only one optimal tax. A system with one tax can achieve 98.3% of the potential gain of regulating transportation. One will, of course, want to get the last 1.7 % of the potential gain (38 mill. DKK a year), but it should be remembered that administrative costs are not included in the model. In the present tax system, there exist some possibilities of putting individual taxes on different kinds of transportation. If the costs of this system could be reduced by more than 38 mill. DKK a year by only using uniform taxation, then this would be preferred to a system of multiple taxes.

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ESTIMATING THE DEMAND FOR FREIGTH TRANSPORT AND FREIGHT TRAFFIC IN A VAR-MODEL

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SUMMARY[1]

Empirical studies on price elasticity and price substitution in the freight transport sector are often based on the firms' demand for *transport*. However, most of the environmental external effects from the freight transport sector are more closely connected with the freight *traffic* volumes (kilometres) than with the *transport* volumes (measured in tonnes kilometres). Therefore, an explicit distinction between demand for freight transport and freight traffic is useful. This can be done by regarding traffic as an input in the shippers' production of transportation services, while the demand for transport is derived from the firms' demand for spatially distributed input that needs to be transported. In this setting an environmental tax may have larger impact on the traffic volumes than on transport volumes.

Intuition suggests that higher transport costs would induce firms to substitute away from »distant and heavy« input and thereby reduce the aggregate transport demand. However, this intuition need not be correct. For some spatial distributions and price structures higher transport costs could result in a constant demand for transport even for »well behaved« firms.

An empirical analysis based on aggregated time series for the freight transport in Denmark by large trucks gives an estimate of -0.81 with respect to traffic volumes, but only -0.47 with respect to transport volumes. The statistical model used is a VAR model and the stationary long run relationships were estimated using the so-called »Johansen Procedure«.

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1 INTRODUCTION

In Denmark, transport activities account for a rising share of the total energy use. Especially, the energy used for transportation of goods on the road has been increasing (see Schipper et al. 1992). Due to the global emission of CO_2 as well as the long list of other external effects of freight transport it is important to find out how transport activities are linked to production and how different economic instruments affect the transport activities, i.e. to estimate price and production elasticities.

Surveys of the studies from the last two decades on price elasticities for freight transportation are given by Oum et al. (1992), Zlatoper and Austrian (1989) and Winston (1985). There are two things to note from these surveys. The first is that only a fairly small number of studies have been published on the price elasticities for goods transportation, while there seem to be an endless number of studies on transportation of persons. The second thing to note is that the empirical studies on freight transportation result in very different price elasticities. In comparison transport of persons generally seems to be price inelastic.

Most of the aggregate studies in the above surveys focus on substitution between transport modes in freight transportation (using a translog or logit model to estimate price substitution between transport modes) while the aggregate transport volumes (often) are left unexplained. This paper focuses on the aggregate transport volumes by trucks, but ignores the issue of substitution. In Denmark, three quarters of all freight transport is carried out by trucks, and a study using the translog approach finds rather limited price substitution among modes in Denmark (Jensen and Bjørner (1995)). This implies that it does make sense to look isolated at the demand for freight transport on roads.

In the next section a small theoretical model is presented, where transport is derived from the firms' demand for inputs. A transport production function is further considered, where traffic is modelled as an input in the transport production function. If there is substitution between traffic and other factors in the production of transport the effect of changing transport costs will differ between aggregate traffic and transport volumes.

2 DERIVED DEMAND FOR FREIGHT TRANSPORT AND TRAFFIC

The demand for transportation is usually being described as having a »derived nature« in the sense that the individual or firm do not receive any kind of satisfaction or benefit from the transport itself. Transport can be viewed as complementary to some other good (buying input from spatially separated input suppliers or driving to a recreative area.). In this section I will set up an illustrative model where freight transport demand has such a derived nature. Mode choice will not be considered, thus there is only one means of transportation (trucks). Firms produce output y using n different inputs (x_i):

$$y = f(x_1,..x_i...x_n) \quad i = 1...n \tag{1}$$

The production function is assumed to be well-behaved (quasi-concave). The supply/production of each input takes place at a specific location, which can be described by a parameter (d_i) measuring the distance between the supplier of x_i and the place of production of y and another parameter (v_i) measuring the unit weight. The demand for y is assumed to be purely local and the spatial distribution of the supply of inputs is considered as fixed. Alternatively, some firms can be interpreted as retailers.

Together $v_i d_i$ measures the transportation needed in order for a firm to use one unit of x_i. The distance could be zero for a locally produced input, implying that no transport is needed for the firm to use the specific input. Each x_i is sold at a price (p_i) at its location. The firm considers the cost of transporting one tonnes kilometre (p_t) as fixed. The unit cost of inputs for the output-producing firm is given by the price and by the transportation cost:

$$w_i = p_i + v_i d_i p_t \qquad (2)$$

The cost minimizing input demand can be written as a function of output (y) and the vector of unit costs (**w**), which according to (2) is a function of the input prices' vector at their location (**p**) and the transportation cost (p_t).

$$x_i = x_i(\mathbf{w},y) = x_i(\mathbf{p},p_t,y) \qquad (3)$$

The cost function is assumed homogeneous of degree one in unit cost (**w**), so that input demand is homogeneous of degree zero with respect to **w**. In that case it can be seen from (2) that input demand is also homogeneous of degree zero with respect to **p** and p_t. A per cent increase in p_t has the same effect on the demand for each input as a per cent decrease in all the prices at their place of production (**p**):

$$\Delta x_i \bigg/ \left(\frac{\Delta p_t}{p_t}\right) = -\Delta x_i \bigg/ \left(\sum_1^n \frac{\Delta p_i}{p_i}\right) \qquad i=1...n \qquad (4)$$

The derived demand for transportation (TA) for the firm is given as a summation over the cost minimizing bundle of input:

$$TA = \Sigma_i x_i v_i d_i \qquad (5)$$

A change in the transportation price p_t affects the cost of the input differently according to weight and the spatial distribution. Locally produced inputs will not be effected at all[2], while the price of other inputs will rise. The relative price changes imply, that demand for some input may rise, while it will fall for other.

Intuition suggests, that TA should fall when p_t goes up, because of substitution away

2) A number of theoretical models have focussed on the inventory cost as an explanation of transport and traffic (see Winston (1983) or Allen (1977)). In this model, inventory could be looked at as a locally produced factor.

from the »far and heavy« inputs towards the »close and light«. However, this intuition need not be correct. It is possible to find distributions of d_i,v_i,**p** and p_t so that $\Delta TA/\Delta p_t$ is zero. If transport cost rises, the cost of using a far and heavy input will always increase more in absolute prices than locally produced goods. But if the far and heavy inputs have a high price before transportation the relative cost of inputs can be unchanged. Since there is price homogeneity of all x_i with respect to **p** and p_t, price homogeneity also applies to the firms' derived demand for transportation because (6) is a weighted sum of the equation in (4):

$$\Delta TA \ / \left(\frac{\Delta p_t}{p_t}\right) = -\Delta TA \ / \sum_{1}^{n}\left(\frac{\Delta p_i}{p_i}\right) \qquad i = 1....n \tag{6}$$

Transportation services are supplied by trucking firms or shippers, which will be labelled as »shippers« in the following. Traffic, measured in driven kilometres (KK), can be looked upon as an input in the shippers' production function. The price of KK consists of fuel cost, depreciation of the material in use etc. Other inputs in the shippers' production function like management resources and capital are named O. Production of transportation service can be written as a production function.

$$TA = g(KK,O) \tag{7}$$

The production function implies, that the shipper may substitute between driven kilometres and another input. The idea is that shippers by increasing management and capital resources devoted to planning are able to reduce the driven kilometres. This could be due to pooling of a number of different transports. Many trucks drives around only half loaded or even without any load at all (return trips)[3]. Increased planning could improve the average capital utilisation or reduce the number of empty return trips and thereby substitute the kilometres (as well as rolling stock). The derived demand for kilometres can then be written as a function of the shippers' output (TA), the »price« or cost of the driven kilometres (p_{KK}) for the shipper and the price of the other factor(s) in the shippers production function (p_O).

$$KK = KK(p_{KK},p_O,TA) \tag{8}$$

The unit transport cost (C_{TA}) of a cost minimizing shipping firm is given by the cost of driving (p_{kk}) and the other factor prices:

3) In Denmark, the average utilisation of all trucks (larger than 6 ton) has been between 40-42% from 1990 to 1994. These figures include the kilometres driven without any load. Looking only at the trips with load, the average utilisation has been between 51-55%. A 100% utilisation of the capacity is of course unrealistic, but the rather low capacity utilisation suggest that there is some scope for increased planning.

$$C_{TA} = C_{TA}(p_{KK}, p_O, TA) \tag{9}$$

If there is perfect competition the shipping firm will behave as a price taker and the transport cost in equation (9) will be equal to the transport price faced by firms buying inputs from other locations.

$$p_t = C_{TA}(p_{KK}, p_O, TA) \tag{10}$$

Notice that p_t is only independent of the level of production (of TA), as assumed in equation (2), if the production function has constant returns to scale. The transport price can then be written as $C_{TA}(p_{KK}, p_O) \times TA$.

Summarising, price homogeneity of factor demand implies that firm's aggregate demand for transportation is price homogenous too. An increase in the transport cost could result in an unchanged or falling derived demand for transportation, depending on the spatial distribution of input production/demand, input prices etc. Further, freight transport and freight traffic may react quite differently to changes in the cost of freight transport/traffic.

3 STATISTICAL MODEL AND DATA

The data used for estimation are aggregated time series. The estimation of economic relationships using time series should take account of the special statistical properties of such series. If these properties are not accounted for then the time dependency of the observations could give spurious results because of misleading and inefficient standard errors.

If (some of) the series are non-stationary then cointegration between the series can be interpreted as long-run relationships. The long-run relationships can be estimated by the so-called »Johansen procedure«. The ML estimation procedure is described in Johansen (1988, 1991 and 1995a) and Johansen & Juselius (1992). A short presentation of the statistical model will be given in the following.

The basic statistical model for the time series properties of the data is a VAR model (vector auto regressive model). Let Z_t be a vector consisting of p time dependent economic variables. All variables in Z_t are viewed as stochastic. In the error correction form the unrestricted VAR model with two lags can be written as:

$$\Delta Z_t = \Gamma \Delta Z_{t-1} + \Pi Z_{t-1} + \mu + \Psi D_t + \epsilon_t,$$
$$\text{With } \epsilon_t \sim \text{Niid}(0, \Sigma) \tag{11}$$

In equation (11) D_t is a vector of non-stochastic variables. Ψ are the coefficients to the non-stochastic variables that need to be estimated. μ is vector of constants to be estimated. Z_t, μ and ϵ_t have the dimension $p \times 1$. Π and Γ are matrixes with the dimension $p \times p$ of coefficients to the stochastic variables.

If the series in Z_t are integrated of order 1 and if some of the series in Z_t cointegrate, then the rank of Π is reduced. Thus, the hypothesis of cointegration can be formulated as reduced rank of the Π-matrix:

$$H(\text{rank}=r<p): \Pi = \alpha\beta' \tag{12}$$

α and β are $p \times r$ matrices. Under H(rank=r) the process Z_t is non-stationary, while the processes ΔZ_{t-1} and $\beta' Z_t$ are stationary. $\beta' Z_t$ are the stationary (co-integrating) relations between the non-stationary variables. β consists of a number of cointegrating vectors, that can be interpreted as the long term economic relationships between the components in Z_t. When β (or Π) has the rank r, there are r cointegrating relationships (and p-r stochastic trends in the process). The α-vector's (loadings) can be interpreted as the adjustment coefficients of the stochastic variables to (last period) disequilibrium errors in the stationary relationships. A test of weak exogeneity of the variables in Z_t with respect to β can be formulated as restrictions on the α matrix. If a variable is independent of disequilibrium errors in the long-run relations it is considered as weakly exogenous.

The data used are aggregate quarterly time series from 1980:1 to 1993:4 (56 periods). This is a relatively small number of observations, considering that test values and estimates are asymptotic. The measures for aggregate transportation (TA) and traffic in kilometres (KK) only include the activity taking place domestically (in Denmark) by Danish registered trucks (larger than 6 tons without load). Thus, there is no transit traffic by foreign trucks, which seems appropriate when transport is looked upon as a derived demand of domestically located firms.

Aggregate production is used as a proxy for firms' input demand and therefore as an explanation for transport demand (see equation (3) and (4)). Production measured in fixed prices (without seasonal adjustment) is named FP. The price of production (PP) is used as a proxy for the input price vector (**p**).

An index for the cost of freight transport has been calculated (by Statistics Denmark) from *suggested* (not observed) prices originally calculated by the Danish Road Haulage Association. The suggested prices are calculated from drivers salaries, fuel cost, depreciation (including the change in the prices of trucks), tyre and repair cost, overhead etc. The index is based on the cost of driving as well as more general costs suggesting that it can be interpreted as a measure for *transport* cost (p_t). However, the cost index is calculated using a fixed number of annual kilometres. Thus, the calculation does not take account of the possibility of substituting kilometres for other inputs. This suggests that the index might instead be a better measure for the cost of kilometres (like p_{KK} in equation (10)). The index will be used as a common measure for both the transport and traffic cost. It is clear from the model that p_t and p_{KK} could indeed develop very differently, but they could also be »fairly« close for a number of cost functions (especially if the driving cost is a major component in the transport cost). The same name (PT) will be used in the following. As an indicator of p_o the general price of production (PP) is used. In order to ease interpretation of the estimated coefficient all series were measured in logarithm. Indicated by an »L«. The relative prices (LPT-LPP) are used instead of the two prices separately. The transformation means that price homogeneity will also be imposed in the short run and not just in the cointegration space. In order *not* to impose price homogeneity in the short run, the inflation rate (or alternatively the change in the transport cost) should be included (Juselius, 1995 and 1996). The transformed vector can be written as[4]:

$$\mathbf{Z_t = (LTA_t, LKK_t, LFP_t, LPT\_PP_t, \Delta LPP_t)'}$$

The non-stochastic component (D_t in equation (11)) consists of (centred) seasonal dummies and an outlier dummy (D88Q1) for the first quarter of 1988 (taking the value 1 in this quarter and -1 in the second quarter of 1988).

4 ESTIMATION RESULTS[5]

The first step in the cointegration analysis is to determine the rank, since testing of restrictions on α and β depends on the chosen rank. Based on the testing procedure described in Johansen (1988, 1991, 1995a and 1995b) and in Paruolo (1996) two co-integration vectors (r=2) have been chosen (described in details in Bjørner, 1996).

Next, identifying restrictions are imposed on the data in order to find interpretable long-run estimates. Different identifying restrictions on the long-run coefficients that still have a sound economic interpretation are reported in Table 1 together with the likelihood ratio test (comparing the unrestricted model with the restricted). No restrictions are imposed on the loadings (α).

4) In fact, the price homogeneity restriction has been tested starting out from a more general model. It has also been tested that the error terms are well behaved (normal and without autocorelation). This is described in a longer version of the paper (Bjørner, 1996).

5) The estimation was carried out with a CATS programme procedure for RATS. The CATS programme has been developed by Hansen and Juselius (1995). The manual is also a useful introduction to cointegration.

Table 1. Estimates of β for Z_t (LTA_t, LKK_t, LFP_t, LPT_PP_t, ΔLPP_t)

Hypothesis	Estimates of	LTA (»t«)	LKK	LFP	LPT_PP	ΔLPP	Test
H_1	β_1	1	0	-1.38 (14.3)	0.47 (2.8)	0	$\chi^2(2)$ = 2.04
	β_2	-0.71 (11.7)	1	0	0.47 (3.6)	0	p-value = 0.36
H_2	β_1	1	0	-1.38 (14.3)	0.47 (2.8)	0	$\chi^2(2)$= 2.04
	β_2	0	1	-0.98 (10.3)	0.81 (4.9)	0	p-value = 0.36
H_3	β_1	1	0	-1.19 (14.3)	0	0	$\chi^2(3)$ = 8.33
	β_2	-0.77 (11.9)	1	0	0.65 (5.0)		p-value = 0.04
H_4	β_1	1	0	-1.43 (14.0)	0.64 (3.8)	0	$\chi^2(3)$ = 10.92
	β_2	-0.60 (7.9)	1	0	0	0	p-value = 0.01

The restrictions labelled H_1 are the restrictions on the β-vectors that correspond to the theoretical description in section 2.1. In the first vector transportation cointegrates with aggregate production and (relative) prices. In the second vector traffic (LKK) cointegrates with transportation and relative prices.

From β_1 it appears that there is a negative transport price elasticity[6]. The transport elasticity is -0.47. The output elasticity is 1.38, i.e. an elasticity a bit higher than constant return to scale.

The second vector (β_2) shows a traffic cost elasticity of -0.47 and a positive elasticity with respect to transport at a little less than one (+0.7). All elasticities seem significant. The restrictions of H_1 are clearly accepted. The restrictions in H_2 are the same as in H_1 with respect to the first vector, but *apparently* different with respect to the determination of traffic. Instead of letting traffic be determined by transport volumes, production is used directly as an activity measure. Thus, traffic and transport are both determined by production, while in H_1 traffic was only indirectly (through transport) determined by production. This gives a higher (direct) cost elasticity of -0.81. The higher elasticity is similar to the one that can be calculated from the model in H_1 (-0.47×0.71 (indirect effect from transport) - 0.47 (direct effect) $\cong$ -0.81). Thus, H_1 and H_2 are just different representations of the same

6) The signs of the coefficients in Table 1 correspond to an equation where all variables are on one side and the error term on the other side. To get the signs »right« the numeraire should be isolated; thus all other signs changes.

restrictions on the cointegration vectors. From the test values it can also be seen that there is no statistical difference between the two models. There is one restriction plus the restriction on inflation rate on each vector in H_1 and H_2. Without the restriction on the inflation rate, both models are just identified, and they give the same description of the data.

In H_3 and H_4 the prices have been removed from one of the cointegration relations. The restrictions in H_3 reflect that transport prices does not influence the demand for transport, but should be included in the shippers production function. H_4 corresponds to a world where real transport prices has an effect on the demand for transportation, but where the transport cost does not influence the number of kilometres used to produce the amount of transport (i.e. the shippers' production function). Both restrictions are rejected. Thus, transport costs matter for the demand for transport as well as for the traffic volumes used to produce the demanded transport.

In Table 2 the H_1 restrictions are used on the long-run parameters together with exogeneity of inflation and real transport cost. The unrestricted loadings are reported in this case. For the β-vectors the appropriate »headers« are the ones in levels (like LTA). For the loadings (α_i) the appropriate headers are the differences (like ΔLTA). The restrictions can be accepted at a 5% level (but not 10%). The restrictions on the loadings only cause minor changes in the estimated long-run parameters. The estimated loadings in the final model in Table 2 have a reasonable interpretation. Transport volumes seem to adjust to disequilibrium in the transport demand vector (β_1), but not to disequilibrium in the derived demand for traffic (β_2), where traffic is »explained« by transport volumes. As expected traffic volumes adjust to disequilibrium in β_2. Traffic volumes also adjust to disequilibrium in the transport demand relation (β_1), but this is not very disturbing as transport volumes »explains« traffic. Sofar the loadings correspond quite well to the theoretical model. Production seems to adjust to disequilibrium in both long-run relations, which is a bit surprising and perhaps counterintuitive. However, the estimated loadings to production are both very small compared to the loadings to transport and traffic. The time path of the recursive estimates are shown in appendix 1. The estimated coefficients all seem stable over time, and there is no sign of misspecification. The real transport cost has been significant for a long period in the second cointegration vector, but only in the last years in the first cointegration relationship.

Table 2. »Final« estimates of β and α (r=2)

Hypothesis	Estimates of	LTA/ ΔLTA (»t«)	LKK/ ΔLKK (»t«)	LFP/ ΔLFP (»t«)	LPT_PP/ ΔLPT_PP (»t«)	ΔLPP/ ΔΔLPP (»t«)	Test
H1 and exogeneity of real transport cost and inflation	β_1	1	0	-1.32 (12.8)	0.47 (2.7)	0	$\chi^2(6)$ = 11.58
	β_2	-0.70 (10.8)	1	0	0.47 (3.4)	0	
	α_1	-1.18 (5.7)	-0.75 (5.0)	0.07 (2.0)	0	0	p-value = 0.07
	α_2	0.12 (0.4)	-0.53 (2.5)	-0.10 (1.9)	0	0	

Summarizing , one transport demand cointegration vector and one traffic input (or traffic demand) cointegration vector were estimated jointly. Transport cost could not be removed from any of these vectors. Thus, transport cost seems to play a part both for the freight transport demand and in the transport production function. At this stage, it should be remembered that the same measure was used for the cost of transport and for the cost of traffic. This is not in correspondence with the theoretical model. If the theoretical model is correct, then the information set used in the empirical analysis is not accurate. However, the actual differences in the correct transport cost and traffic cost *need* not be large (but of course it might indeed be large).

For this reason the cost elasticities should be interpreted with some care. The theoretical model, however, offers an explanation for the differences in the transport cost elasticities with respect to transport and with respect to traffic. The direct and indirect elasticity of relative cost with respect to traffic was -0.80 while (the direct effect) was only -0.47 with respect to transport volume. From a statistical viewpoint the model seems to be well specified. The production elasticities also seem robust and the estimated coefficients are plausible. However, it is a bit surprising that production in most of the models does not seem to be an exogenous variable. However, the loadings to production are very small indicating that »the problem« is not very pronounced.

4 CONCLUSION AND DISCUSSION

A small theoretical model of the demand for freight transportation has been presented. Transport (measured in tonnes kilometres) is modelled as derived from the firms' demand for spatially distributed inputs. Traffic (measured in kilometres) is modelled as an input in the transport production function. The interpretation is that shippers' – producing a given amount of transport services – are able to reduce traffic by devoting more resources to planning, effort or other factors in their production function.

Concerning the demand for *transport* intuition suggests that higher transport cost would induce firms to substitute away from »distant and heavy« input and thereby reduce the aggregate transport demand. However, this intuition need not be correct. For some spatial distributions and price structures higher transport cost result in an unchanged transport demand even for firms that have »well behaved« demand for input. The model emphasises that higher transport cost (could) lead to a higher reduction in the freight traffic volumes than in the transport volumes. From an environmental viewpoint this is important because traffic volumes are more closely linked to the external effects than transport volumes.

An empirical study has been carried out using aggregate time-series data for the freight transport by (large) trucks. The statistical model used was a VAR model. Cointegration (long-run) relationship was estimated using the so-called »Johansen Procedure«.

The estimates of the long-run elasticities are reported in Table 3. The data seem to support the idea that freight traffic is more elastic than freight transport. It is possible to reach a given reduction in traffic volumes (environmental effect), with a less than proportionate reduction in the productive sector's transport demand. Thus, the impact on the productive sector need not be as large as indicated by the environmental goal, at least not when »impact« is measured by reduction in derived transportation. The elasticities are calculated for total cost, so the elasticities should not be mistaken for fuel-cost elasticities. The fuel cost is only around 10% of total transport cost with trucks which indicates that the fuel-cost elasticity is much lower.

Table 3. Long-run elasticities of freight transport and traffic with trucks

Elasticity of:	With respect to:		
	Total transport cost (price)	Production	Transport (tonnes kilometre)
Transport (tonnes kilometre)	-0.47	+1.32	
Traffic (kilometres) – Direct effect	-0.47		+0.70
– Direct and indirect effect[1]	-0.80	+0.92	

1 The elasticities in this row can be calculated from the two first rows.

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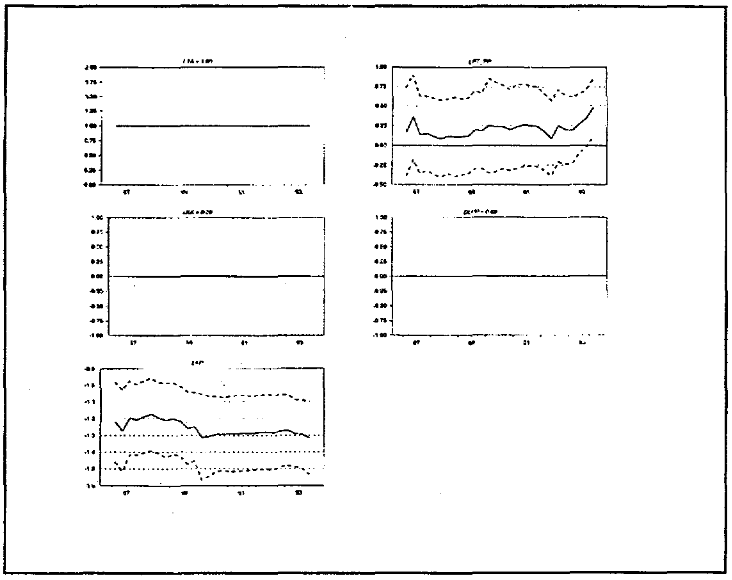
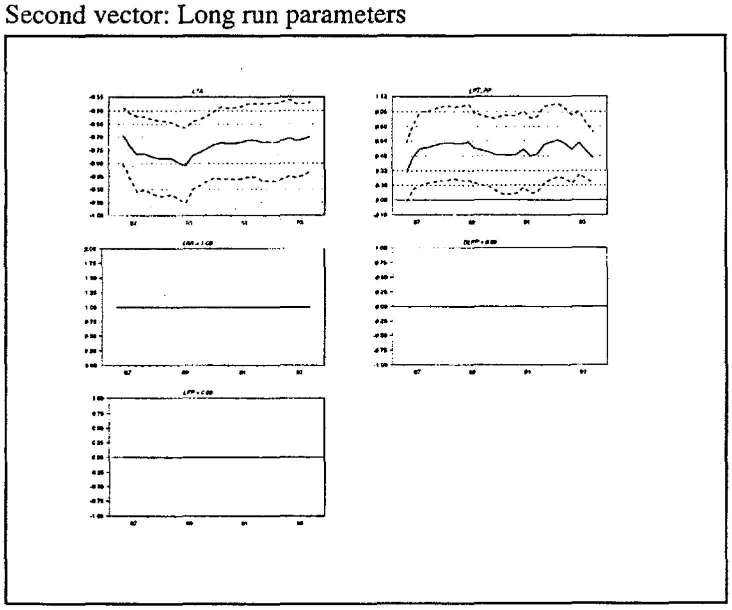
Appendix 1 Recursive estimates of the restricted model (as given in table 2).

First vector: Long run parameters



Second vector: Long run parameters



ENERGY DEMAND MODELLING IN TRANSPORT FOR UKRAINIAN NATIONAL ENERGY STRATEGY CREATION

By Valeriy A. Kravchuk, Vladimir Dounaev, Victoria Software Developers Group, Ukraine, Victor Perchuk, Institute of Energy Saving Problems, Ukraine

1. PROBLEM OF UKRAINIAN NATIONAL ENERGY STRATEGY CREATION

Among the main functions of the Government there are creation and implementation of economy and social development strategy for Ukraine, coordination of all economy sectors' activity, including the most important long-term solutions by means of which the Government aspires to satisfy the public interests.

These tasks are complicated by the current state of economy, that is characterized by the ineffictive structure serviced the former Soviet Union as a whole and by the intensive decline because of separation from the USSR, breaking of old economic ties, and attempts to proceed to market relations at all levels.

On these conditions the economy restructuring to achieve the economic independence and rational usage of all available resources is the most important task.

Fuel and energy sectors are the most important counterparts of the Ukrainian economy and key factors of industry's and population's vital activity providing.

Development and introduction of the National Energy Strategy (NES) are the most important lever that allows to use energy resources and industry capacities efficiently, change fuel and energy sectors orientation towards the increasing of energy supply for the population share and maintenance of household needs, transport, food production, while decreasing the industrial energy consumption share.

Ukrainian NES should not be a set of plans and directives, but rather a system of priorities and means of energy policy implementation. NES should be supported by a number of laws, that regulate the concrete conditions of its realization. Among the already adopted laws of this kind are: the Law of Ukraine "On energy saving" of

01.08.94 [1], "On environment protection" of 25.07.91, "On atmospheric air protection" of 20.08.95 and others.

All the national laws and regulations would conform to the international legislation and obligations, in particular to the environment protection ones (Sofia and Helsinki protocols).

Modern mathematical means, that unite econometric forecasting models and mid- to long-term development scenarios' analysis methods should be used for NES development.

2. CURRENT STATE AND FUTURE DEVELOPMENT OF TRANSPORT IN UKRAINE

Transport sector of Ukrainian economy unites all kinds of transport: road transport, aircraft transport, water transport (sea and river), rail transport and pipe-lines, as well as public roads. It has a complicated infrastructure for providing transport services, including realization of Ukrainian foreign trade relations.

Transport takes an important place in the economy of Ukraine. Thus, 18% of population work in the transport sector, transport consumes 27% of oil refining products and 5.1% of electricity. 30% of main funds are concentrated in transport

The data below [2] confirm the importance of transport for national economy. Ukraine has:

Highways	172300 km
Railways	22700 km
Navigable rivers	3600 km
Air traces	205000 km
Pipelines	44300 km

The summary of goods' turnover and passengers' departure (for 1994 and 1995) is presented in Table 1. Table 2 presents the quantity of registered vehicles in Ukraine.

Future development of road transport is connected with the increase of public transport share, use of diesel vehicles, and improvement of motor vehicle fleet towards more efficient fuel usage.

The future of the air transport in Ukraine is widening of international communications net and improving the home plain fleet by introducing and exploitation of efficient small planes.

Future development of rail transport is connected with the more efficient utilization of existing infrastructure (optimization of carriages flows, stocks forming, introduction of modern traffic control systems, etc.), development of international transport lines, including high-speed ones, extending of the electrified lines' net, etc.

Future development of pipeline transport includes restoring of existing capacities complete load, increasing of transit gas transport capacity up to 140 billion cubic meters per year, improvement of compressor- and pumping stations.

The important incentive for the development of all kinds of transport in Ukraine is the maintenance of transit among Western Europe, Eastern Europe and Asian countries, because of Ukraine's geographical position at the nearest ways among their main territories.

	road	*air*	*rail*	*sea*	*river*	*pipe-lines*	*Total*
Goods sent, million tones:							
1994	1869	-	408	26	20	244	2567
1995	1604	-	360	21	13	234	2232
Average distance of goods transport, km:							
	19	-	492	6797	282	684	
Goods turnover, billion tones * km:							
1994	35.3	-	200.7	176.7	5.6	166.9	585.4
1995	30.5	-	177.1	142.7	3.7	160.1	514.1
Passengers sent, million:							
1994	4040	2	736	10	7	-	4795
1995	3526	2	577	8	6	-	4119
Average distance of passengers transport, km:							
	14	1750	112	2700	1620	-	
Passengers turnover, billion of passengers * km:							
1994	56.6	3.5	82.4	27.0	11.3	-	180.8
1995	49.4	3.5	64.6	21.6	9.7	-	148.8

Table 1. Summary of goods' and passangers' turnover in Ukraine

Lorries	81400
Public cars	113900
Pri·ate cars	4092600
Buses	45600
River boats	756
Goods carriages	220100
Passengers carriages	9900
Locomotives	4142
Electric locomotives	1950

Table 2. Quantity of vehicles in Ukraine, 1994

3. TRANSPORT'S ENERGY DEMAND MODELLING WITH PROJECTIONS TO 2010.

Transport's energy demand in market economy is determined by three main factors:

- economy development scenario and transport's share in the economy structure;
- energy carriers prices' dynamics;
- power consuming efficiency.

Three scenarios of economy development are considered: optimistic, reference and pessimistic. They correspond to the different rates of reforms and investment policies. Figure 1 (snapshot from the screen of workstation running the VICTORIA™ system, courtesy of Baltic Mercantile Ltd.) presents GDP dynamics' scenarios for Ukraine that corresponds to the above mentioned economy development scenarios.

Energy carriers' prices are of special importance in case of Ukraine. Prices that do not correspond to the real expenses and far from the world market ones were inherited from the former USSR's directive economy. For example, the average cost of gasoline-super for motor cars in Kyiv, the capital of Ukraine, is 0.3 US dollars per liter, that is, three times cheaper than in the Western Europe. Ukrainian Government conducts the policy of economy stabilization and transition to the world prices in all sectors. Thus, on September 2, 1996, new national currency -- hrivna, was introduced ($ 1 US = 1.76 UKH), the exchange rate of which will be attached to one of the hard currencies (US dollars or DM) in 1997. It is an additional stimulus that guarantees economy stabilization and fast transition to world prices. On the other hand, sharp transition may cause the disproportion of economy sectors development.

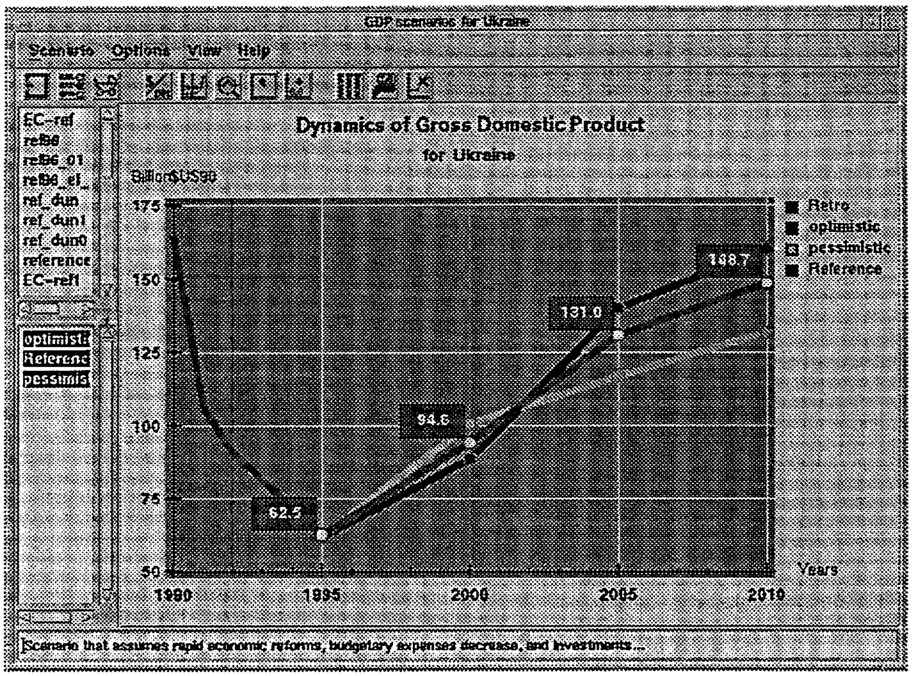


Figure 1. GDP scenarios for Ukraine

This phenomenon is taken into account when modeling energy demand of transport. Three scenarios of energy carriers' prices approach to the world level are considered: fast, medium, and slow (run up to world prices in 1997, 2003 and 2005, respectively). Figure 2 shows these scenarios in case of oil prices.

Among the additional issues considered while modelling the economy restructuring, transport share changes and energy demand of transport the most important ones are foreign trade relations and environment protection.

As a result of modelling, forecasts of economy sector's development, including transport, were obtained. Figure 3 shows the forecast of the economy restructuring directions, in cases of transport, machine building, chemical industry and ferrous metallurgy, when the reference GDP dynamics scenario and medium scenarios of energy carriers' prices are considered.

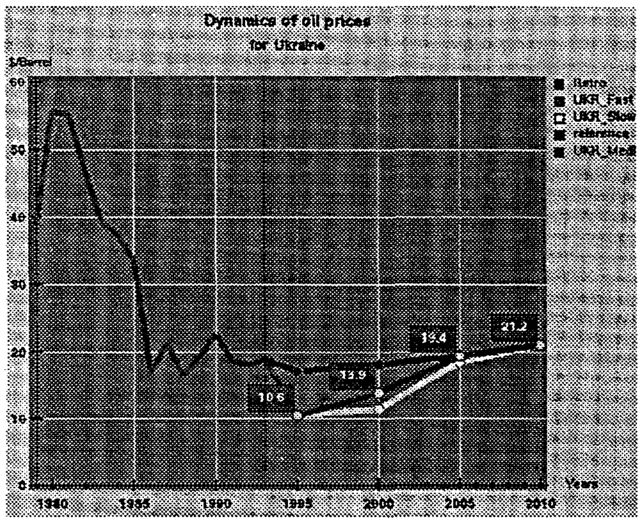


Figure 2. Oil prices scenarios for Ukraine

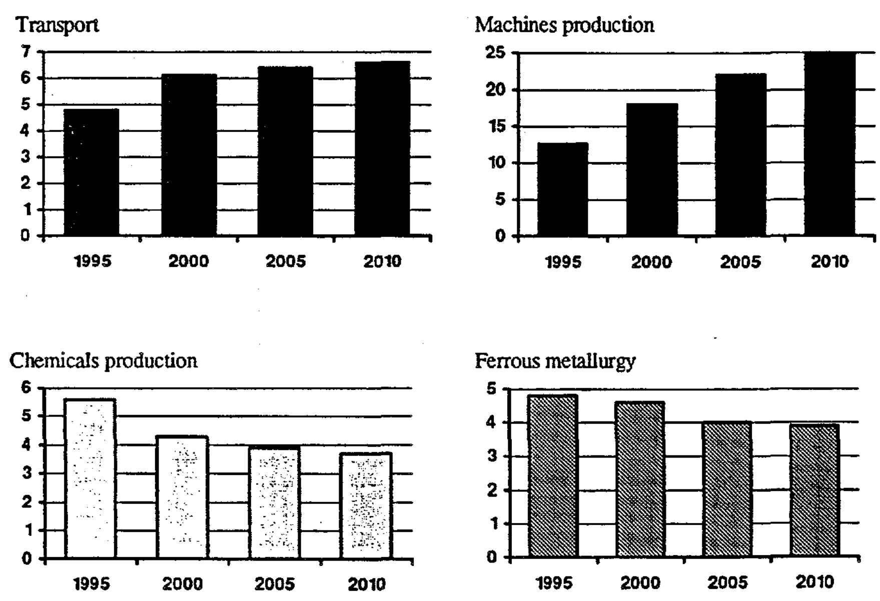


Figure 3. Forecast of sectors' contribution (%) in the overall economy structure

The results of transport need forecast obtained under the different assumptions, show that the share of transport services should be increased by 25% on average as compared with 1990 (from 4.8% in 1990-1995 to 6.6% in 2005-2010).

These qualitative results were used as a base for estimation of transport's energy demand. Table 3 contains data on the real consumption of energy carriers in million tones of conditional energy (million TCE, 1 million TCE = 29.899 PJ = 0.7142 million TOE) in 1990-1993 and demand forecasts up to 2010. Data used for the computations can be found in [2,3].

	1990	1992	1993	1995*	2000	2005	2010
Motor fuel	7.2	5.2	3.5	4.1	6.1	7.7	9.6
Boil-stove fuel, including gas	5.3	4.7	4.1	4.1	4.6	5.6	6.5
Electric power	5.0	4.3	4.1	4.0	4.4	5.3	6.1
Total	17.5	14.2	11.7	12.2	15.1	18.6	22.2

* additional confirmation needed

Table 3. Energy resources consumption (million TCE) by transport with projections to 2010

All the above mentioned modelling results had been obtained using the VICTORIA™ System - software that supports the objective study of economic, environmental and energy policy in different countries and regions across the globe. The VICTORIA™ System is developed by the VICTORIA Software Developers Group in cooperation with Baltic Mercantile Ltd. (London, UK). The system is intended for generating and study of energy demand and power-consuming economy sectors' development projections with respect to the efficiency of the economy as a whole, state of the world market and environment protection issues.

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DYNAMIC ANALYSIS OF ENERGY, ENVIRONMENT AND CONGESTION EFFECTS OF URBAN TRANSPORT POLICY - VARIABILISATION OF CAR TAXATION

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1. Introduction

Road transport is an important cause of external costs. In general three types of external costs can be distinguished : congestion, air and noise pollution causing environmental damage and health hazards, and road accidents. Policy measures aiming at the reduction of external costs mostly are limited to a specific cost-type. The lack of integration of policies causes inefficiencies, because external costs are strongly interlinked. A consistent framework for policy-making is desirable.

In Ochelen and Proost (1996), congestion, pollution and road accidents are treated as externalities. An optimal pricing and regulation policy for transport is calculated for Brussels in 2005. Regulation consists of prescriptions to car producers concerning the environmental characteristics of car-technology. Optimal prices charge transport users the social cost of their trips, with possibly a correction for the marginal cost of public funds. In a perfect pricing policy, prices would be differentiated according to conditions of congestion and pollution at each moment in time. The instruments necessary to implement such optimal prices are not readily available. The model is flexible enough to simulate the effects of more realistic policy packages. This flexibility has its cost in terms of degree of detail of the model. This feature is captured by the term 'strategic' model. This paper deals with an extension of the Ochelen and Proost model, in two directions.

First, a distinction is made between ownership and use of cars. We link transport volumes, expressed in passenger-kilometer, to the size of the vehicle stock and the intensity of usage. The second extension is the introduction of dynamics into the model. Instead of evaluating policies in a comparative static fashion, we calculate a time path of policy impacts. A dynamic model allows us to know the delay before policies achieve the intended effect, and the effects of timing of policy can be studied. The first extension (distinguishing ownership and use of cars) is useful in itself, and is a prerequisite for the construction of a dynamic model.

The model is currently still a prototype. We concentrate on the main issues involved in making the model dynamic. The degree of detail therefore is rather limited. Magnitudes of policy effects must be interpreted carefully. We are more confident as to what concerns the directions of the effects.

The paper first deals with the methodology of the model (section 2). Section 3 is on the the calibration of the model and on the base case scenario, which serves as reference cases for the policy evaluation in section 4 (variabilisation of car taxation). Section 5 briefly concludes.

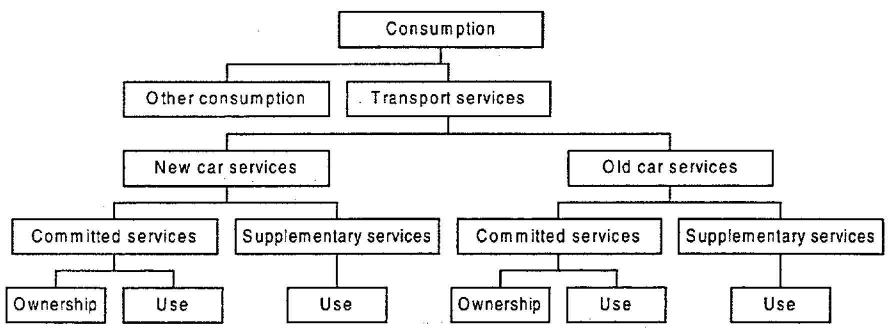
2. Method

The dynamic model is constructed as an interlinked sequence of static equilibrium submodels. The link is made by a model which represents the scrappage process in the car market. This section treats (1) the basic idea behind the static equilibrium submodel, (2) the utility tree of the static submodel, (3) the treatment of scrappage and dynamics and (4) the representation of congestion.

The static model is a partial equilibrium model of the urban transport sector. A market equilibrium results from the maximisation of the sum of consumer and producer surplus under a set of policy constraints. Production of vehicles is assumed to take place in an environment of perfect competition under constant returns to scale. Imposing different sets of policy constraints allows us to construct different equilibria. These equilibria can be compared consistently. Since the model is a simulation model and not an optimisation model, it is not possible to compute the socially optimal policy package. More detail on the welfare economic background of the model can be found in De Borger et al. (1996).

The structure of consumer preferences is represented by the utility tree shown in figure 1. The choice between other consumption and transport services, and the choice between new car services and old car services is determined by a CES utility function. This implies homothetic preferences. The next level concerns 'committed' and 'supplementary' services. Committed services are those transport services which have induced the consumer to purchase a car : the costs of owning a car are fully allocated to this type of transport services. Supplementary services are services which are consumed on top of committed services. The costs of owning a car are less relevant for these services, and they are more sensitive to variations in the costs of car use. This level of the tree is represented by a LES utility function, which implies gross complementarity between committed and supplementary services. Consequently, flexible services are sensitive to variations in ownership costs, as committed services are influenced by costs of using a car. On the lowest level, a Leontief function splits up committed services into ownership and use. The idea that the decision to own a car is related to (expected) use is explained in De Jong (1990), De Jong (1996). The specific way to model this in the utility tree for an representative consumer is taken from Denis et al. (1994).

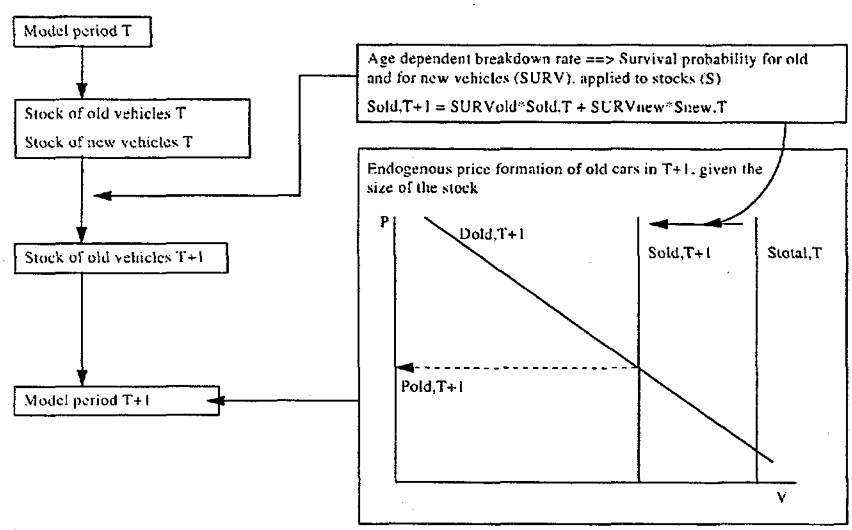
Figure 1 Utility Tree



The dynamic specification is a sequence of five static submodels. Figure 2 shows how, after each static model run, account is taken of the scrappage process within the vehicle stock. Since the volume of scrappage is calculated before the static model for the next period begins, the stock of old vehicles is exogenous to this period. Therefore, the price of old cars is endogenous, in the assumption that (maximally) the complete stock of old cars is purchased.

Time costs of trips are taken into account by assigning an exogenous valuation to the time needed to make a trip. The time cost is determined by a speed-flow function, which relates the speed at which trips are made, to the volume of vehicles. Since the volume of vehicles changes over time, the conditions concerning congestion also change. The model takes account of the time costs of trips. Technically, this is done through the use of generalised prices and generalised income. The generalised price of a trip is the sum of monetary costs and time costs.

Figure 2 **Dynamics of car stock and price formation of old cars**



3. Calibration and Base Case Scenario

The model is calibrated to an observed reference situation for Brussels in 1991 (Febiac (1990-1994), IRIS (1993)). Data on elasticities are taken from the literature and represent medium term behaviour (approx. 5 years)(Goodwin (1992), Oum et al. (1992)). The complete dynamic model thus covers a period of ca. 20 years. Table 1 summarises the results from the calibration/simulation exercise for the dynamic base case scenario. The following assumptions were made concerning the evolution over time of exogenous variables :

- fuel efficiency of new cars improves by 2% in every 5 year period, due to technological evolution (generation effect);
- the price of new cars increases in every period, also with 2%; this can be interpreted as the cost of technological improvements;
- the costs of using an old car increases by 1.5% compared to the previous period (when it was new); this age effect is due to deterioration of fuel efficiency and increasing maintenance costs;
- generalised income is assumed to grow by 10% in every period; the value of time is linked to the level of productivity, and therefore also increases by 10% in each period;
- road capacity remains fixed over the whole period.

Table 1 Main results for the reference scenario (section 3) and *variabilisation scenario* (section 4)

	Period 1	Period 2	Period 3	Period 4	Period 5
Prices					
Gprice transport (index)	1.00	1.06 ; *1.06*	1.15 ; *1.13*	1.20 ; *1.19*	1.25 ; *1.24*
Gprice new car services / Gprice old car services (index)	1.15	1.10 ; *1.05*	1.02 ; *1.01*	1.03 ; *1.02*	1.05 ; *1.05*
Ownership price new / ownership price old (ratio)	2.13	1.63 ; *1.57*	1.16 ; *1.19*	1.16 ; *1.17*	1.21 ; *1.28*
G use cost new / G use cost old (ratio)	0.94	0.96 ; *0.96*	0.98 ; *0.97*	0.98 ; *0.98*	0.98 ; *0.98*
Volumes					
aggregate. transport services (index)*	1.00	1.05 ; *1.05*	1.08 ; *1.09*	1.15 ; *1.16*	1.22 ; *1.23*
ownership old cars (index)	1.00	1.00 ; *1.00*	0.95 ; *1.00*	1.01 ; *1.06*	1.09 ; *1.15*
ownership new cars (index)	1.00	1.08 ; *1.15*	1.17 ; *1.24*	1.24 ; *1.32*	1.32 ; *1.40*
total ownership (index)	1.00	1.03 ; *1.07*	1.05 ; *1.11*	1.12 ; *1.18*	1.19 ; *1.26*
use old cars (index)	1.00	1.03 ; *0.99*	1.01 ; *1.01*	1.08 ; *1.08*	1.16 ; *1.17*
use new cars (index)	1.00	1.08 ; *1.11*	1.18 ; *1.20*	1.26 ; *1.29*	1.33 ; *1.37*
total use (index)	1.00	1.05 ; *1.04*	1.09 ; *1.10*	1.16 ; *1.17*	1.24 ; *1.26*
average mileage all cars (km/year)	14 203	14 436 ; *13 889*	14 727 ; *14 106*	14 751 ; *14 181*	14 741 ; *14 197*
stock new / stock old (ratio)	0.81	0.88 ; *0.93*	1.00 ; *1.01*	1.00 ; *1.01*	0.98 ; *0.98*
mileage new / mileage old (ratio)	0.81	0.86 ; *0.91*	0.95 ; *0.96*	0.95 ; *0.97*	0.94 ; *0.95*
other consumption (index)	1.00	1.10 ; *1.10*	1.21 ; *1.21*	1.32 ; *1.33*	1.46 ; *1.46*
External congestion costs					
marg. cong. cost (index)	1.00	1.24 ; *1.22*	1.48 ; *1.53*	1.93 ; *2.00*	2.55 ; *2.71*
total external cong. cost (index)	1.00	1.30 ; *1.27*	1.62 ; *1.68*	2.24 ; 2.36	3.15 ; *3.41*

* aggregate transport services refer to the volume of transport services as defined in the top level of the utility tree

The growth of the volume of aggregate transport consumption is considerably smaller than that of other consumption. The change in other consumption closely follows the increase in income. The cause of the slower growth of transport consumption is the increase in its generalised price. This is due to the increase in the valuation of time (exogenously imposed) and to the rising level of congestion. Congestion increases because total transport demand grows and capacity remains fixed. It works, through rising average time costs, as a brake on the growth of transport demand.

The relative generalised price of new car services w.r.t. old car services declines over time. One reason is that the relative cost advantage of new cars in terms of fuel efficiency becomes smaller. This can be seen from the ratio of generalised use costs of new and old vehicles. Since time costs per trip are the same for old and new vehicles, the declining difference in use costs is due to an increasing similarity of old and new vehicles. A second and more important reason for the relative price decrease of new car services is that ownership costs of old vehicles increase strongly; cfr. the ratio of new and old car ownership costs. The ownership costs of old vehicles increase because :

- Their fuel efficiency improves over time. The decrease in variable costs induces a higher willingness to pay for ownership.
- The observed value in the reference situation for ownership costs of old cars is below the steady state level. The steady state level is defined by the characteristics of the calibrated demand system and by observed scrappage rates. Ownership costs are expressed within the model as capital cost per period. The calibration implies that consumers are primarily interested in car services, and not so much in the type of car which is used to produce these car services. Consequently there is a built-in tendency for the price (per period) of old cars to converge towards that of new cars, if the supply of old cars is sufficiently restrained by scrappage in the previous period. Still, the calibration also incorporates a taste effect : the consumer is not completely indifferent between old and new cars. The ownership price of old cars therefore remains below that of new cars.

The share of old cars in the stock declines, and stabilises at about 50%. The total stock of cars grows by 19% while aggregate mileage increases by 24%, implying an increase in average mileage per car. Average mileage per new car is more or less constant, but that of old cars increases significantly (6%). The reason lies again in the price evolution of old cars, i.e. the decline of the share of use costs in the total costs. This pushes the consumer towards a more intensive use of old vehicles.

From these comments it is clear that the model results are to a large extent determined by the characteristics of the demand system in the static submodels (as implied by the functional forms and the calibrated parameters) rather than by the representation of scrappage within the model.

A last remark on the base case scenario concerns congestion costs. The table shows that the marginal and total external congestion costs increase considerably. This is due to higher valuations of time and increased consumption of transport services. The increase in purchasing power is an important stimulus for demand for transport services. Despite the fact that this increase in transport is slowed down by the increase in time costs per trip, the external costs of congestion will rise over time.
We assume that the evolution of congestion over time is linked to aggregate mileage. This implicitly means that we take the distribution of traffic over daily time periods to be constant. A richer model would endogenise the allocation of trips over time periods (peak and offpeak).

4. Variabilisation of Car Taxation

Currently transport services are taxed on fixed and variable inputs. The reasoning behind the variabilisation proposal is that it is better to concentrate taxes on variable inputs, since those inputs are more closely related to the consumption of car services. Taxing car ownership may have an impact on the decision to buy a car or not, but the effect on car use is rather limited. Since the main externalities in transport are related to car use, variabilisation could be a means to tax transport services more efficiently.

We simulate the effect of abolishing all taxes related to car ownership in combination with a redefinition of taxes on variable inputs, such that government revenue remains unchanged in the first period. Government is assumed to behave myopically, since it does not take account of the dynamic effects of its intervention : the new tax rates are calculated by running the static submodel for period 1 under the constraints that government revenue does not change and that ownership taxes are zero. This tax structure is implemented from period 2 onwards. The reform takes place in a macro-environment where changes in exogenous variables are the same as in the base case scenario from section 3, which serves as point of reference. Table 1 gives results for variabilisation in italics. Since it is assumed that the policy is implemented from period 2 on, the results for period 1 are identical to those of the no intervention scenario. Some comments are worth mentioning :

- Implementing variabilisation has no significant differential effect on the aggregate price of transport services. In early periods, the tax reform is advantageous for new cars because the share of ownership costs in total costs is larger for this type of cars. Since tax rates are (nearly) identical for old and new cars, an equal tax rate reduction implies a larger absolute cost reduction for ownership of new cars. This advantage for new cars grows smaller as the price structure of new and old cars converges over time (as in the reference scenario).
- There is no differential effect of variabilisation on the consumption of *aggregate* transport services. However, *ownership* of new cars, and therefore in later periods of old cars, rises considerably. Total *use* of old cars grows at about the same rate as in the reference scenario, while total use of new cars grows much faster. Variabilisation leads to an immediate decline in average mileage per vehicle, and the subsequent growth is slower. These volume effects are typical for the variabilisation policy. In fact, the result boils down to a decrease of fixed costs, which leads to a larger stock that is used less intensively. Individuals face a lower initial investment cost, and will therefore decide to buy a car even if their expected use of the car has not increased. On the aggregate, the volume effect is negligeable in terms of transport services.
- Since the demand effect on aggregate mileage is small, there is not much to be expected from variabilisation as an instrument for environmental policy, at least as far as such a policy would aim at a global reduction of mileage demand. On the other hand, table 1 shows that variabilisation would lead to a larger share of new (and supposedly more environmental friendly) cars in the total stock and in total mileage. Total mileage in itself grows at the same rate as in the reference. In balance,

variabilisation entails positive environmental effects as far as environmental costs are linked to the composition of the vehicle stock. We do not deal with the size of these effects here any further.

- Congestion costs, average and marginal, rise after the implementation of variabilisation. Despite the fact that mileage demand is only 1%-point higher in periods 3 to 5 in the variabilisation scenario, the marginal and total external congestion costs are much higher. This result is due to the non-linearity of the congestion function, and the fact that this nonlinearity increases as the initial mileage level is higher. It is the rise of average congestion costs which, through its effect on generalised costs of trips, partly explains the very limited positive demand effect of variabilisation. This illustrates the importance of taking account of congestion in long term policy analysis.

Table 2 shows calculations of the equivalent variation, of changes in government revenue and in external congestion costs. These elements allow a welfare assessment of the variabilisation proposal, if abstraction is made of environmental effects. We do not use a discount factor in the summation of welfare effects over time.

Table 2 Welfare effects of implementing variabilisation in period 2

	Period 1	Period 2	Period 3	Period 4	Period 5	Sum
Equivalent variation	0	-0.061	0.817	0.545	0.664	1.965
d(gvt. revenue)	0	-0.94	-1.94	-2.26	-2.44	-7.58
d(tot. ext. cong. cost)	0	0.022	-0.043	-0.079	-0.178	-0.278
Sum	0	-0.979	-1.166	-1.794	-1.954	-5.893

For the consumer, the welfare effect is positive in general. This is due to the increased flexibility which he acquires in allocating the budget : purchasing a car becomes useful even when the expected use has not changed w.r.t. the situation before the policy change. This positive effect is counteracted by the increasing congestion costs, which explain the very limited size of the positive welfare effect. Government revenue drops substantially if variabilisation of car taxation is implemented. This is of course related to our assumption of myopic behaviour. A government with perfect foresight could impose overall revenue neutrality, thereby taking the effect of increasing congestion into account. Total external congestion costs also increase. On balance, the welfare effect of variabilisation is negative.

The main reason for the negative welfare effect is the decrease in government revenue. The objective of revenue neutrality was calculated within a static setting, and it is not reached in the dynamic setting. There are two reasons for this :

- On the individual level there is an incentive to decrease average mileage. The simulation results, however, show that this does not lead to a relative decrease in aggregate mileage (since the ownership volume rises). Given the higher tax rate on variable inputs, there is an extra revenue from variabilisation as compared to the reference scenario.
- The improvement of fuel efficiency constitutes an erosion of the tax base, when mileage demand is not perfectly price elastic. The variabilisation policy is much more sensitive to this erosion than the existing tax structure, since it focusses taxes on variable costs exclusively. Also, we assumed that car ownership costs will increase because of the new technologies they embody. In the reference scenario, this means that the tax base expands, while there is no positive effect on government revenue in the variabilisation scenario.

5. Concluding Remarks

We presented a simulation framework for analysis of road transport policies in an urban setting. The model operates on an aggregate level, which makes it suitable for the analysis of a wide range of proposals. An example of such analysis was given for the proposal of variabilisation of car taxation. It was shown that this policy has a negative welfare effect, which is explained by the perverse effect on the level of congestion over time and, more importantly, by its negative effects on government revenue. This conclusion is conditioned by the assumption of myopic government behaviour.

The model can easily be extended : new transport modes can be introduced, and more detail in the representation of the car stock can be taken up. This would allow more detailed analysis of environmental effects, and welfare effects in general, of transport policies. A more detailed analysis of variabilisation will become feasible when the peak - offpeak distribution of trips is made endogenous.

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EMISSIONS FROM THE TRANSPORT SECTOR IN DENMARK

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1 Introduction

By combustion of fossil fuels, CO_2 is emitted to the atmosphere. The new assessment report from the Intergovernmental Panel on Climate Change (IPCC, 1996) reveals that scientific uncertainty - a major barrier to action - is being steadily reduced. The report goes further than ever before by stating that scientists now believe that " the balance of evidence suggest a discernible human influence on global climate". This significant conclusion will certainly contribute to mobilizing political support for stronger commitments.

Developed countries which has ratified the United Nations Framework Convention on Climate Change (UNFCC) have committed themselves to returning their greenhouse gas emissions to 1990 levels by the year 2000. At the second Conference of Parties (COP-2) in Geneva in July in was decided to start the development of a protocol on binding reduction targets after the year 2000 to be agreed upon at the next COP in Japan in December 1997. However most developed countries do not seem to be on track to even achieve their current commitment of stabilizing their emissions.

Denmark already have decided on strong reduction targets. It is the goal of the government to reduce the CO_2 emissions from the energy consuming sectors by 20% in 2005 compared to 1988 and to reach futher reductions up to the year 2030 (Energi- og Miljøministeriet, 1996).

In 1990 the government presented an action plan for the transport sector, where the present goals for the Danish transport sector were determined. The aim is to stabilize the emissions of CO_2 for the transport sector in the year 2005 at the 1988 level and to reduce it with 25% in the year 2030. The Danish Folketing has on several occasions, latest in February 1996, confirmed these goals and they were again mentioned in the latest action plan from the transport sector (Trafikministeriet, 1996). Concerning emissions of other air pollutants the aim in the action plan is to reduce the emissions of NOx and volatile organic compounds, called VOC (the sum of CH_4 and NMVOC) by 40% in 2000 and 60% in 2010 compared to 1988.

Denmark has also signed a number of protocols under UN's Economic Commission for Europe (ECE) which have implication on the emission of other air pollutants from the transport sector:

- the Sulphur Protocol from 1994 commit Denmark to reduce the emissions of SO_2 in the year 2000 to 20% of the 1980-level.

- the NOx Protocol, including a declaration, committing Denmark to reduce the NOx emissions in 1998 to 70% of the emissions of a year in the period 1980-86.

- the VOC Protocol where the commitment is to reduce the emissions of Non-Methane Volatile Organic Compounds (NMVOC's) in 1999 to 70% of the 1985-level.

The following sections will show how the emissions to the air from the transport sector have developed since 1972. Before that year no reliable energy statistic exist for Denmark, as it was first developed after the oil crisis in 1973. The first part will focus on the CO_2 emissions from the Danish transport sector and the second part will cover the other main air pollutants.

Since 1987 the Systems Analysis Department at Risø has regularly calculated the emissions of air pollutants from Danish sources based upon the energy statistics from the Danish Energy Agency. The results were first published in "Danish Budget for Greenhouse Gases" (Fenger, 1990) and later updated and developed further in (Fenhann, 1994). The data used in this paper are from (Fenhann, 1996). The work behind this report was done in a collaboration with the National Environmental Research Institute (DMU). The reports mentioned also cover the emissions outside the energy sector.

2 CO_2 emissions from the transport sector in Denmark

The total Danish primary energy consumption is shown in table 1. Some basic assumptions behind the data must be mentioned: They are based on the actual energy consumption and are not climate corrected by the yearly number of degree-days.

Table 1. Primary energy consumption in the main emitting sectors for 1994 (PJ)

Power/heat plants	411.8
Residential & Service	107.3
Process	127.4
Off-road	26.8
Road transport	131.3
Other transport	15.3
Total	819.9

In the guidelines for the reporting to the UNFCC it is recommended to use the sales of energy in the countries. However in order to reflect the behavior in Denmark we use in this paper the energy consumed in Denmark. Therefore a correction is made for the road traffic bunkers, which has been estimated by the Danish Energy Agency to be of the order of 100 kt CO_2 for diesel and 400 kt CO_2 for gasoline in the period 1993-95. Earlier the price for gasoline was lower in Germany than in Denmark and some gasoline was therefore bought in Germany giving rise to a negative value for diesel bunkers. Finally the emissions from energy consumption for electricity production are corrected for the highly varying import/export of electricity.

It is important to define the transport sector precisely. In table 1 road transport covers all cars on the road fueled by diesel, gasoline and a small amount of LPG. Other transport consists of railways, domestic navigation and airtransport plus transport by the defense. The fuel consumption for domestic transport is the fuel sold for domestic transport lines.

The off-roaders is a relatively new category included in the Danish emission inventory. It covers the diesel and gasoline consumption by mobile machinery like tractors, harvesters and other mobile agricultural material plus mobile machinery in construction and industry. This separate category has been included because the emission factors here are very different from other vehicles or combustion. The energy consumption for off-roaders is mainly subtracted from the process and the transport sector based on the calculation method in (Abrahamsen & Nielsen, 1992). The energy consumption from off-roaders are also not included in the above mentioned targets for the transport sector.

Since the CO_2 emissions from transport are directly related to the energy consumption by multiplication with the CO_2 emissions factors in table 2, we therefore in the following do not show the energy consumption data but only the CO_2 emissions.

Table 2. CO_2 emissions factors used in the Danish inventory.

Fuel type	CO_2 emission factor kg CO_2 /GJ
Residual oil	78
Diesel oil	74
Gasoline	73
Jet Petroleum	72
LPG	65

The development in the total emissions of CO_2 from fuel combustion from 1972 until 1995 are shown in table 3. No data is shown for 1973-1974 due to lack of energy statistics. In 1995 the share of CO_2 emissions from domestic transport was 19% of the Danish total, an increase from 14% in 1972.

Some conclusions can be made from table 3: The total CO_2 emission from the Danish energy sector has been almost stable since 1972. However, it can be seen that the various energy consuming sectors have developed differently. After an initial drop the CO_2 emissions from process have stabilizes since 1982. The emissions from the power sector increased until 1980, due to fuel substitution from oil to coal, and have since then been almost constant in spite of the high increase in the use of district heating . This increase combined with a successful policy to conserve energy in buildings have decreased the emissions from individual burners in the residential & service sector by about 60%.

The only sector where the CO_2 emissions have continued to increase is road transport, where the CO_2 emissions have increased by about 50% since the early 1970's, and 15% since 1988. CO_2 emissions from gasoline cars had a rapid increase of 3-4% p.a. from 1993 to 1995 presumably due to a high growth in private consumption combined with a high economic growth.

Table 3. Total CO_2 emissions from fuel combustion in Denmark

kton CO2	Power/heat plants	Residential & Service	Process	Off-road	Road transport	Other transport	Total
1972	20524	16581	10974	1820	6429	1544	57873
1975	20075	13786	9917	1820	6194	1426	53218
1976	22422	15638	10476	1820	6688	1477	58521
1977	24000	15188	10845	1820	6933	1413	60199
1978	26278	15055	11028	1820	7612	1497	63291
1979	28144	15524	11464	1820	7500	1577	66029
1980	28145	12496	10379	1820	7009	1358	61207
1981	28042	10671	9071	1820	6654	1350	57607
1982	28207	9926	7980	1820	6917	1479	56328
1983	28883	9014	7750	1820	7203	1395	56065
1984	29772	8518	8510	1820	7968	1170	57757
1985	31332	9856	8645	1820	8184	1111	60948
1986	31219	9321	9257	1820	8667	1101	61385
1987	32183	9207	8647	1820	8574	1224	61656
1988	31799	7801	8199	1820	8625	1029	59274
1989	31663	6739	8032	1820	8747	1013	58014
1990	31060	6461	7975	1820	9085	956	57357
1991	31913	6895	8759	1820	9342	1108	59838
1992	31785	6506	8404	1820	9304	965	58785
1993	31166	6663	8179	1820	9243	1193	58265
1994	29866	6278	8451	1966	9639	1134	57334
1995	29171	6288	8617	1966	9950	1112	57104

In 1995 the gasoline vehicles accounted for 56% of the CO_2 emissions from road transport. From table 4 it can also be seen that 1.6 million passenger cars were responsible for 63%, and the 320 thousand goods motor vehicles for 37%. The emissions for off-roaders are constant due to lack of information.

Table 4. Distribution of CO_2 emission from road transport in 1995

Gasoline	56%
Diesel person	7%
Diesel freight	37%
LPG	0.2%
Total	100%

The emissions of CO_2 from passenger cars has increased since 1981 (see figure 1) and can be explained the rapid increase of passenger transport performance by about 50% since that year. From 1988 until 1995 the CO_2 emission from passenger cars increased by 11%.

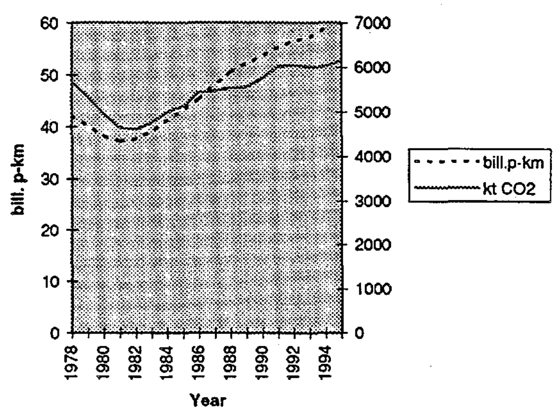

Figure 1. Development of passenger car performance and CO_2 emissions

The increase in CO_2 from freight transport by goods motor vehicles has increased even faster than emissions from passenger transport in cars. Table 5 shows that the CO_2 emissions increase by 22% from 1988-1995 (2.5% since 1994) and was more than tripled from the early seventies.

Table 5. CO_2 Emissions from road freight transport

Year	kt CO_2
1972	1121
1975	958
1980	1937
1988	2978
1995	3626

Table 3 showed that the CO_2 emissions from other transport has been almost constant the last 10 years with a share of 11% in 1995 as shown in table 3. The emissions from railways at only 2% shown in table do not include the emissions due to the electricity consumption by trains, which was 239 GWh in 1995. This increases the emissions from railways in 1995 from 303 kt CO_2 to 487 kt CO_2.

Table 6. CO_2 emission in other transport in 1995 as % pct. of transport emission

1995 % of CO_2 transport emission	
Rail	3.9%
Sea	5.1%
Air	2.0%

The increases of the CO_2 emissions from the transport sector since 1988 are summarized in table 7.

Table 7. Increases in the CO_2 emissions from transport 1988-1995

Transport sector	1988-95 pct.increase
Total transport	14%
- passenger cars	11%
- goods motor vehicles	22%
- other transport	10%

The emissions from international transport are not included in the total Danish emissions shown in table 3, and the Danish government has no obligation under the UNFCC to stabilize these emissions. The trends in the development of these emissions since 1975 (See table 8) are that after a stable period until 1985 a rapid increase takes over. In the last 10 years the CO_2 emissions from international air transport increased by 22% and the international sea transport multiplied by almost a factor of four. A large part of the increase in sea bunkers is caused by low prices on residual oil from Danish refineries which are bunkered by ships in transit. However a large part of the increase must be caused by the increase in the export/import in tons of goods by ship from Denmark by 100%/25% respectively in the last 10 years. An international agreement to stabilize the increasing CO_2 emissions from international sea and air transport is needed, since nobody at the moment has the responsibility to do that.

Table 8. CO_2 emissions from international transport, refuelled in Denmark

International transport (kt CO_2)			
Year	Sea	Air	Total
1975	1694	1629	3323
1980	1339	1642	2982
1985	1331	1601	2932
1988	2813	1917	4730
1994	4825	1910	6735
1995	5131	1957	7088

3 Other emissions from the transport sector in Denmark

We have not yet finished the emission inventory for the year 1995, only the CO_2 emissions have been calculated. In the following the time series therefore end with the year 1994. The emissions from the road transport were calculated with the COPERT model, used by the European Environmental Agency (Commission of European Communities, 1992). COPERT operates with 30 vehicle categories. For each of these COPERT has an emission factor for all pollutants and their speed dependence. Furthermore the climate dependent extra emission from cold start of the engines and the evaporative emissions are included.

In table 9 the emissions of the major air pollutants from road traffic in Denmark is shown for the years 1988 and 1994 together with the increase in this period. The reason for choosing the year 1988 in the table is that this year as mentioned before was chosen as the reference year for the emission reduction goals in the Governments action plan for the transport sector.

Table 9. Emissions from road transport in 1988 and 1994

Road transport	1988	1994	1988-94
	1000 tons		pct.change
CO_2	8625	9639	12%
NOx	95.5	88.3	-8%
N_2O	0.3	0.8	155%
NMVOC	95.0	74.8	-21%
CH_4	1.8	1.6	-11%
SO_2	6.9	1.7	-75%
CO	526.6	411.2	-22%

The most pronounced development has happened for SO_2 , where the emissions from road traffic decreased by 75% in the period. This was mainly due to the reduction in the sulphur content in the diesel from 0.5% to 0.3% in 1986 , further to 0.2% in 1989 and now to 0.05% in 1993.

Until 1990 the emissions of NOx, NMVOC and CH_4 increased, but since then the introduction of 3-way catalytic converters has been effective so the emissions of these three substances were reduced by 4%, 19% and 11% respectively in the period 1988-94 (see table 9). Since October 1990 all new cars in Denmark must have these converters installed. The CO emissions already started to decrease earlier than the introduction of the catalytic converters due to better engine technology. However the introduction of catalytic converters has been the reason for an increase in the N_2O emissions from road transport. Emissions of lead are not shown in table 10, since these emissions now are almost zero. The lead content in the gasoline was reduced in the 1980's and since 1985 more and more cars were running on unleaded gasoline. Today leaded gasoline is no longer sold in Denmark.

In general table 9 shows that there is a long way to reach the goals in the transport action plan of a 40% reduction of NOx, NMVOC and CH_4 in the year 2000.

The last table (table 10) shows how the emissions from other transport have developed in the period 1988-1994. As mentioned before the domestic emissions of CO_2 from air transport was based on the energy sold to domestic air traffic. However, for the other air pollutants the method recommended by ECE was adopted. Here the emissions attributed to Denmark are the pollutants emitted below a height of 1000 meters, i.e. the emissions in the landing and takeoff cycles (LTO-emissions) from as well domestic as international traffic, the rest, the cruising emissions, is international. This means that a larger fraction of the emissions is domestic. The calculation was based on detailed statistics of the total annual LTO's of different types of air planes.

Table 10. Emission from other transport in 1988 and 1994

Other transport	1988	1994	1988-94
	1000 tons		pct.change
CO_2	1029.0	1134.0	10%
NOx	15.1	15.8	5%
N_2O	0.06	0.06	0%
NMVOC	6.9	5.1	-26%
CH_4	0.6	0.4	-33%
SO_2	6.3	5.2	-17%
CO	13.0	10.1	-22%

The decrease in SO_2 emissions from other transport are largely due to a decrease in sulphur content of the diesel oil used for railways resulting in the a reduction of the emissions from railways of 85% in the period 1988-1994. The total SO_2 for other transport did not decrease that much since the sulphur content in diesel oil and residual oil in sea transport did not change.

4. Conclusions

The total CO_2 emission from the Danish energy sector has been almost stable since 1972. However, the only sector where the CO_2 emissions have continued to increase is road transport, where the CO_2 emissions have increased by about 50% since the early 1970's, and 15% since 1988. The increase of the CO_2 emissions from goods motor vehicles were even higher, 22%, since 1988. The total CO_2 emission from the transport sector increased thus by 14% in the period 1988-94, showing that a very strong policy and coordinated efforts in restructuring the whole transport sector is needed to reach the targets in the transport action plan to stabilize the emissions of CO_2 from the transport sector in the year 2005 at the 1988 level.

Concerning the emissions of other air pollutants the greatest success is about lead where leaded gasoline is no longer sold in Denmark. The emissions of SO_2 from the transport sector has dropped drastically due to lower sulphur content in the diesel oil. The introduction of 3-way catalytic converters has been effective in reducing the emissions of NOx, CH_4 ,NMVOC and CO. However a large effort is still needed to reach the target in transport action plan to reduce the emissions of NOx, CH_4 and NMVOC by 40% in 2000 compared to 1988.

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