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International Comparison of Transport Activity, Energy Intensity, and Modal Split Effects on Transport Energy Consumption and Carbon Dioxide Emission

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Author's declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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ABSTRACT OF THESIS submitted by:
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for the degree of Master of Science and entitled: *International Comparison of Transport Activity, Energy Intensity, and Modal Split Effects on Transport Energy Consumption and Carbon Dioxide Emission*

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This study examines the dominant factor for the change in the energy consumption from the transport sector in 7 OECD countries (4 Central and 2 Western European countries and Japan) from 1990 to 2007 by decomposing the energy use change into changes in the transport activity, modal split, and energy intensity effects and measuring the degrees of the contribution. LMDI method is used for the decomposition analysis to weight the effects properly. The major finding of this study is that the changes in the transport activity and the energy intensity have the dominant factors of the change in the energy use but the modal shift effect also contributes to it. The energy intensity is affected by the relative shares of the transport activity, and this study proves that the modal shift towards the energy-intensive road transport in enhances the energy intensity and the energy use increase in some of Central European states. To constrain the further growth in the energy use and relevant CO2 emission, not only transport volume and energy intensity but also the modal shift should be taken into account for the policymaking.

Keywords: transportation, modal split, energy intensity, transport volume, energy intensity, CO_2 emission, Central Europe, Japan, decomposition analysis

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Abbreviations

Country and Groups

AT Austria

BE Belgium

BG Bulgaria

CE Central Europe: Czech Republic, Hungary, Poland, Slovakia, and Slovenia

CEE Central and Eastern Europe (OECD): Albania, Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovak Republic, Slovenia, Estonia, Latvia and Lithuania.

CH Switzerland

CY Cyprus

CZ Czech Republic

DE Germany

DK Denmark

EE Estonia

EL Greece

ES Spain

EU-12 New EU members including Bulgaria, Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Marta, Poland, Romania, Slovak Republic, and Slovenia,

EU-15 Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom

EU-27 Austria, Belgium, Bulgaria, Czech Republic, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Marta, Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, and United Kingdom

FI Finland

FR France

HR Croatia

HU Hungary

IE Ireland

IS Iceland

IT Italy

JP Japan

LI Liechtenstein

LT Lithuania

LU Luxemburg

LV Latvia

MK Republic of Macedonia

MT Malta

NL Netherlands

NO Norway

PL Poland

PT Portugal

RO Romania

SE Sweden

SI Slovenia

SK Slovakia

TR Turkey

UK United Kingdom

US The United States of America

Units

Koe kilogram of oil equivalent

GJ Giga Joule

MJ Mega Joule

Mtoe millions of tonne oil equivalent

Pkm passenger kilometer

t CO_2 tonne Carbon Dioxide

Tkm tonne kilometre

Toe tonne of oil equivalent = 41.868GJ

Others

EC European Commission

EC DG TREN European Commission, Directorate-General for Energy and Transport

ECMT European Conference of Ministries of Transport

EEA European Environment Agency

EU European Union

GEO Global Environment Outlook

GHG Greenhouse Gas: carbon dioxide (CO_2), methane (CH4), nitrous oxide (N2O), sulphur hexafluoride (SF6), hydrofluorocarbons (HFC), and perfluorocarbons (PFC).

IEA International Energy Agency

IPCC Intergovernmental Panel on Climate Change

ITF International Transport Forum

MLITT Japanese Ministry of Land, Infrastructure, Transport and Tourism

OECD Organization for Economic Cooperation and Development

UITP International Association of Public Transport

UNFCCC United Nations Framework Convention on Climate Change

UNSD United Nation Statistics Division

USDE United States Department of Energy

Introduction

A drastic increase of energy use amplified by population growth and industrial society expansion has brought a potentially destructive force, Global Warming and Climate Change, besides air, water, and soil pollutions (Davis 1996). The dominant component of greenhouse gases (GHG), *very likely* to be the cause of the global warming since the late twentieth century according to Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, is carbon dioxide (CO_2) and for example the emission was 77% of total GHG emission in the world in 2000 (Baumelt et al 2005). Hence, the reducing CO_2 can be the potential key for mitigating global warming.

The largest factor of CO_2 emission is energy use and the transport sector is one of the dominant emission parts. Although the contribution of transportation on the whole GHG emission is 14% (need source), it accounts for 23% of energy-related CO_2 emission (IEA 2008a and IEA 2008c). The dominant energy source of the transport sector is oil (97%, IEA 2008b), which is one of the biggest contributor of CO_2 emission from fuel combustion (38% in 2006 according to IEA 2008a), and 'transport accounts for more than half the oil used worldwide' (IEA 2008c). In addition to that, both global CO_2 emission from the transport sector and its share have increased since 1990 (IEA 2008a) so that transportation is the key factor to mitigate of CO_2 as well as GHG emission and energy consumption.

Transport is essential for our daily lives, and it increases our personal mobility for various activities. Also almost all of goods even including the transport energy resources such as oils and coals are conveyed by means of transports from place to place before and after the consumption (Hoyle and Knowles 1996). Modern transport systems in industrialized countries are well developed and their transport innovation enables people to reach wherever they want to and get what they want wherever they live in the society.

However, massive transportation growth for population increase and technical development also brought adverse effect to our environments and health. It consumes huge amount of oils as mentioned above, and the combustion emits air pollutants such as CO_2, nitrogen oxides (NOx), sulphur Oxides (SOx), particular matter (PM), and etc, which increase human health problems and global concerns about the climate change. The technological advance of engines has managed to improve energy efficiency and drastically decrease NOx, SOx, and PM concentration, but not for CO_2. The technological contribution to CO_2 emission intensity reduction seems to be smaller than the growth of transport volume and the modal shift towards the more energy-intensive modes. As a result CO_2 emission from the transport sector had increased by 40.9% from 1990 to 2006 in the world (IEA 2008a). So, it is very important to discuss how we should reduce the CO_2 emission from the transport sector besides the technological improvement of vehicles and it directly comes how we should reduce the transport energy use. For that, the understanding of the factors that drive the energy use growth is essential.

International Energy Agency (2006) identified that energy use in the transport sector depends mainly on the following four factors:

- Transport activity (the level of demand for personal mobility and for the transport of goods).
- Modal mix (the chosen mix of transport modes like cars, buses, planes, ships, aircraft, etc.).
- Fuel mix (the types and the mix of fuel used in each transport mode).
- Energy intensity (including the fuel efficiency of the different modes)

The change in CO_2 emissions also depends on the above effects, plus CO_2 emission coefficient, which is expressed as CO_2 emission amount per energy use (e.g. t CO_2 per toe).

Past studies such as Papagiannaki *et al*. (2007) and Scholl *et al*. (1996) and this study also show that the transport activity level has the largest impact on the total energy consumption and CO_2 emission amount at least in Organization for Economic Cooperation and Development (OECD) states. However, the other three factors also must be considered to properly and deeply examine the reasons for the CO_2 level boost. Also it seems to be more unrealistic to focus on restraining the demand for the personal mobility than to try to reduce the energy intensity, improve the modal structure, and use more energy efficient resource. All of these four factors contribute to the total energy use and the shares of the contributions have been changing. To track and analyze the changes in these decomposed factors should be useful for the better understanding of the transport energy use and policymaking to reduce CO_2 emission.

As mentioned above, the changes in the energy use for the transport sector can be decomposed into transport activity, modal structure, fuel mix, and energy intensity effects. In this study, the index decomposition analysis using Log Mean Divisia Index (LMDI) approach is used to properly weight these effects and deeply examine how each factor affects the energy use change, besides the simple analysis of the graphs of transport activity, modal share, energy use, CO_2, and energy/ CO_2 intensity. The fuel mix effect is excluded in this study mainly for the lack of data and lower preference.

Transportation should be divided into passenger and freight transportation and they should be analyzed separately since their units for the transport activity are different from each other (passenger kilometer and ton kilometer, respectively) and they may have the different patterns of the energy use and decomposed factors, though such divided data are not available for many countries except a few industrialized countries.

This is a comparative study of the transport activity, modal mix, and energy intensity effects on the transport energy use and the correlation among the effects, and it is limited on the quantitative analysis using the composition analysis. Hence, the possible social and economic effects are not discussed in this study. The research areas are discussed later in detail but Central Europe (Czech Republic, Hungary, Poland, and Slovakia) are the main focus areas where few researchers have studied, as well as Austria and UK for the comparison in EU and Japan for the international comparison to examine the factor in broader scale.

Aim

The aim of this study is to investigate the effects of the changes in transport volume, modal split, and energy intensity on the changes in the actual energy use and carbon dioxide emission on the transport sector.

Objectives

The key objectives to achieve the aim are:

- To track and analyze trends of transport activities and modal share for passenger and freight transportation
- To track and analyze trends of energy consumption and CO_2 emission from transport sector.
- To calculate and analyze the transport energy intensity and CO_2 emission intensity from the transport sector
- To analyze the results of the decomposition analysis to examine the weight of modal shift, energy intensity, and activity levels effects on the actual energy consumption.
- To compile results of these analyses and discuss the relationship between modal split and energy/carbon emission intensity and consumption.

1. Methodology

The main research methods used to achieve the aim and objectives are literature reviews which provide background and supplemental information and support the analyses and quantitative data analyses such as a simple spread sheet analysis and more aggregated index decomposition analysis where the data are mainly collected from first hand statistics sources. The detail descriptions of each method are discussed later in this chapter.

1.1. Scope and limitation

This study focuses on the quantitative analysis of simple and aggregated data collected from first and second hand statistics and partially calculated by the author, and the research areas and time scale are determined by the data availability/accessibility and author's interests. Transport indicators which are used to meet objectives are derived from simple calculation of collected data. Spreadsheets are mainly used for data compiling and analyses.

1.1.1. Research area and period

Four Central European (CE) countries, Czech Republic, Hungary, Poland, and Slovakia are the main research area. And Austria and the United Kingdom (UK) are also selected to examine the difference of the modal share pattern and the energy intensity change between developed states and transitional states on the same region. In addition, Japan and USA are also selected as other research areas to justify the linkage among modal split, energy intensity, and energy use in general. Especially Japan is deeply examined as well for its rich data availability related to the study field. The comparison of Europe with non-EU developed countries can be important especially for CEE region, where the energy intensity on transport sector is relatively low but has been increasing as their economies grow (Urge-Voltaz, 2007), to clarify the common key points that keep energy intensity high on the transportation sector and avoid following the ways that developed countries fell down.

The available years of data are all up to the kinds and countries, but most of data are available since 1990, which is the base year of Kyoto Protocol. Although Kyoto Protocol does not indicate specific emissions reduction commitments percentage by each sector, it can be useful to track and analyze the trends of GHG emission on transport sector since the base year to see how the sector has been contributing to the whole GHG emission amount that each ratified country has targets or obligations of reducing or keeping the emissions to a certain level below 1990 levels.

1.1.2. Limitation

There are some kinds of limitation on this study. First of all, this is a general analysis of transport activities on each transport mode and their contribution to transport energy consumption and CO_2 emission but not a comprehensive analysis which can show the exact relationships among them. The correlation is estimated largely based on simple quantitative data on national level although more detail and aggregated data on local level should be taken into account for more precise estimation.

Secondly, the data availability is also a huge limitation especially for Central Europe. The decomposed data (passenger and freight transportation) of energy consumption and CO_2 emission amount in Europe are mostly unavailable or inaccessible so that only total transportation can be considered in this study for aggregate data and indices. And for rail transport, allocated data (direct and indirect CO_2 emission and energy consumption data) are not available but only data for final energy consumption (how much electricity was used). Furthermore, the aviation and navigation volume (pkm and tkm) are available only for total EU 27 (estimated value) but not for each country so that road and rail transportation are main focuses on this study.

Thirdly, this study is mostly limited on numerical analyses and not mention about possibly relating economic and social factors. Also the background information for each country which is necessary to understand the situations of each transport sector and relevant problems are not provided in detail.

And finally, study area is quite limited and therefore it is not sure whether the findings in this study can apply to other areas.

1.2. Data collection and indicators

Data collection

Necessary data are collected mainly from the first hand statistical sources such as Eurostat (transport activity), UNFCCC greenhouse gases inventory (CO_2 emission), EEA (CO2 emission), IEA (Energy use), and ITF (transport activity), and the secondary sources such as GEO data portal, EC DG TREN statistical pocket books and data tables (the main data provider in this study), and UNSD and database such as EDES to fill in the gaps that are usually old data originating from the first hand statistical sources but no longer available on their original pages. For Japan, transportation volume data are derived from Ministry of Land, Infrastructure and Transportation, transportation related energy data are from Agency for Natural Resource and Energy under Ministry of Economy, Trade and Industry, and CO_2 and GHG data are collected from Greenhouse Gases Inventory Office. For the United States, already organized dataset from United States Department of Energy (USDE) are used in this study.

Transport sector (Level 1) is divided into two categories, passenger transport and freight transport (Level 2) as shown on Table 1. And they are subdivided into several transport modes (Level 3); road, railway, (maritime), and aviation for passenger transport, and road, railway, navigation (maritime and inland waterway), aviation, and pipelines for freight transport. For the passenger road transport, it is further broken down into passenger car and buses (Level 4). For each level, the data of transport activity, energy consumption, and CO_2 emission amount are collected from the data sources as much as possible. Also, both national and international transport activities are partially mentioned although international aviation and maritime transportations (international bunkers) are excluded from the obligation under the Kyoto Protocol. For Europe, the data of energy consumption and CO2 are available for each mode but they are not divided into the passenger and freight so that some raw and aggregated data are not available for the lower levels and therefore some aggregated data which requires such level data are missing, and again this is the largest limitation in this study. Moreover, these divisions are also up to the data availability and/or accessibility of each country; for example, Japan does not use (or use very little) pipeline and inland waterway for the freight transport, while it is quite a large part in Europe or the US.

Level: 1 2 3 4

- Total Transportation
  - Passenger Transportation
    - Road Transportation
      - Private Vehicles
      - Busses and Coaches
    - Air transportation (commercial carriers and general aviation)
    - Rail transportation
    - Maritime transportation
  - Freight Transportation (road, rail, air, water, and pipelines)
    - Road Transportation
    - Railway Transportation
    - Inland Water Transportation
    - Air transportation
    - Pipeline Transportation
    - Maritime Transportation

Figure 1: Hierarchy of transport sector
Sources: Modified from USDE 2008.

Units and indicators

Following units and indicators are used in this thesis to examine the relationship between modal share and energy consumption (table 1). For each transport mode on both passenger and freight transportation, these units and indicators are derived or calculated from the collected data although some data are missing. The main indicators discussed on this study are transportation energy and CO_2 intensity indicators, which are expressed as "toe per pkm or tkm" and "gCO_2 per pkm or tkm." These indicators can show which transport modes consume energy and generate greenhouse gases less than others. These three indices are for examining the changes in main factors of transport energy use amount and are calculated using Log Mean Divisia Index (LMDI) approach. The detail is discussed on the next section, but this approach is useful to decompose transport energy use into factors such as transport activity, transport structure, and energy intensity at component level and examine the changes in each factor without residual (USDE 2009).

Tkm	for freight and total transport activity	toe/tkm	Energy intensity for freight and total transportation
Pkm	for passenger transport activity.	toe/pkm	Energy intensity for passenger transport
Toe	Amount of energy used	Component intensity index	Base year =1.change in energy intensity
MJ	Amount of energy used	structural index	Base year =1. modal shift
gCO_2	amount of CO_2 emitted	activity index	Base year =1. change in transport volume

Table 1: Unites and Indicators used in this study.

1.3. Data analysis method

There are two steps for the data analyses in this study; the first step is to analyze the absolute value of collected raw data (transport volume, energy consumption and CO_2 amount) and calculated aggregated data (energy intensity and modal split) by spreadsheet. Energy intensity is expressed as toe/ pkm or tkm, simply calculated from energy consumption divided by transport volume. Modal split is the share of transport activity (pkm or tkm) of each transport mode on the sum of all available transport modes. This study trucks and analyses the changes in these indicators from the drawn graphs, the tables, and also calculated percent changes from 1990 to 2007 (or other available periods depending on the data availability or needs). For Japan, the energy and CO_2 emission intensity can be split into passenger and freight transportation and subdivided into each transport mode, and for UK only energy intensity can be split into these two but not CO_2 for data availability. Due to the limited data availability and accessibility of energy use and CO_2 emission data, the energy intensity indicator in Central Europe only can be calculated for 'total transportation' (passenger + freight) for each mode. Transport activity is expressed as tkm for freight transport and pkm for passenger transportation, and they are usually considered separately. To calculate the energy intensity and do further analysis using more aggregated indices, they should be integrated and the units must be unified. In this study, the indicator called 'net mass movement' (Stead 2000) is used for the integration. Net mass movement represents a total transportation volume in tonne km, based on the assumption that average people weight with their luggage is 90kg (Stead 2000). Therefore, it can be derived from the following equation;

*Net mass movement (tkm) = pkm*0.09 (t per person) + tkm (freight)*

Again this is only used for Central European states where energy consumption data are not divided into passenger and freight, because the use of this indicator; for example, uncertainty (for example, the average weight of passenger should also depend on each mode and vehicle). And the split data should be more desirable for examining possible difference between freight and passenger transport energy intensity and modal shift pattern.

Log Mean Divisia Index Analysis

Index decomposition method is used as a next step to see the modal share effect on energy intensity and entire transport energy use in this study. Log Mean Divisa Index (LMDI I) approach which is proposed by Ang and Liu (2001) is chosen as the tool after reviewing literatures on similar topics, because this method seems to be the most commonly used and has the smallest residuals and errors among currently used approaches such as the Laspyres, the refined Laspyres, and Arithmetic mean Divisa index (Ang and Zhang 2000 and Ang and Chew 2003). For the index decomposition method, the analysis focuses on the energy consumption and excludes CO_2 emission. And fuel mix is not included in this approach mainly because of the lack of data.

The calculation process mostly follows the organized paper of United States Department of Energy (USDE) (2003), which uses LMDI I for their energy intensity research as well, and Ang *et al* (2003). First, total energy consumption (***E***) on transport sector can be expressed as the sum of energy use for each component ***i***, which can be subsector (freight and passenger) or/and each transport mode, as well as ***E=AI,*** where ***A*** is the transport activity (pkm or tkm) and ***I*** is the transport energy intensity (toe/tkm or pkm). The following equation (1) is the formula of the total energy consumption from the transport sector. The share of the transport activity (modal split) for component (mode) *i* on total transport activity (Ai/A) is expressed as $\mathbf{S}_i$.

$$E = \sum_i E_i = \sum A_i I_i = \sum_i AS_i I_i \tag{1}$$

Take the derivative of equation (1) with respect to time (equation 2), divide both side of the equation (2) by E, and perform some manipulation on the right side to express logarithms or percentage growth rates of total energy (equation 3).

$$\frac{dE}{dt} = \left(\sum_i S_i I_i \frac{dS_i}{dt} + \sum_i AI_i \frac{dS_i}{dt} + \sum_i AS_i \frac{dI_i}{dt}\right) \tag{2}$$

$$\frac{d \ln E}{dt} = \sum_i w_i \left[\frac{d \ln A}{dt} + \frac{d \ln S_i}{dt} + \frac{d \ln I_i}{dt} \right] \tag{3}$$

where, $\frac{AS_i I_i}{E} = \frac{E_i}{E} = w_i$ = share of energy used by component i $_{str}$

Then integrate the equation (3) over a discrete time period (0 to T) to yield a useable result:

$$\ln(E_T / E_0) = \sum_i \int_0^T w_i \frac{d \ln A}{dt} dt \qquad \text{Activity effect } (\mathrm{D}_{act})$$

$$+ \sum_i \int_0^T w_i \frac{d \ln S_i}{dt} dt \qquad \text{Structural effect } (\mathrm{D}_{str})$$

$$+ \sum_i \int_0^T w_i \frac{d \ln I_i}{dt} dt \qquad \text{Intensity effect } (\mathrm{D}_{int}) \tag{4}$$

Therefore, the logarithmic or percentage change in total energy use between any two points in time (D_{eng}) can be decomposed into three effects:

$$\mathrm{D}_{eng} = \mathrm{D}_{act} + \mathrm{D}_{str} + \mathrm{D}_{int} \tag{5}$$

where,

$$\mathrm{D}_{act} = \left(\sum_i w_i^* \right) \ln(A^T / A^0) \tag{6a}$$

$$\mathrm{D}_{str} = \sum_i w_i^* \ln(S_i^T / S_i^0) \tag{6b}$$

$$\mathrm{D}_{int} = \sum_i w_i^* \ln(I_i^T / I_i^0) \tag{6c}$$

where, the weights w_i^* (Log Mean Divisia weight)

$$w_i^* = L(w_i^T, w_i^0) / \sum_i L\left(w_i^T, w_i^0\right) \tag{7}$$

The function L (x,y) is the logarithmic average of any two positive numbers x and y given by

$$L(x, y) = (y - x) / \ln(y / x) \tag{8}$$

In equation 7, the logarithmic mean (equation 8) is normalized to exactly sum to one.

Divisia index decomposition can be applied over any time period so that it also can be applied to annual observations in the transportation system of energy intensity indicators. By taking the exponential of each side on equation 5, an index number for the second year (set the starting year = 1) is obtained.

$$Exp(D_{eng}) = Exp(D_{act} + D_{str} + D_{\text{int}}) \tag{9}$$

$= I_{act}$ (Activity Index, year-over-year)

x I_{str} (Structure Index, year-over-year)

x I_{int} (Intensity Index, year-over-year)

where $I_{act} = Exp(D_{act}), I_{str} = Exp(D_{str})$ and $I_{int} = Exp(D_{int})$.

The indexes from one level of the hierarchy to the next can be aggregated by the Divisia approach, and for that, the logarithmic changes for all of the indexes from a specific level of the hierarchy should be calculated and then the aggregation with the weighting scheme (equation 6a-c) should be performed. The detail calculation process is abbreviated (see USDE 2009 for detail), but the results can be as follows.

$$E^m = \sum_k (E_0^{m+1,k} / A_0^{m+1,k}) A^m S^{m+1,k} I_{str}^{m+1,k} I_{\text{int}}^{m+1,k} \tag{10}$$

Equation 10 is similar as equation 1 so that the same Divisia decomposition method can be applied to yield a solution for the logarithmic changes in following indexes:

$$D_{act}^m = \left(\sum_k w_k^* \right) \ln(A_T^m / A_0^m) \tag{11a}$$

$$D_{str'}^m = \sum_k w_k^* \ln(S_T^{m+1,k} / S_0^{m+1,k}) \tag{11b}$$

$$D_{str''}^m = \sum_k w_k^* \ln(I_{str,T}^{m+1,k} / I_{str,0}^{m+1,k}) \tag{11c}$$

$$D_{\text{int}}^m = \sum_k w_k^* \ln(I_{\text{int},T}^{m+1,k} / I_{\text{int},0}^{m+1,k}) \tag{11d}$$

where *m* is level of hierarchy and *k* is the indexes of subsectors to be aggregated.

The structural effect index I_{str}^{m} can be separated to $I_{str'}^{m}$ and $I_{str''}^{m}$ (from 11b and 11c). The first one is called, "between sub-sectors effect", for the changing composition of activity between or among the sub-sectors. And the second one is called, "within sub-sectors effect", for the changing composition of components within each of the subsectors (USDE 2009). Therefore, index of energy use at m level of hierarchy can be expressed as follows.

$$I_{eng}^{m} = I_{act}^{m} I_{str'}^{m} I_{str''}^{m} I_{\mathrm{int}}^{m} \qquad (12)$$

1.4. Literature Review

Since the first oil price shock occurred in 1973, the oil and other natural resources management and energy use study have come to the hot topic among energy researchers. In addition, climate change issue has also come to the hot topic and it reveals that artificial CO_2 level increase, which is very likely to contribute to the global warming, mostly originates from the energy use especially fossil fuel combustion. The transport sector is one of the largest consumers of fossil fuels, for instance more than half or oils are used in the sector, and therefore the study of the factors that affect energy consumption and CO_2 emission pattern for the transport sector has become popular. Following the line, many research papers and books about energy use on transport sector has been published all over the world.

Many of research papers, including Greening (2004), Scholl *et al* (1996), Kveiborg and Fosgerau (2007), Schipper *et al* (1996), Lakshmanan and Han (1997), Timilsina and Shrestha (2009), Steenhof *et al* (2006), and Papagiannaki *et al* (2007), studied factors affecting energy consumption and/or CO_2 emission growth from the transport sector by statistical approaches. The index decomposition analyses, which are considered as the most useful and commonly applied tool for examining the mechanism influencing energy consumption and its side affects (Papagiannaki 2007), are mostly used as their methodologies. Two major decomposition analysis techniques in energy and environmental analysis are introduced in some academic journals, including Ang (2004), Ang *et al* (2003), Ang and Zhang (2000), and Sun (1998); one is using Divisia index and another is using Laspeyres index. The main research areas of available publications are OECD countries where the enough data for the analyses are available, though Timilsina and Shrestha tried to apply the analysis to Latin American and Caribbean countries with limited data and results.

Although there are many research papers which analyze transport energy use pattern by decomposing it into several factors such as transport activity, modal mix, fuel mix, economic energy intensity few of them are especially focusing on modal shift effect maybe because many of them show that the most contributing factors are transport activity level and energy intensity both on passenger and freight transport, and the effect of modal shift is relatively small. In addition, some of above papers analyze each transport mode separately and they do not consider the modal shift effect in that case.

The closest papers to this study are Scholl *et al* (1997) and Schipper *et al* (1997), which focus on energy use and carbon emission from passenger and freight transport, respectively. Although they do not use the index composition method using LMDI approach, only cover 10 industrialized countries, and the data is old (from 1973 to 1992), they (Scholl and Schipper) split transportation sector into passenger and freight and provide comparative analyses of energy consumption and CO_2 emission, by decomposing factors into transport activity, modal mix, energy intensity, and fuel mix. They mainly focus on transport volume, modal shift, and energy intensity and use raw data collected from IEA and national statistics and calculated aggregated transport intensity using these data, as well as decomposition analysis using Laspeyres indices to estimate effects of changes in each factor on total energy use and CO_2 emission amount.

Scholl *et al* (1997) concluded that the growths of transport activity and modal shift towards passenger car sharply increased the energy use and CO_2 emission and the transport volume increase was the largest contributor for that from passenger transport sector in all cases. They also found that the energy intensity decline had a marginal impact, except the case in the United States where CO_2 emission increase was brought under the control. They analyze effects of each factor on whole energy consumption differently and put their calculation results on the table with the change in modal share (1973-1990) and energy and

CO_2 intensity (1973-1992) for each country chosen. It represents that the car energy intensity (MJ/vkm) decrease no matter whether the modal share increases or not from 1970 to 1992 in the all countries, while MJ/pkm decrease more slightly or even increases in some countries. However, the difference between the change in MJ/vkm and MJ/pkm is mostly for the change in number of passenger per vehicle so that the car modal shift effect on car energy intensity cannot be seen clearly there, though total energy intensity was not shown and therefore cannot estimate the intensity effect on the total energy intensity from passenger transport.

Schipper *et al* (1997) found that increased freight volume and modal shifts towards trucks offset the positive impact of lower energy intensity and led to the whole increase in energy consumption and carbon emissions in all chosen countries. They also found that freight transport was the only sector where transport activity and modal shift significantly affected the total energy consumption growth, while modal shift slightly affected the energy use for passenger transport with some exception.

Another research paper written by Schipper et al (1992) decomposed the change in the energy use into the changes in the transport activity and the aggregated energy intensity and further split the aggregated intensity into the structure, intensity, and interaction effects. Their research areas are 8 countries from OECD including Japan and UK as this study, but the analyzed data period is 1970-1987 so that it is out of the range of this study. They found that shifts among transport modes toward more energy intensive ones and the large increases in volumes of travel increased their total energy use for passenger transport in many OECD countries more rapidly than GDP growth. Another finding is that the energy intensity of passenger transport fell down only in few countries between 1970 and 1987 although individual automobiles have become more energy-efficient.

2. Transport Activity Trends

2.1. Passenger transport

Japan

The following graphs (figure 2.2.1) show the transport activity level on the national passenger transport. The dominant mode for passenger transportation has been roads and railways. The volume had been gradually increasing till the year of 2003 and then has been decreasing since then, but again increased in 2008. Railway transportation has been next popular mode and the transportation amount has been around 400 billion pkm since 1990. Although the domestic aviation is not a major mean of national passenger transport comparing to private car and rail, the volume has been rapidly increasing. The volume of bus transportation was twice larger than that of aviation for domestic passenger transport in 1990 but it has decreased and they are almost same in 2007. Domestic navigation is very small part of entire passenger transport system and the volume has been decreasing (MLITT 2009). Passenger road sector is split into private car, taxi, and bus. Private car amount reached the highest (756 billion Pkm) in 2002 and has started decreasing although it increased a bit in 2007, while buses had the lowest value (86.2 billion Pkm) in 2004 and then has started increasing their volumes. Taxi accounts for very small part on road transport and the volume has been decreasing as well.

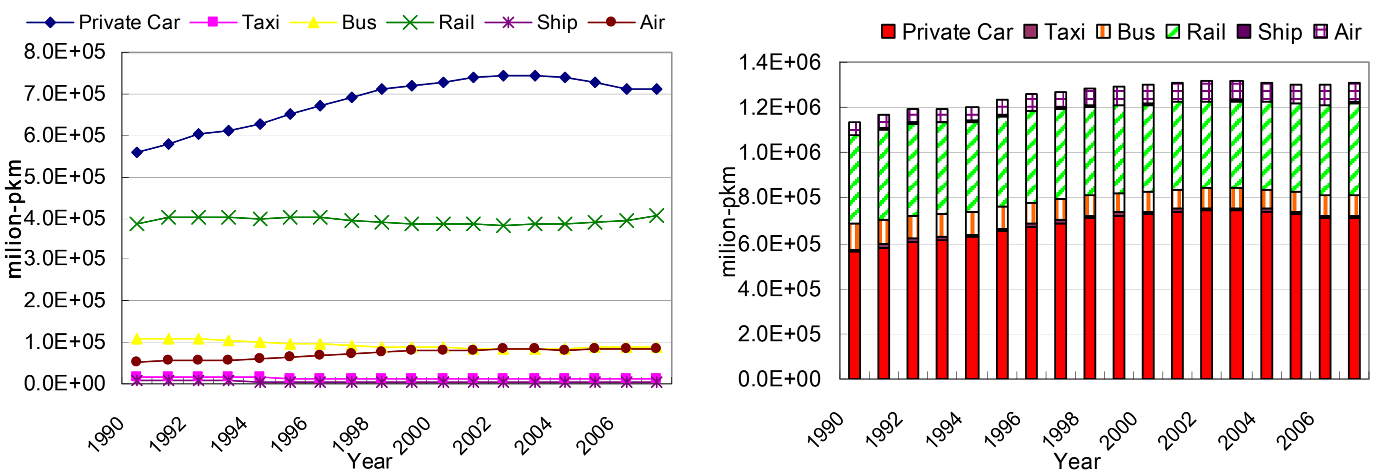


Figure 2: Passenger Transportation Volume (movement) in Japan.

Data Source: MLITT, 2008

A next figure (2.1.2.) shows the percent change of passenger transport volume change from 1990 to 2007. All of major means of transportation had increased their activity levels and as a result the total volume had increased by 16%. Especially the changes of aviation (63%) and passenger cars are large. The volumes of taxi, private use bus and domestic navigation for travel have sharply declined, but they are too small to contribute to the restraint of the whole transport activity level. The increase of passenger car (26%) and the decrease of bus (-19%) volume plus small change (+5%) of rail indicate the relative decrease of public transportation availability.

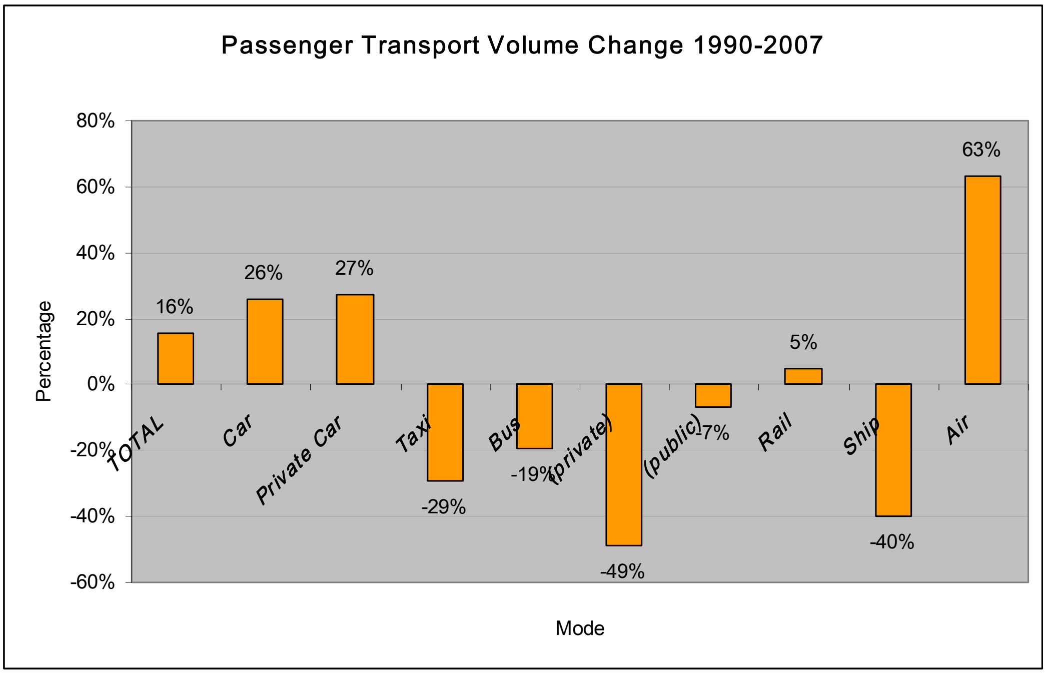


Figure 3: *Passenger Transport volume change in Japan.*
Road change is 1990-2006, aviation and rail changes are 1990-2007 change, maritime change is 1990-2006, and total change (road + rail + aviation; maritime is excluded) is 1990-2006. Data Source: MLITT, 2008

Modal share of passenger transport has been changed since 1990 as it can be seen on the following graph (figure 2.2.3.). From 1990 to 2002, the modal shift towards private car had increased, while the share of mass public transport mode such as bus and rail had decreased. And after 2002 the gradual modal shift towards the rail has been proceeding, though the share of bus has kept decreasing. Also the use of aviation has been getting popular even for domestic travel and the share has been increasing since 1990 although it decreased a bit in 2007. In 1990, the shares of cars (private car and taxi), bus, rail, and aviation were 51%, 10%, 34%, and 4%, respectively, but they shifted to 55%, 7%, 31%, and 7%, respectively in 2007 (MLITT 2009). The share of domestic aviation is almost same as that of bus in 2007

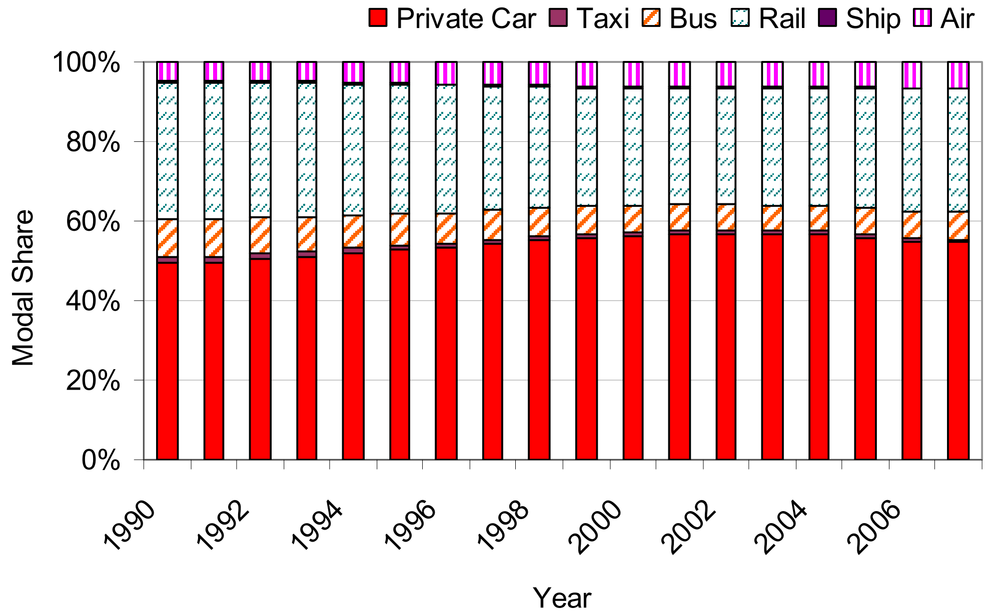


Figure 4: Modal Share of Passenger Transportation in Japan based on passenger kilometer
Data source: Transport Research and Statistics Office, Information Security, Research and Statistics Division, MLITT, 2008

Europe

The breakdown of communism in 1989 revealed that formerly socialist countries such as Central Eastern Europe (CEE) and the former Soviet Union had some of the highest energy intensities in the world and also brought the radical economic and lifestyle change there (Vorsatz et al 2006). Different from the other sectors, their transport systems under the communism were very organized and they had the high share of public transportation for both passenger and freight transportation, as an example of 80% in Warsaw and similar as Budapest (Vorsatz 1997, Vorsatz et al 2006). For the high public transportation availability and also transportation energy efficiency, the transport energy intensity (energy consumption per passenger-km) in these areas was much lower than that of OECD including Japan (Vorsatz 1994).

However, their transportation activities have rapidly changed in CEE countries after the iron curtain period. In this study, Central Europe including Austria, Czech Republic, Hungary, Poland, and Slovakia's trends are tracked although Austria is not the former socialist country, as well as the United Kingdom's data is sometimes attached for the comparison with another area in Europe.

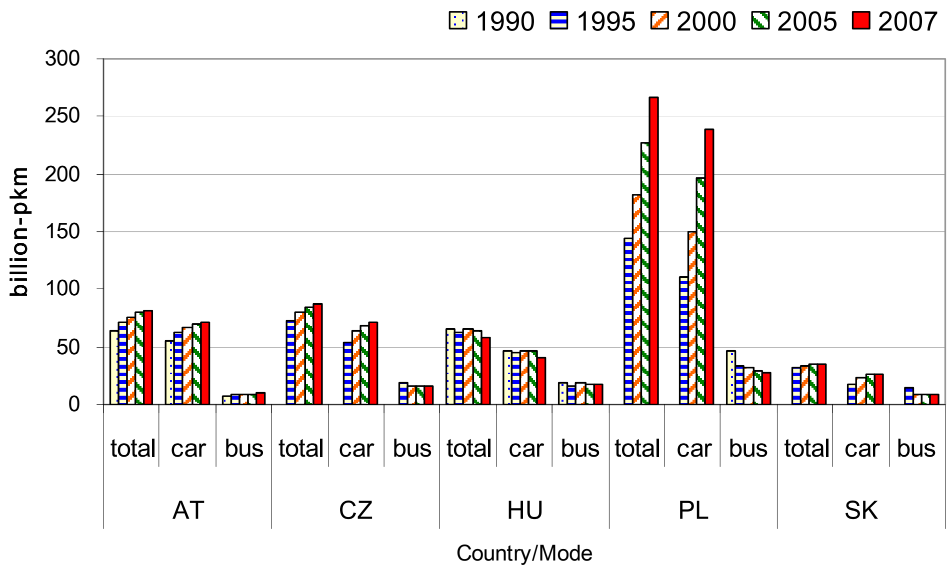


Figure 5: **Road Passenger Transport Volume in Central Europe.**
Source: EC DG TREN, 2009b

The passenger road transport volume in Central Europe has generally increased since 1990 except the case of Hungary where it has slightly decreased (figure 2.2.4). In Poland, the road passenger transport volume had increased by 86% from 1995 to 2007 with 116% car growth and 41% bus decline (EC DG TREN 2009b). Czech Republic also had the 20% higher road passenger volume (+31% car and -13% bus) in 2007 than that in 1995, as well as Slovakia with 7 % total passenger road growth (+45% car and -40% bus) for the same period (EC DG TREN 2009b). The trend in Hungary is quite different from other three countries and it has decreased the passenger road transportation by 12% with 12% car and 11% bus reduce from 1990 to 2007 (EC DG TREN 2009b). Different patterns also can be seen in Austria and United Kingdom where both car and bus has increased and as a result the total road volume increased by 29% and 16%, respectively, from 1990 to 2007 (EC DG TREN 2009b). The main findings from this graph are; 1) the use of buses has decreased in all CE countries while it has increased in Austria and UK, 2) Only in Hungary the passenger car and the total road volume has decreased, 3) the road volume growth rates in Central Europe are not much sharper than that in Austria and UK except the case of Poland.

The train, accounting for the second largest part of whole passenger transportation, has decreased the shares in all Central Europe while Austria and UK has increased the use from 1990 to 2007 (figure 2.2.5a). Especially, the decreasing ratios are very sharp in Poland and Slovakia (61% and 66% respectively) and also high in Czech Republic (48%), though Poland had increased the volume from 1990 to 1996 and has recovered again since 2005 and the volume in Slovakia had kept shrinking since 1990. Hungary also has decreased the volume of passenger train by 23% but it is still much lower rate than other CE states and the trend is different from there. It had declined from 1990 to 1995, raised from 1995 to 2003, and then again has decreased. In Austria, the volume had increased from 1990 to 1996, decreased from then to 1999, and then again has increased after that, and as a total 7% growth from 1990 to 2007. The large growth of passenger train activity can be seen in UK (50%) not like other countries analyzed here. In summary, all of CE states had reduced their activity level of train on the passenger transport and the changes are huge except the case in Hungary. But the volumes started recovering since 2004 or 2005 in Poland and Czech Republic, while it has kept decreasing since 1990 in Slovakia and since 2003 in Hungary as well. The two Western states, UK and Austria, raised their train volumes and the change is large in UK.

The tram and metro movement change has had different trends from that of the train in some of the countries it can be seen on Figure 2.2.5 (b). All of CE states except Czech Republic have decreased their train/metro volumes by around 10% from 1995 to 2007. Czech Republic where the volume has increased by 1% has started decreasing since 2004; however, tram and metro are especially popular there and the per capita distance travelled (pkm/capita) by metro are pretty higher compared to CE states, Austria, and even UK, where the volume has increased by 47% from 1990 to 2007 (IEA 2008b and EC DG TREN 2009b). The volume in Austria has also increased by 38% since 1990, so it can be said that the tram/metro activity level has hugely increased in the Western two countries and slightly decreased in CE countries. Also considering train and rail/metro together, the railway transport movement has been increased in UK and Austria by 47% and 14% from 1990 to 2006, respectively, while it has decreased in Czech Republic, Poland, and Slovakia by 7%, 11%, and 45% respectively.

Hungary has had very slight change for the railway transport volume and it has increased only by 0.8% from 1995 to 2007 (EC DG TREN 2009b).

(a) (b)

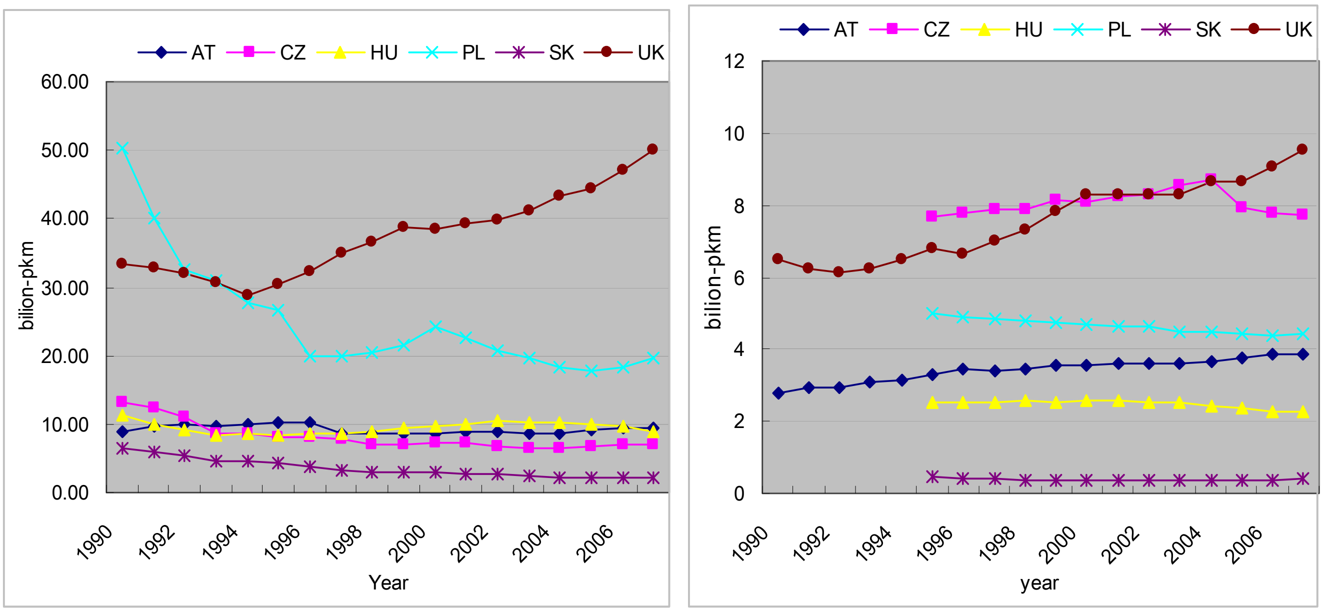


Figure 6: (a) Train and (b) Tram/Metro Passenger Transport Volume in Central Europe.
Source: EC DG TREN 2009b.

The next graphs (figure 7a-f) represents the modal share trends in all selected countries. In general, all of CE states except Hungary have increased the road share while they have decreased the other modes especially the railway.

The modal shift towards cars can be slightly seen in Austria (figure 7 a). In 1990, the modal shares of car, bus, train, and tram/metro were 74%, 10%, 12%, and 4% respectively, but shifted to 76%, 10%, 10%, and 4%. All of transport mode volumes have increased in Austria but the car growth rate was the sharpest. Czech Republic had the relatively high share of public transportation (bus, train, and tram/metro) and it accounted for 39% of total inland passenger transportation in 1995. But as the motorization has proceeded, all of them have decreased and the share in 2007 fell to 30% by 2007. The decrease rate in the train mode was the largest but in terms of modal split the bus lost the share the most.

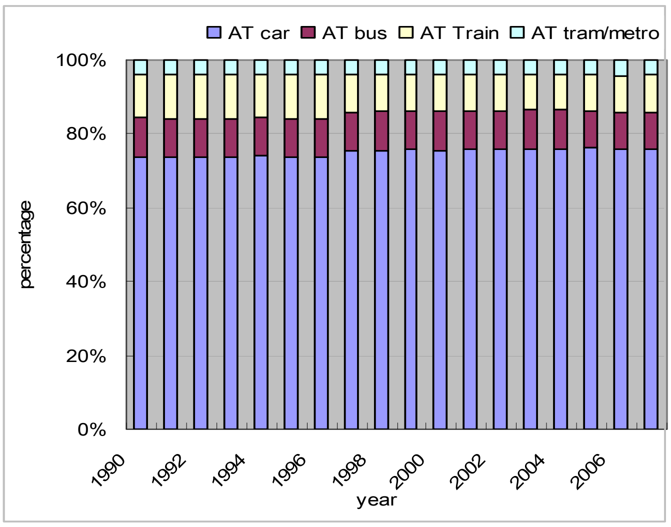
Hungary is the only country where the motorization has not proceeded since 1990. Both the absolute road transport volume and the modal share of car have decreased from 1990 to 2007. It also has reduced the volumes of all other land passenger transport modes.

Also the modal share of car has declined from 62.2% (1995) to 59.5% instead of the increases in bus and train.The sharp increase of car travel and decrease of public transportation obviously brought the increased modal shift towards the private cars in Poland. In 1990, the modal share of car was 63%, which was similar as Czech Republic and Hungary, but it has reached 82% in 2007. Buses, trains, and tram/metro had reduced their shares from 19%, 15%, and 3% respectively (1995) to 9%, 6%, and 1.5% (2007) (EC DG TREN 2009b).

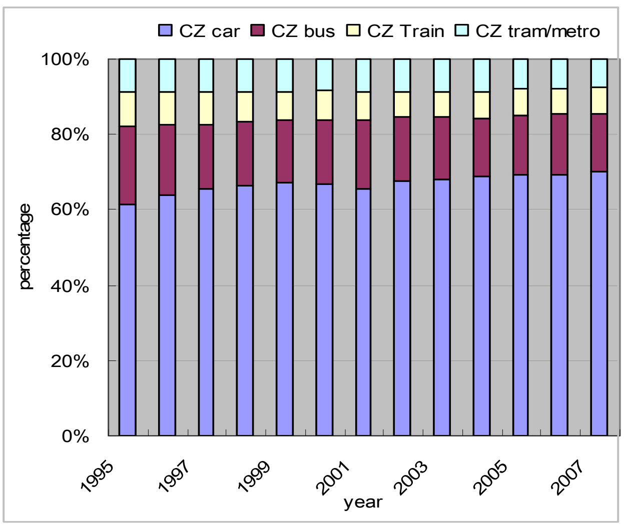
The drastic change in the modal share of passenger transport can be seen in Slovakia as well (2.1.6.e). The car share rate was 48.5%, less than half of total and the lowest among all analyzed countries even including Japan, and the bus and train shares were 39% and 11% correspondingly in 1995. However, again the large increase of cars (45%) and decrease of bus (40%) and train (66%) allowed the rapid growth of the car share (70% in 2007) and decline of other modes (23% and 6% for bus and train).

Different from Central Europe, UK already had very high share of the cars (87%) in 1990. Although the modal split balance has not changed sharply from 1990 to 2007, the small decrease of road (cars and buses) share and increase of railway (train + tram/metro) can be observed (cars 87% → 86%, buses 7.1% → 6.4%, train 5% → 6.4%, and tram/metro 1% →1.2%)

(a)



(b)



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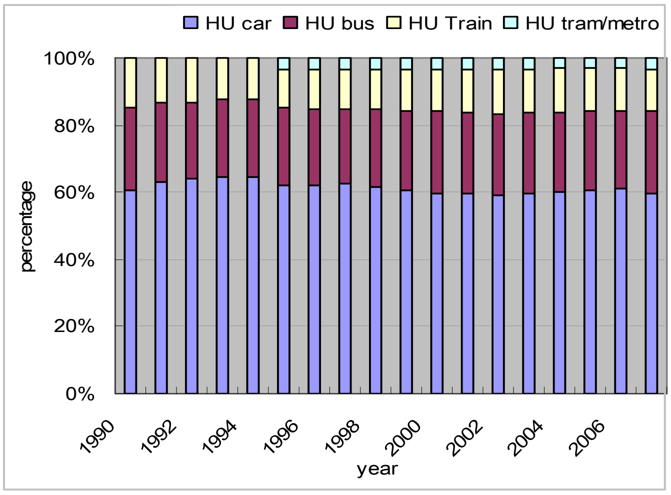

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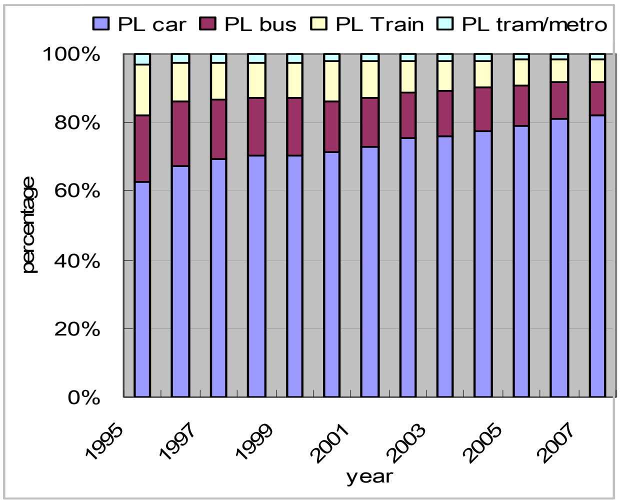
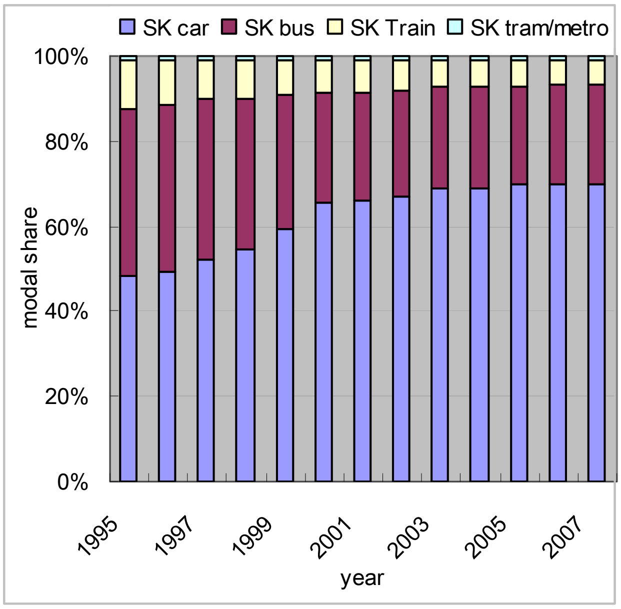


(e)



(f)

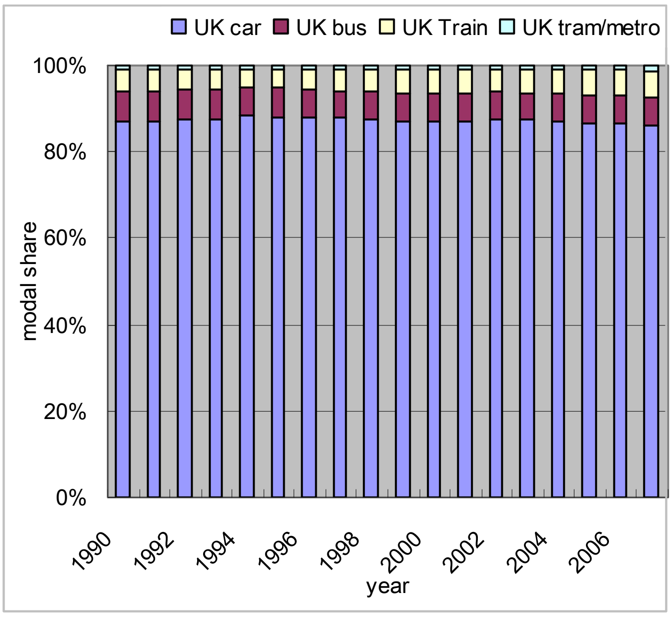


Figure 7; Modal Share of Passenger Transport in (a) Austria, (b) Czech Republic, (c) Hungary, (d) Poland,(e) Slovakia, and (f) United Kingdom.

Source: EC DG TREN 2009b

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2.2. Freight transport

Japan

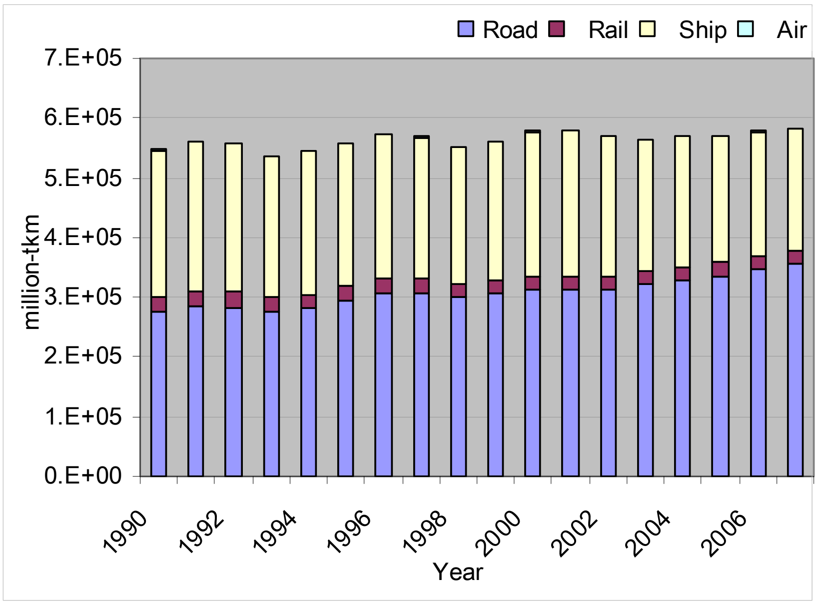


Figure 8: Freight Transportation activity levels in Japan.

Data Source: MLITT, 2008

The volume of freight transport activity in Japan has also been increasing in general although it goes up and down year by year as shown on Figure 2.2.1. The two main means of goods transportation are trucks and ships, and these two have been accounting for around 95% of total freight from 1990 to 2007 (MLITT 2009). However, the volume of road transport has been increasing while ship transport has been decreasing as well as rail transport. Freight transport by aviation is still very small although it has increased by 43% from 1990 to 2007 (table 2.2.1). The change in freight transport activity from 1990 to 2007 is smaller compare to that of passenger transport, but still it has increased by 6% in total during the period. The changing patterns of each mode are also different from the passenger transport, and only 2 out of 5 modes have increased. Road freight transportation is split into business and private use and there is a huge difference between two. The business use of trucks and other road modes for goods had rapidly increased but private use had sharply dropped oppositely, and the total road goods transport had grown. The ship transportation, another main good transportation, has declined by 17% and the rail use also has decreased by 14%.

The aviation is one of the only two which had increased the volume since 1990, but the absolute volume is very small compare to other transports, so it can be said that the sharp increase of business truck transport bought the increase of whole freight transportation. It is proved by the next graph (figure 2.2.4) that shows the modal share of business truck has sharply increased and of ships declined.

Mode/change	07/90	90/00	00/07	Mode/change	07/90	90/00	00/07
Road	29%	14%	13%	**Rail**	-14%	-19%	5%
Business	60%	32%	21%	**Ship**	-17%	-1%	-16%
Private	-44%	-28%	-23%	**Air**	-14%	-19%	5%
Total	43%	35%	7%				

Table 2: Freight Transport Volume Change from 1990 to 2007 in Japan.

Data Source: MLITT, 2008

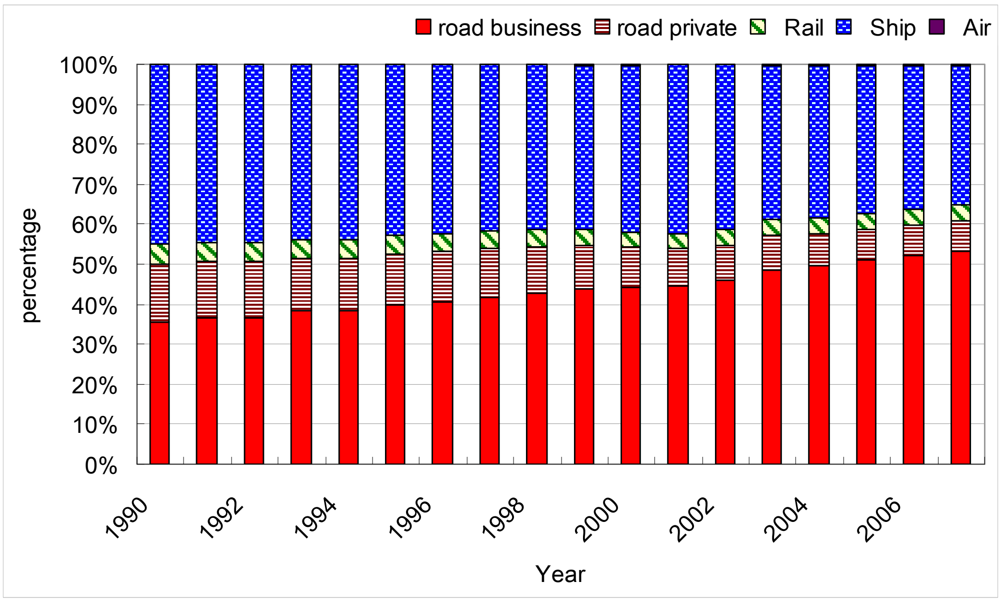


Figure 9: Modal Share of Freight Transportation in Japan based on passenger kilometer

Data source: MLITT, 2009

The dominant mode for freight transport was ship in 1990 (45%) and business truck was 35%, but they changed their places and the truck came to dominate the freight transport (53%) and the ship decreased the weight to 35% in 2007(MLITT 2009). The use of private truck, which accounted for 15 % of total in 1990, also went down to 8% by 2007. The share of rail has marginally decreased as well (5% to 4%). Thus the modal shift towards car has been proceeding in the freight transport sector not like the passenger transport that has started decreasing since 2003 (figure 2.2.4).

Europe

In general, the main two freight transport modes, road and maritime have increased their transport volumes in Europe (Figure 2.2.5 a, b). All other transports have increased as well and especially the domestic (intra-Europe) aviation has the most sharply increased from 1990 to 2007 (55% in EU 27). The growth rate of both road and total transportation for freight (49.6% and 38% respectively) are higher than that for passenger transportation (21.4% and 22%).

(a) (b)

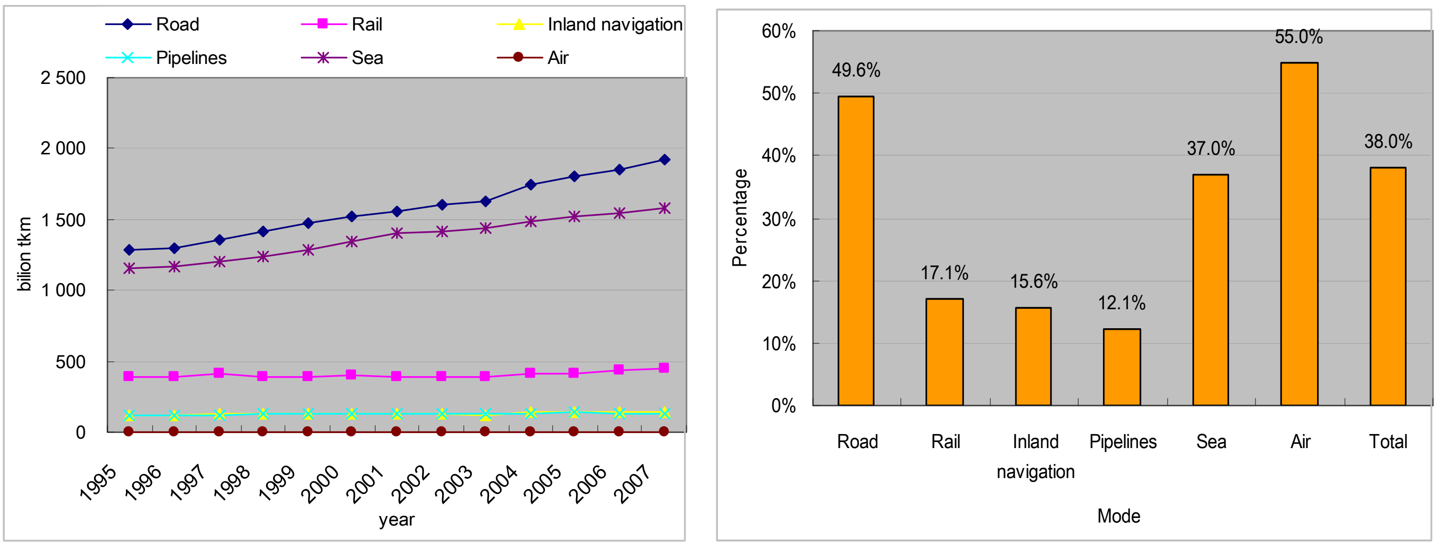


Figure 10: Freight Transport volume (a) and the volume change from 1990 to 2007 (b) in EU 27.
Source: EC DG TREN 2009b

The slight modal shift towards the road transportation can be observed in Europe (fFigure 2.2.6 a). Although the activity levels in all modes have increased for freight transport, the road had the largest growth, and as a result all other transport modes marginally reduced their shares. For the inland freight transport excluding the sea transport, the dominant mode is trucks (road) and the share has increased by 7% (67% to 74%) from 1990 to 2007 (EC DG TREN 2009b), and other three modes have slightly reduced their shares (figure 2.2.6 b). Indeed, the road transportation has been the dominant mode for both passenger and freight transport.

(a) (b)

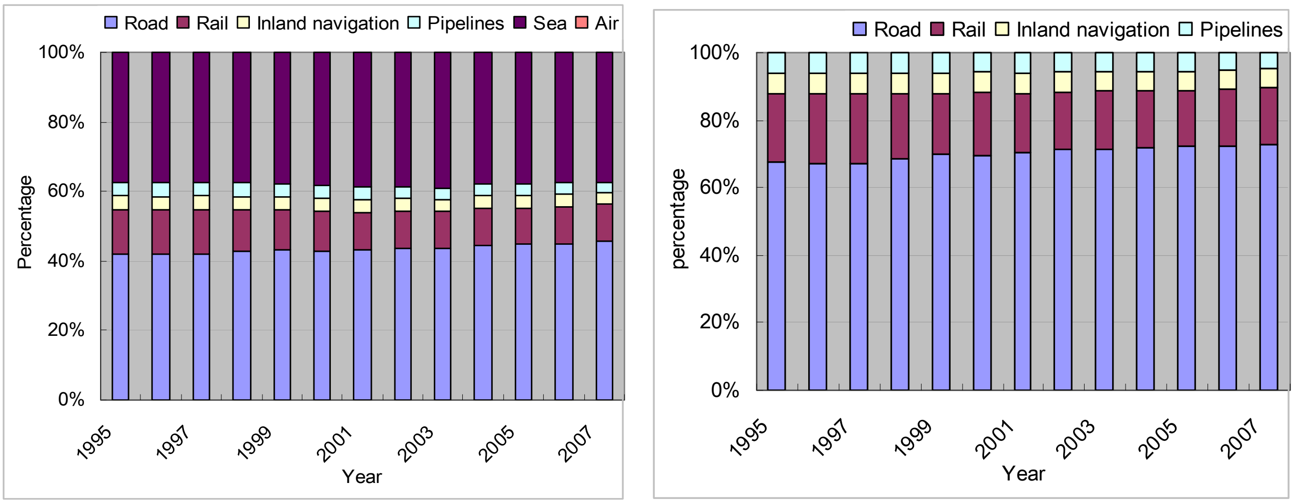


Figure 11: Modal Split of Freight Transportation (a) and Inland Freight Transportation (b) in EU 27.
Soure: EC DG TREN 2009b.

The general trend of road freight transportation volumes in Central Europe follows that of EU 27 and they have sharply increased from 1995 to 2007 (figure12 a). The volume change in Poland is the largest and it has increased by 195% during the period. All three other countries also had very high growth; 160% for Hungary, 71% for Slovakia, and 54% for Czech Republic. All of these increase rates are higher than that of EU 27 average (49.6%) and EU 15 average (35%) and it indicates how fast the goods transport by road has been popular there. Especially, the changes in the international haulage are huge in Central Europe; for example, from 2000 to 2007, Hungary, Poland, and Slovakia have increased the international road haulages, including cross trade and cabotage, by 224%, 215%, and 132% respectively, while Austria and UK have reduced the volume by 0.03% and 28% (Eurostat 2009).

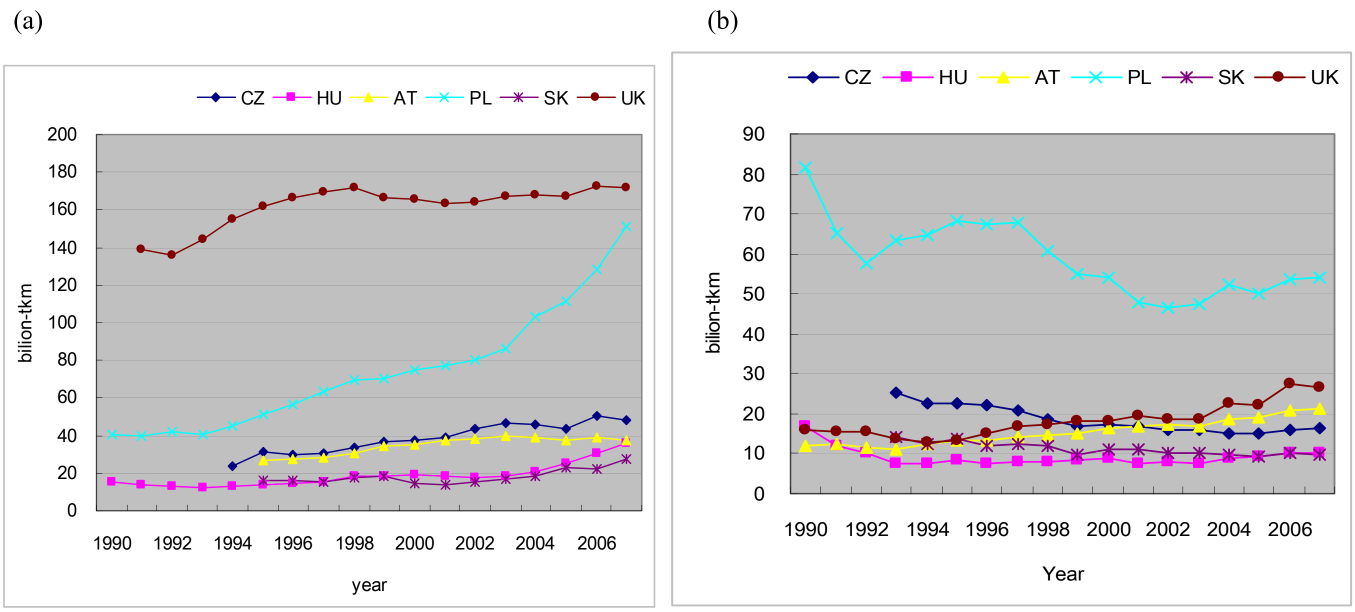


Figure 12: (a) Freight Road Transport Volume (national and international haulage) and (b) Freight Railway Transport Volume in Central Europe

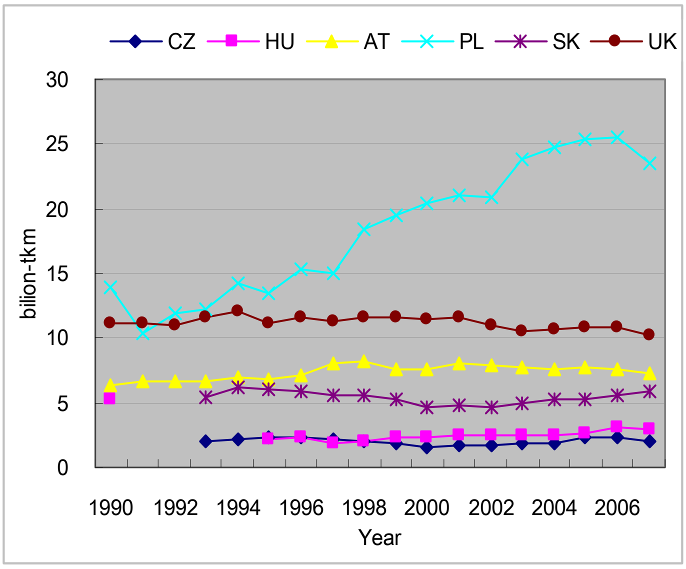
Source: EC DG TREN 2009b.

On the other hand, the trends of train goods transport, which has the second largest share for freight in Central Europe are the opposite (figure12 b). For EU 27 average, the volume has increased by 17%, but it is because EU 15 average has increased by 33% and EU 12 average has slightly decreased (4.5%). The average change in four CE states is -20% with the largest decrease in Slovakia (30%). However, all CE states have started increasing the volumes since 2005. The two Western states have increased their volumes during the period and the growth rate is much larger than EU 15 average (62% for Austria and 98% for UK).

The average increase rate of pipeline volume in CE states from 1995 to 2007 (figure 13 a) is 43%, which is much larger than that of all EU 27 (12%), EU 15 (9%), and EU 12 (19%). However, the trends are very different among CE states and Poland has accounted for the largest part of this growth. The volumes in Poland and Hungary have increased by 74% and 37% correspondingly from 1995 to 2007, while Czech Republic and Slovakia has reduced by 9% and 5%. The changes in pipeline transport seems to be connected to the changes in road transportation, because Poland and Hungary where the growth rates for road transport are high has also had the sharp increase for pipeline transport and Czech Republic and UK which have relatively lower growth rate of road transport has also had the decrease in pipeline volume.

The volume changes for the inland waterway depend on the countries (figure 13 b). In Czech Republic, Poland, and Slovakia, the volumes have sharply decreased by 87%, 73%, and 32% respectively, while Hungary has increased it by 8% from 1990 (1995 for Czech Republic and Slovakia) to 2007. However, the annual changes especially in Hungary, Poland, Slovakia, and Austria and are very large so that it is hard to see the general tendency here. For UK, the volume has been stable since 1992 although it has slightly decreased.

(a) (b)



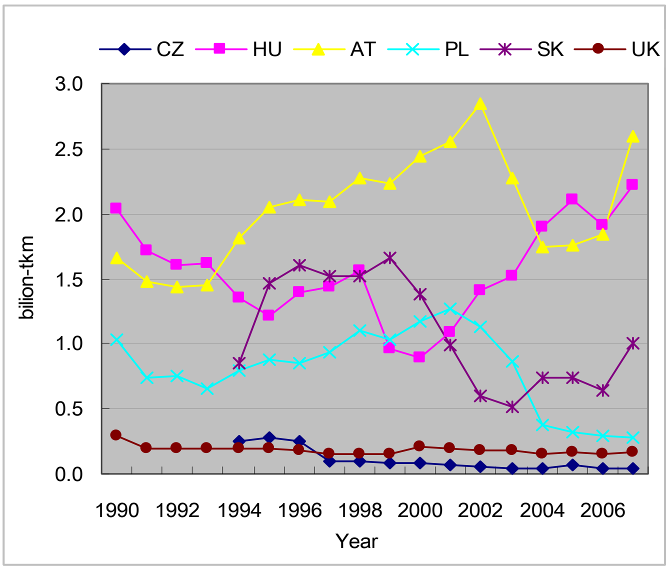


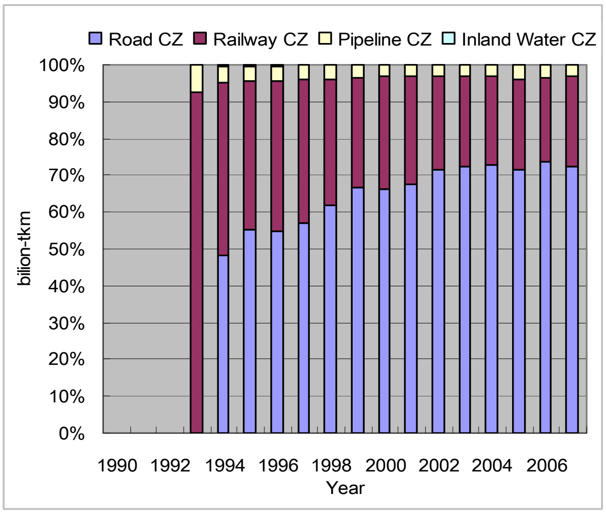
Figure 13: Pipeline Transport (a) and Inland Waterway Transport (b) volume in Central Europe
Data Provider: EC DG TREN 2009b. Data Source: Eurostat, ITF, and national statistics.

The modal split of the freight transport for each country is shown in figure 14 (a)-(f). The common tendencies of modal shift among CE states are that the road share has increased and instead the rail share has decreased from 1990 (or 1995) to 2007. The percentage changes are different from each country but in all of the countries the road share reached above 60% by 2007. Austria has the lower share of road than any CE states and the modal shift towards the railway has proceeded (2.2.8 c). Although the UK has had very high share of the road transport, the railway has increased its share since 1995 (2.2.8 f).

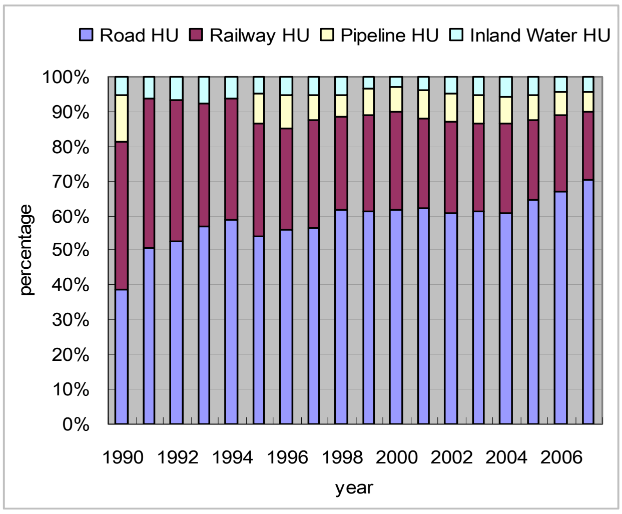
In 1994, the share of road and railway for freight transport was almost same (48% and 47% correspondingly) in Czech Republic. However, the sharp increase of road volume and the decrease of the rail use have led to a shift in modal split toward more the road and the share of road for goods transport reached 72% with dropping the rail share to 23% in 2007. Hungary had even higher share of the railway (43%) than that of the road (39%) for the freight transportation in 1990, but it also has shifted the modal split towards the road and the road share reached 70% in 2007. The pipeline and inland waterway transport in Hungary has had relatively higher share than in other CE state, but both of them, especially pipeline, have lost the share sharply from 1990 to 2007 (13.5%→6% for the pipeline and 5%→4% for the inland waterway. The huge increase of the road and pipeline transport and decrease of the railway and inland water has led the drastic change in the freight modal split in Poland (2.2.8 d). The dominant goods transport mean was the railway and the share was 60% while the car share was 30% in 1990, but the modal shift towards the road has not stopped and the road share reached 66% and the rail share went down to 24%. Although the volume of pipeline has sharply increased, the relative share has not changed from 1990 to 2007. The inland waterway has had very small part of the total freight transport and decreased the share as well as the volume. Slovakia has the similar trends as other CE states and the shift to road transport can be seen (2.2.8 e). The two Western states have different modal shift pattern. Austria had raised the care share from 1995 to 2003 but has decreased after that, and it reached almost same as1995 level in 2007. Also UK has slightly decreased the road transport share (-1.6%) from 1991 to 2007, while the railway share has increased from 9% to 13%.

In summary, the modal shift of freight transport from rail to road can be seen in all of Central European countries and it is different from the selected two Western states where the railway share has increased. And the inland waterways have reduced the shares in all examined countries.

(a)



(b)



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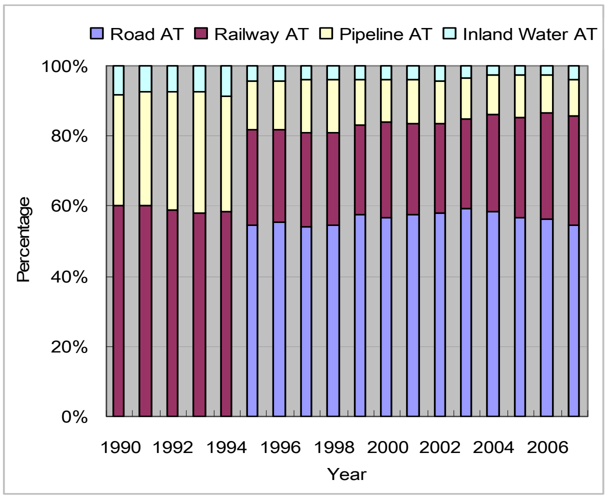

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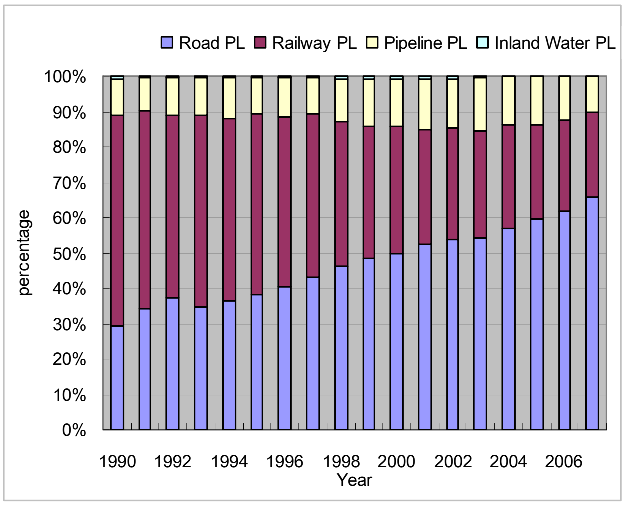
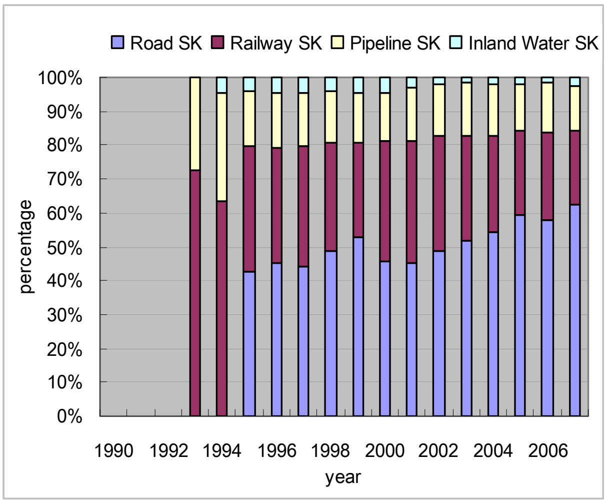


(e)



(f)

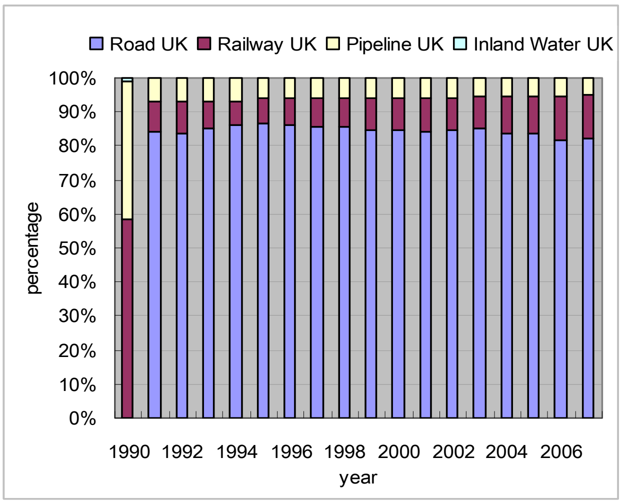


Figure 14: Change in Modal split of Freight Transport in: (a), Czech Republic, (b) Hungary, (c) Austria, (d) Poland, (e) Slovakia, and (f) United Kingdom

3. Transport energy use and CO_2 emission

In this chapter, the trends of energy use and CO_2 emission changes on the transport sector are tracked and analyzed quantitatively. As mentioned in the limitation section, the energy consumption and CO_2 emission data for European countries are available only for the total transportation but not for the passenger and freight transportation separately except the case of energy consumption by vehicle type for the road transport in UK. Although there are some literatures and statistics which show such data, their data sources are usually unclear, simply estimated, or projected scenario, and therefore these data shown in this chapter should be especially considered only as a guide.

3.1. Passenger transportation

Japan

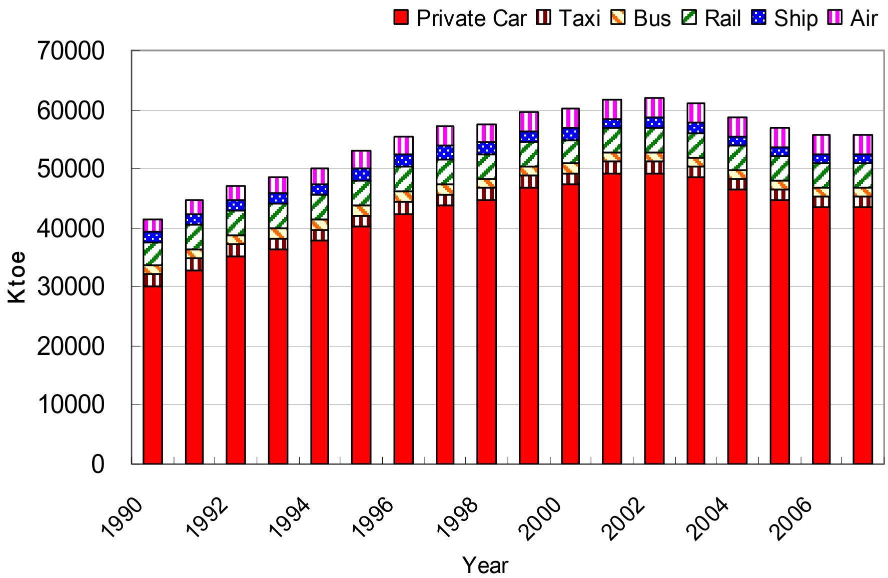


Figure 15: Energy consumption for passenger transport in Japan.

*Primary energy equivalent of electricity used for the calculation for the rail transport (allocated)

Data Source:ANRE 2009.

The amount of the energy use for the passenger transport has changed as the passenger transport volume has had (figure 15). The total amount was 41 million toe in 1990 but reached 59 million (including transportation fraction estimation error which is not shown on the figure) in 2001, and then reduced to 55 million toe in 2007. The passenger transport volume also has reduced since 2003 when the volume reached the peak. Although the peak year is different from that of energy consumption, the trend of transport activity and energy use are very similar as each other. Hence, it can be guessed that the transport energy use mostly depends on the transport activity level.

Table 3 shows the percentage change of the energy use for the passenger transport by each transport mode from 1990 to 2000, from 2000 to 2007, and from 1990 to 2007. The total increase of energy use in the period 1990-2007 is 32.7% as it can be seen, but the periods 1990-2000 and 2000-2007 have very different pattern and also each transport has different changes in the different periods. All of modes except the private household use car decreased the energy consumption in the period 2000-2007 while the energy use in all modes except taxi and bus had increased in the period 1990-2000. The most important thing on this table is that "household use private car", which is the dominant source of passenger transport energy use (45% of total in 1990), has increased even in the period 2000-2007 and the share also reached 51% of the whole passenger transport energy use. For the sharp decrease of the corporation use private car, the whole private car has also decreased the energy use as well as the modal share; however, the private car is still the key point to reduce the whole energy use fofr the passenger transport and the total transport sector.

Mode/change	**07/90**	**00/90**	**07/00**	Mode/change	**07/90**	**00/90**	**07/00**
Road	38.7%	50.7%	-7.9%	**Bus**	-5.5%	-0.3%	-5.2%
Car	41.0%	53.3%	-8.0%	Private Use	-20.0%	-12.2%	-8.9%
Private Car	44.6%	57.0%	-7.9%	Public	-1.4%	3.0%	-4.3%
(Household use)	47.2%	40.2%	5.0%	**Rail**	5.3%	5.6%	-0.2%
(Corporation use)	40.0%	86.3%	-24.9%	**Ship**	-3.5%	16.1%	-16.9%
Taxi	-13.6%	-2.6%	-11.3%	**Air**	55.1%	52.4%	1.7%
TOTAL	32.7%	39.7%	-5.0%				

Table 3: Energy Consumption Change for Passenger Transport in Japan.

*excluding transportation fraction estimation error.

Date Source: ANRE 2009.

The trend of CO_2 emission from the passenger transport sector has been very similar as that of the energy consumption because the CO_2 emission coefficient (CO_2 emission amount per energy use), which depends on fuel mix (and energy efficiency), has not changed drastically since 1990 (figure 16). The railway has the lowest CO_2 emission coefficient for the electricity as the main energy source.

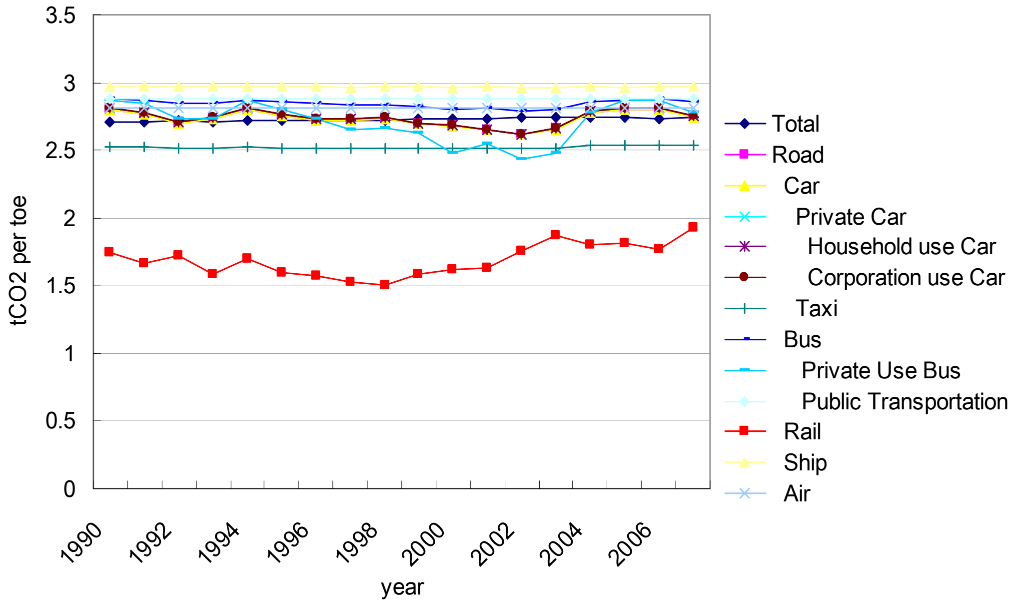


Figure 16: CO_2 emission coefficient for passenger transport in Jaan

Data source: ANRE 2009 and greenhouse gas inventory office 2009.

Europe

The reliable data of the actual energy use and CO_2 emission for the passenger transport could not be found for the study areas in Europe, so the values are mainly estimated from the existing aggregated data (ODYSSEE 2009 and Eurostat 2009) only for the road energy. Such data for other modes, especially for the railway which needs to be split into passenger and freight, could not be found.

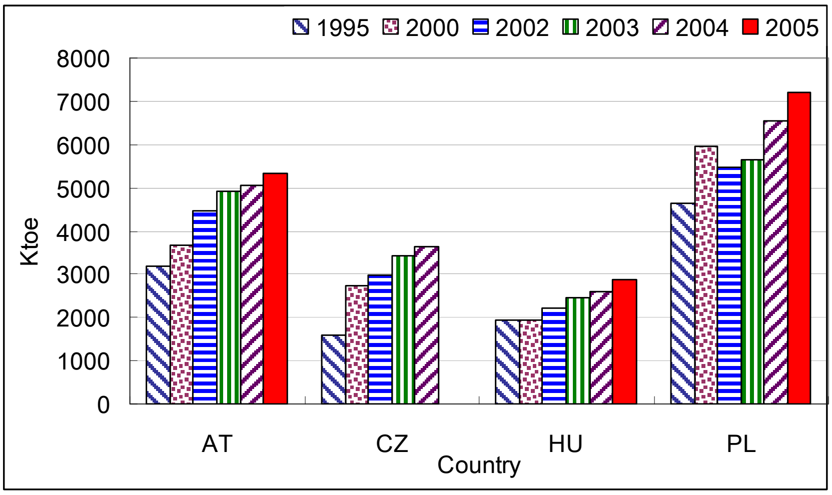


Figure 17: Energy Consumption for road passenger transport in Central Europe from 1995 to 2005.
:*excluding Slovakia for lack of the data.
Estimation based on data from ODYSSEE 2009, Eurostat 2009, and IEA 2008b.

As the volume of the road passenger transport has increased, the energy consumption also has increased in all selected countries (figure 17). In all of the countries the growth rate of the energy use is larger than that of the transport activity except the case of Poland where the change in the transport activity is 1% higher. For instance, Czech Republic and Hungary have increased the energy use by 125% and 67% correspondingly from 1995 to 2004 but only increased the energy volume 13% and 4% during the same period. The similar trend can be seen in Austria. These findings indicate that the energy use increase has been strongly associated with the transport volume growth but there should be other factors which further accelerate or restrain the total energy use, which are discussed later.

3.2. Freight transportation

Japan

Different from the energy consumption pattern for the passenger transport, the freight transportation has decreased the energy use by 6.5% from 1990 to 2006 (figure 18). It had slightly increased the energy use from 1990 to 1996 but has decreased since then. And the trend of the freight energy use change has also been different from that of the freight transport volume. Especially from 2003 to 2007, the volume has increased but the energy use has decreased. Looking at the graph by each mode, it can be found that the total and private use road freight transportation has decreased but the business use road transport has increased.

The energy use for the freight aviation transportation has been increasing sharply although the share is still very small.

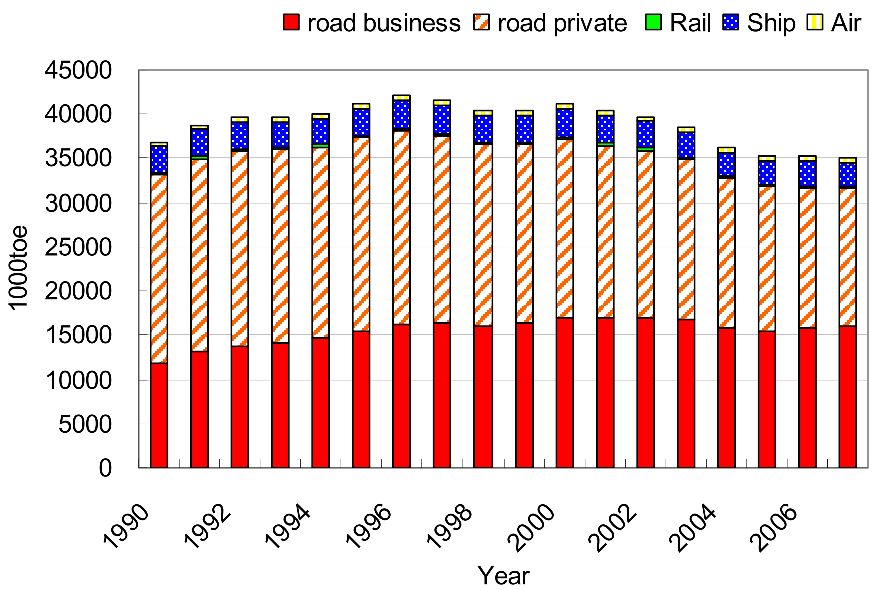


Figure 18: Energy Consumption for Freight Transport in Japan.
Data Source: ANRE 2009.

The energy use for the freight transport during the period 1990-2000 had increased for all modes except the private use road transport and railway transport. Especially the changes in the business use road and aviation growth during the period are very sharp, while the railway had reduced the energy use. On the other hand, all of transport modes except the domestic aviation have decreased their energy uses from 2000 to 2007. The drop rate of the private use trucks and the domestic navigation are sharp, while the decrease rate of the railway became smaller.

Comparing it to the changes in the freight transport volume, some differences and similarities could be found. First of all, the total energy use for the freight transportation has decreased by 6.5% from 1990 to 2007 but the volume has increased by 6% during the period. Also the energy use of the road freight transport has declined but the transport volume has increased although the trends of the business and private use road freight are similar and the business use had increased and the private use road had decreased both the energy use and volumes. These findings show that the fuel and energy efficiency for the road freight transportation has improved especially after 2000. For the rail and ship freight transport, both the volumes and the energy use have decreased from 1990 to 2007, though the percentage decrease of the energy use is larger for the railway transport and smaller for the navigation transport than that of the transport volume.

Mode/change	07/90	90/00	00/07	Mode/change	07/90	90/00	00/07
Road	-4.5%	12.2%	-14.9%	**Rail**	-18.1%	-16.8%	-1.5%
Business	34.0%	42.8%	-6.1%	**Ship**	-13.3%	3.9%	-16.6%
Private	-26.1%	-5.0%	-22.2%	**Air**	36.1%	32.8%	2.5%
Total	-6.5%	2.2%	-8.6%				

Table 4: Energy Consumption Change for Freight Transport in Japan.

*excluding transportation fraction estimation error.

Date Source: ANRE 2009.

The trend of CO_2 emission from the freight transport is very similar as that of the energy use (figure 19). Also the CO_2 emission coefficient is very close to that of the passenger transport. The CO_2 emission from the freight transport in Japan has started decreasing since 1996 and each mode except the business use road and domestic aviation transport has all declined the emission from 1990 to 2007.

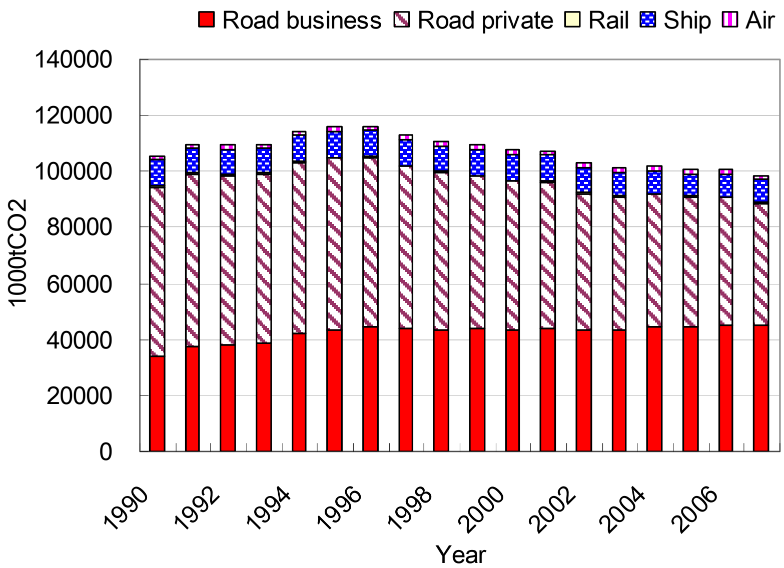


Figure 19: CO2 emission from the freight transport in Japan.

Source: Greenhouse gas Inventory office 2009.

Europe

The volume of the total freight transportation in Central Europe had increased by 29% from 1995 to 2005 with the largest increase in the road transport. As mentioned in the section 2.2, all of the countries had sharply increased the road transport volumes. So how about their energy use? The following graph (figure 20) shows that the energy use for the freight transport has sharply increased for CE states and less sharp for Austria. For Slovakia, the split data was not available and UK is excluded from the graph because of its proportion. The change in the energy use from 1995 to 2005 is slight (6%) in UK. Czech Republic and Poland have kept increasing the energy use from 1995 to 2005 and the growth rates during the period are 80% and 60% respectively. Hungary had rapidly increased the energy use from 1995 to 2000 (177%) but has only increased by 4% from 2000 to 2005. Austria and UK have smaller growth rates than CE states and the trend is similar as that of the transport volume.

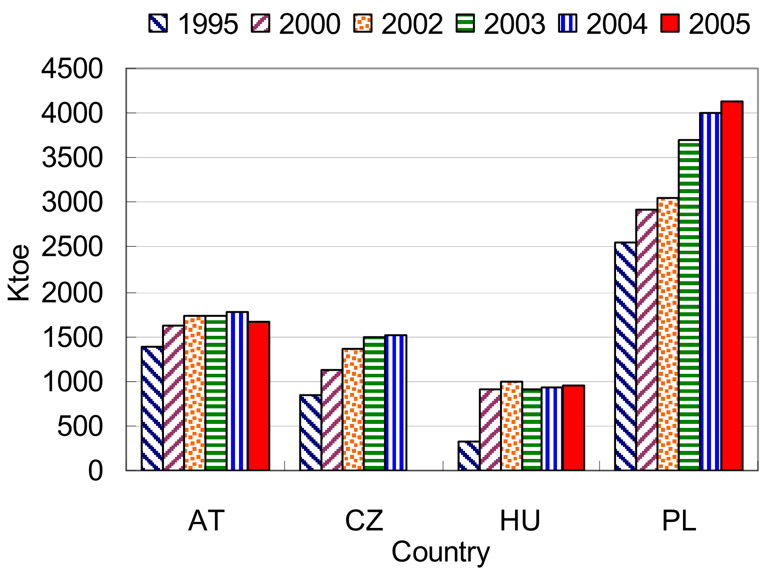


Figure 20: Energy Consumption for Freight Road Transportation in Central Europe from 1995 to 2005. Estimated based on data from ODYSSEE 2009, EUROSTAT 2009, and IEA 2008b.

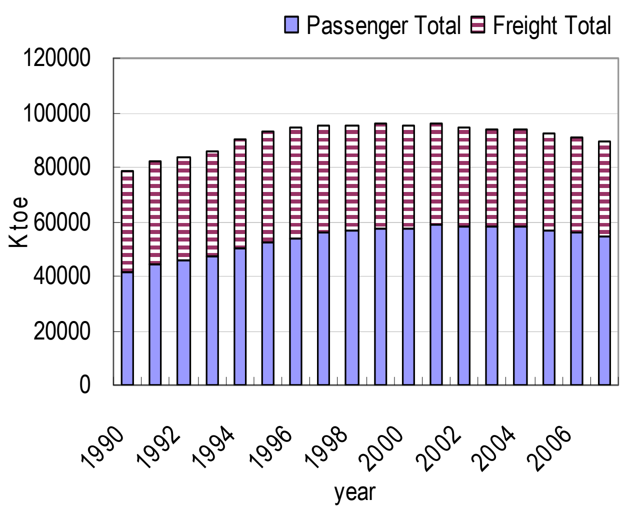
3.3. Total transportation

Japan

The energy consumption trend of the whole transport sector in Japan is as shown in figure 21 a. The consumption amount has increased from 1990 to 2007 but it reached the peak in 2001

(95 million toe) and has started decreasing since then. The energy share of the passenger transport and the freight transport has gradually shifted towards the passenger transport (figure 21 b). The passenger transport share was 53% in 1990 but reached 61% in 2007.

(a)



(b)

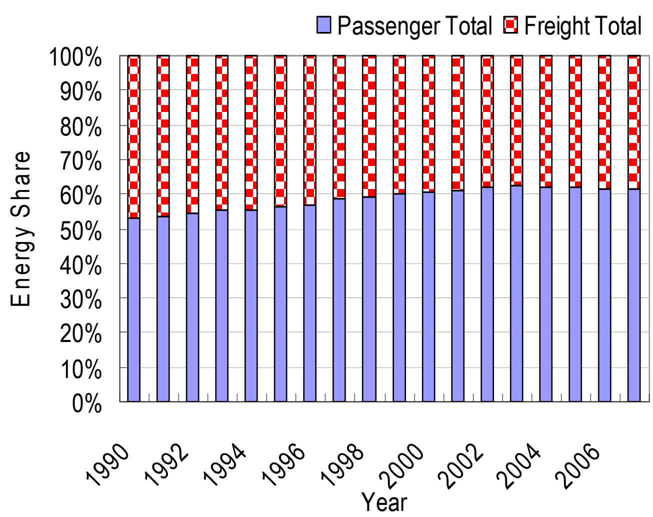


Figure 21: Energy Consumption for the transport sector (a); Energy share of the transportation sector (b)
Data Source: ANRE 2009.

Japan also has increased CO_2 emission from the national transport sector by 15% from 1990 to 2007 but again the emission amount has decreased since 200i same as the energy use (figure 22). In 2007 the emission amount was reduced to 249 million which is the governmental reduction target of CO_2 emission by 2010. The CO_2 emission originating from the international bunker (maritime and aviation) oils are also on the figures and it indicates that the contribution of the international transport to CO_2 emission from the transport sector is not small although they are not included in the reduction target of CO_2 emission of the Kyoto protocol.

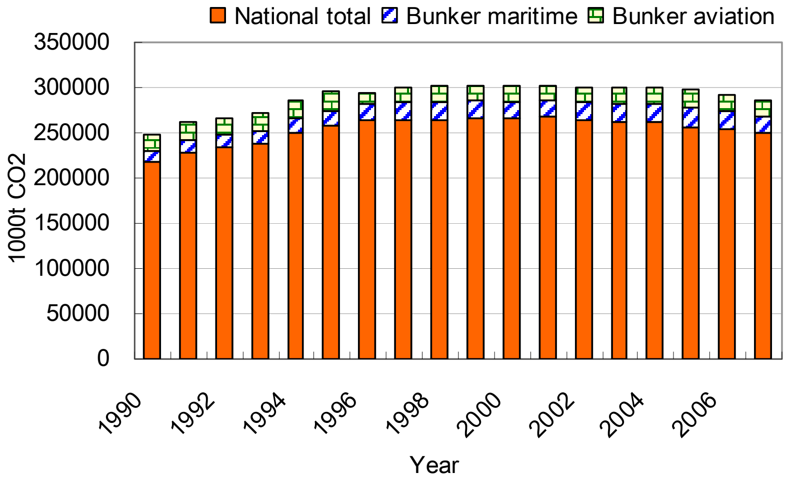


Figure 22: CO_2 emission from the total national transportation and international bunkers.

Data Source: Greenhouse Gas Inventory Office 2009.

Europe

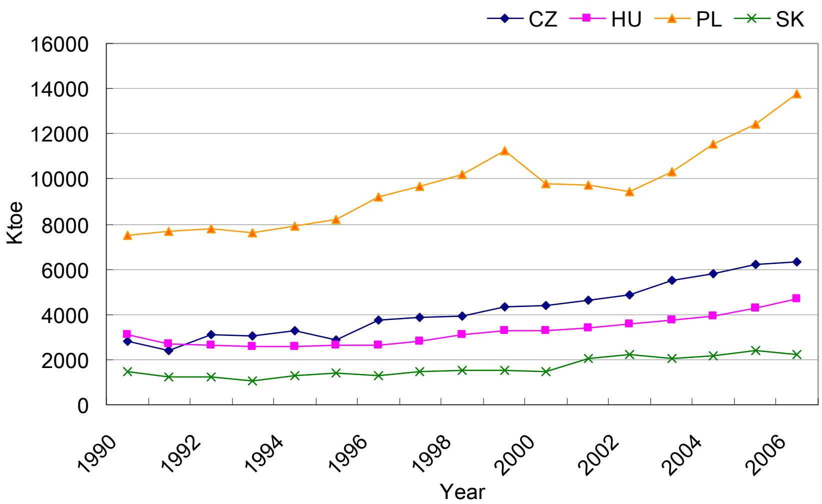


Figure 23: Total Transport Energy Consumption in Central Europe 1990.

Source: IEA 2008b

The transport energy consumption in all chosen countries has increased from 1990 to 2006 with the largest growth in Czech Republic (figure 23) as both the passenger and freight transport volumes have also increased. The following table (5) shows that all of Central European states sharply increased their energy consumption on the transport sector from 1990 to 2006 comparing to that of UK. Austria is considered as the Western Europe but still the increase rate is larger than Hungary and Slovakia. And the changes in the energy use for the period 2000-2006 are sharper in CE states except Czech Republic than the period 1990-2000, while Austria and UK has the lower growth rates of the energy use during the period

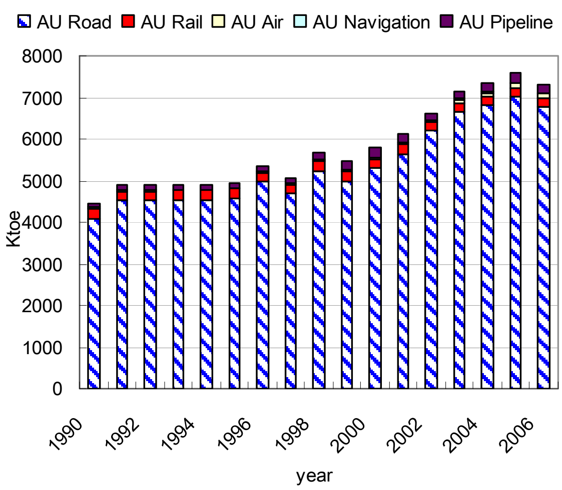
2000-2006.

Country/Change	90/06	**90/00**	**00/06**
AT	67%	34%	24%
CZ	125%	56%	44%
HU	51%	6%	43%
PL	84%	31%	41%
SK	55%	1%	54%
UK	23%	15%	7%

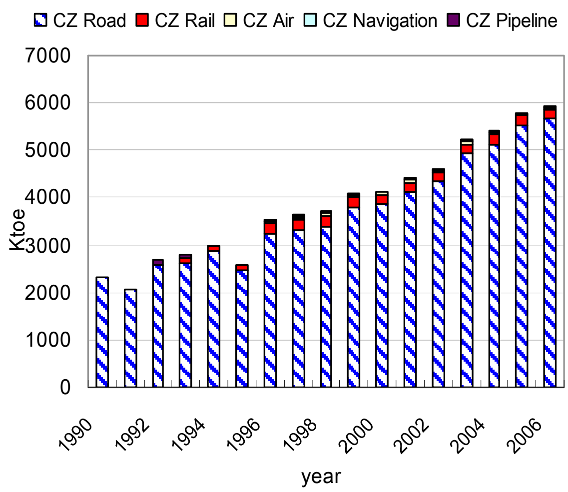
Figure 24: Energy consumption amount change for the transport sector in Central Europe from 1990 to 2006. Data source: IEA 2008b

Since the split energy use data of the passenger and freight transportation could not be found, the energy consumption is directly divided into each transport modes. The trends of the energy consumption by transport mode for each country are shown in figure 25 (a)-(f). All of CE countries have the common trend that the energy consumption from the road transport has sharply increased and from the rail transport has decreased from 1990 to 2006, whilst Austria also has similar trend but the energy use has started decreasing in 2005 and the UK has the very slight growth comparing to other countries. In Slovakia, the energy consumption from the pipeline has accounted for the large part of the total transport energy use since 2002 when the data is available. The pipeline transport volume in Slovakia has the relatively high but the volume of the rail transport is much larger; however, the energy use of the railway transport is much lower than that of the pipeline.

(a)



(b)



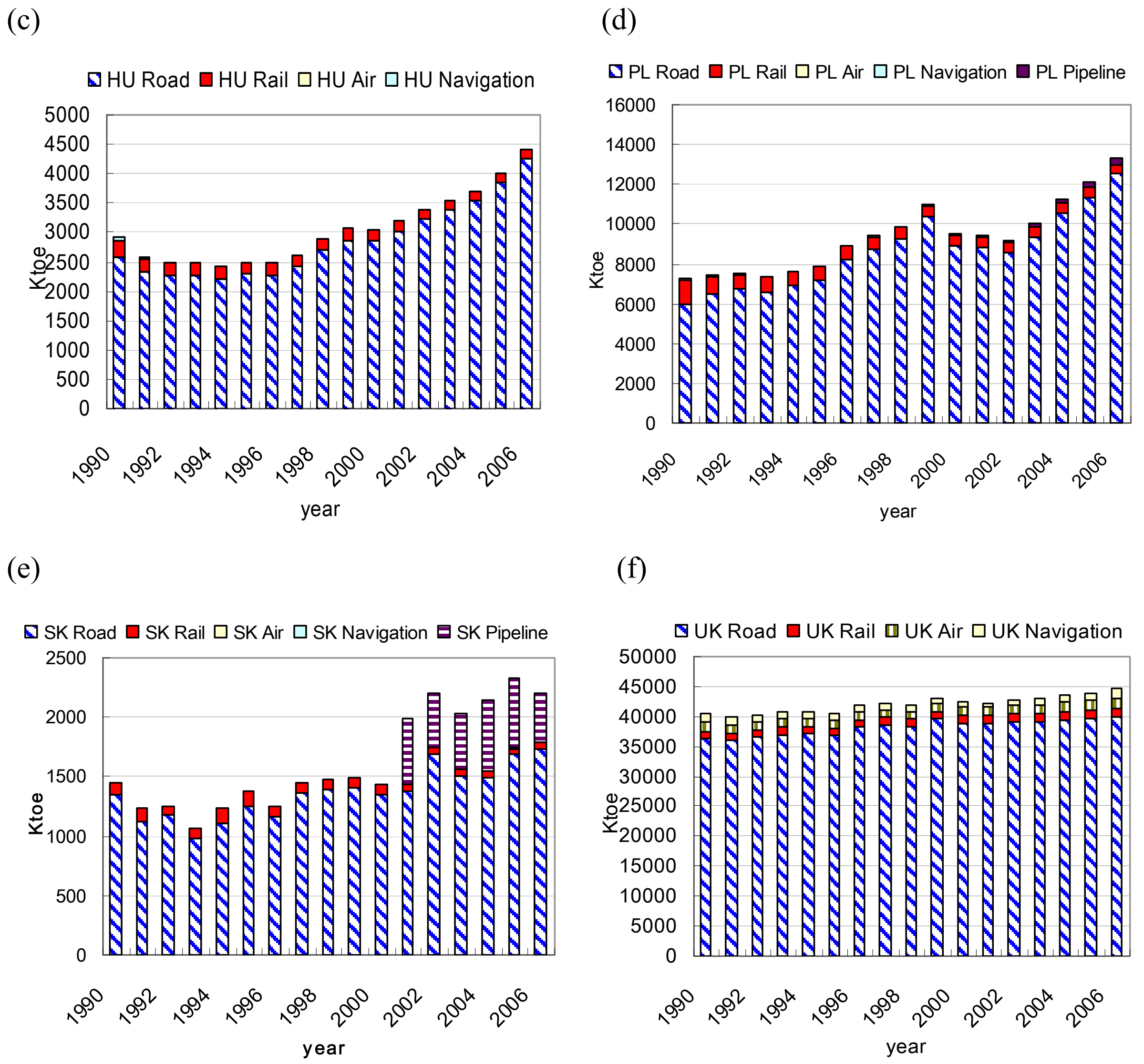


Figure 25: Energy consumption from the total transport sector in (a) Austria, (b) Czech Republic, (C) Hungary, (d) Poland, (e) Slovakia, and (f) the United Kingdom.

Data Source: IEA 2008b

The road transport, the largest source of the energy consumption, could be split into the passenger and freight transport as already analyzed earlier in this chapter although again it is the estimated value calculated from the multiple data sources and the available data are not successive. The energy shares of the passenger and freight road transport on the total road transport for each country in 1995 and in 2005 are shown in figure 26. The energy use for the passenger transport is larger than that of the freight transport in the all selected countries. The changes in the energy share from 1995 to 2005 are different from the countries, but Hungary and Poland decrease the passenger transport share while Austria, UK, and Poland increased it.

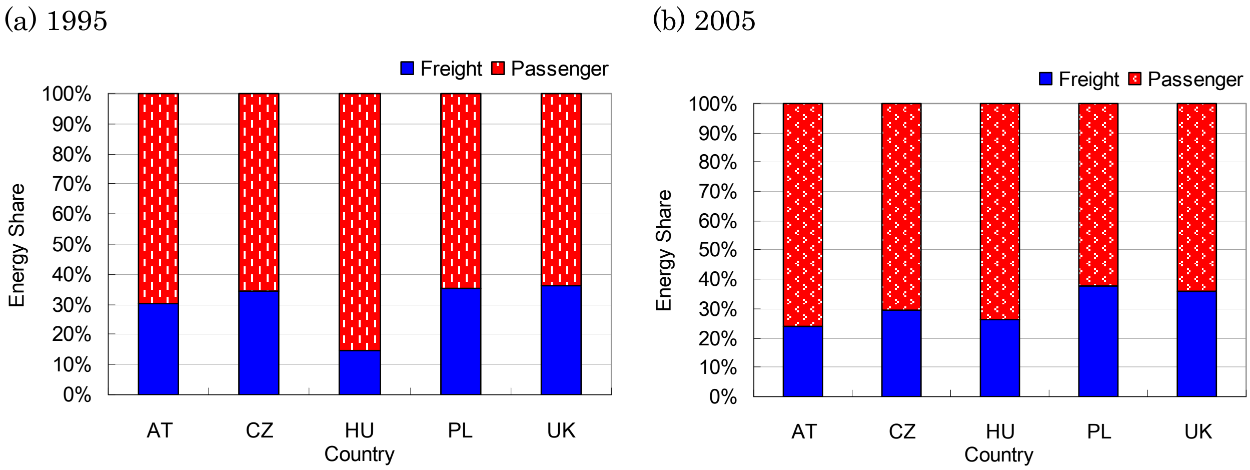


Figure 26: Energy share of the passenger and freight road transport (a) in 1995 and (b) in 2005 (2004 for CZ) Estimated based on data from ODYSSEE 2009, EUROSTAT 2009, and IEA 2008b

4. Energy and CO_2 intensity

Energy intensity and CO_2 intensity, which are expressed as koe (kilogram of oil equivalent) per pkm (for passenger transport) or tkm (for freight transport) and g CO_2 per pkm or tkm, are calculated from the raw data of transport volume, energy consumption, and CO_2 emission. Net mass movement (the unit integration of passenger and freight transport volume to tkm) is used to express the energy consumption from the total transport by each mode for European states where the split data could not be available.

4.1. Passenger transport

Japan

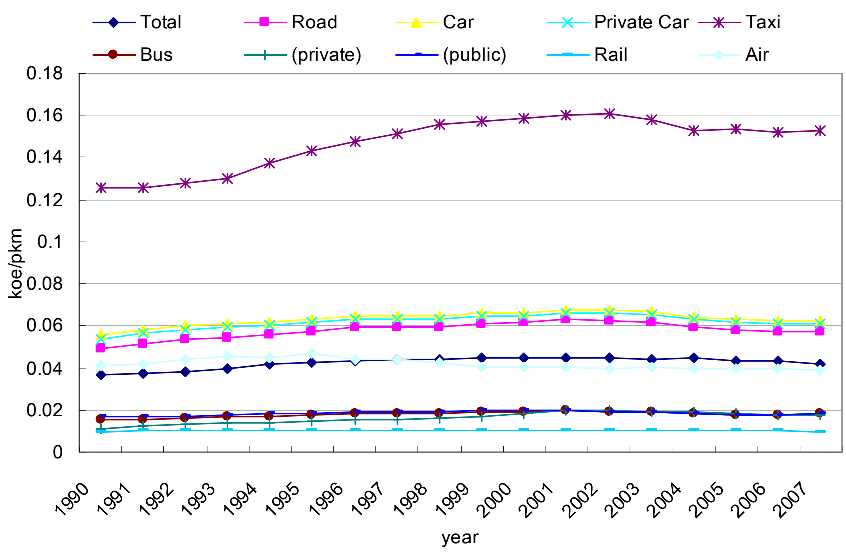


Figure 27: Energy Intensity for Passenger Transport in Japan.
Source: ANRE 2009.

The most energy intensive passenger mode among the passenger transport modes is 'taxi' and the next intensive one is 'private car' (figure 27). And 'domestic aviation' that use has rapidly developed has the higher energy intensity than that of 'bus' transport The least energy intensive mode for the passenger transport is 'railway' and the intensity is almost one tenth of the taxi. And the order of the intensity has not changed from 1990 to 2007 except the case of the aviation intensity which is more sharply lower than that of the total average intensity. The car transport has also the largest transport volume for the passenger transport so that it is obvious that the energy use mostly depends on the transport volume. In 2007, the energy intensity of the car transport is 0.0625 koe/pkm (0.061 for private car and 0.163 for taxi), and it is 3.5 times and 6.3 times higher than that of the bus (0.018 koe/pkm) and train (0.01 koe/pkm) respectively. The domestic aviation has the highest energy intensity among 'public transportation' except the taxi, but it is still less intense than the private car (0.039).

And since the trends of the transport activity and energy consumption are similar as each other, the general trend of the energy intensity is also similar and all of mode had increased the energy intensity from 1990 to around 2001 and have decreased since then. The next table (5) shows the changes in the energy intensity for each passenger transport mode. As it can be seen, all of modes except the domestic aviation have increased their energy intensities from 1990 to 2005, but all of modes have decreased them from 2000 to 2007. The energy intensity has increased by 16.9% for the road transport and it is larger than the total average intensity growth.

Mode/change	90/07	90/00	00/07	Mode change	90/07	90/00	00/07
Road	16.9%	24.7%	−6.3%	**Bus**	17.3%	26.0%	−6.9%
Car	12.0%	19.1%	−5.9%	(private)	55.5%	63.1%	−4.7%
Private Car	13.5%	20.6%	−5.9%	(public)	6.0%	14.6%	−7.5%
Taxi	21.7%	26.4%	−3.7%	**Rail**	0.6%	6.4%	−5.4%
Air	−5.1%	−1.3%	−3.9%	**Ship**	60.0%	69.2%	−5.4%
Total	14.8%	21.9%	−5.8%				

Table 5: Energy Intensity Change for the passenger transportation in Japan

Data Source: Agency for Natural Resources and Energy (ANRE) 2009 and MLITT 2009. Own Calculation

The trend of CO_2 emission intensity is almost same as that of the energy intensity. As it can be shown in table 6, the car transport has the highest intensity and the railway has the smallest one. And the all of the transport modes except the aviation have increased the emission intensity from 1990 to 2007.The ship transport has much higher intensity than other transport modes, but it may be because of the small transport volume and high energy consumption for its associating with the goods transportation.

	1990	2007		1990	2007
Road	138	159	**Bus**	44	51
Car	156	172	(private)	33	49
Private Car	152	168	(public)	49	52
Taxi	317	388	**Rail**	17	19
Air	115	109	**Ship**	764	1224
Total	99	115			

Table 6: CO_2 emission intensity from the passenger transport in Japan (unit: g CO_2 per pkm**)**
Data Source: Greenhouse Gases Inventory Office 2009 and MLITT 2009. Own Calculation.

Europe

In previous chapters, it is found that the transportation volume of the passenger transport has generally increased in all studied areas except Hungary. Especially, the increase of the road transport including passenger car and bus is huge and it accounted for more than 90% of the total all of examined countries except Hungary again. The energy consumption of the passenger road transport has also increased in all countries even including Hungary and these finding reached the next graph (figure 28). Three of five selected states, Austria, Czech Republic, and Hungary had increased the energy intensity from 1995 to 2004 or 2005. The energy intensity increase when the growth rate of the energy consumption exceeds that of the transport volume. And the reasons why it happens might be not only for the component energy intensity (including fuel efficiency) but also for the modal share. The relationship is examined and discussed in the later chapters. Hungary sharply increased the energy intensity because they decreased their transport volumes but increased the energy consumption. On the other hand, Poland decreased the energy intensity although both the transport volume and energy consumption had increased sharply. For UK, the volume sharply increased but the growth rate of the energy consumption was slighter.

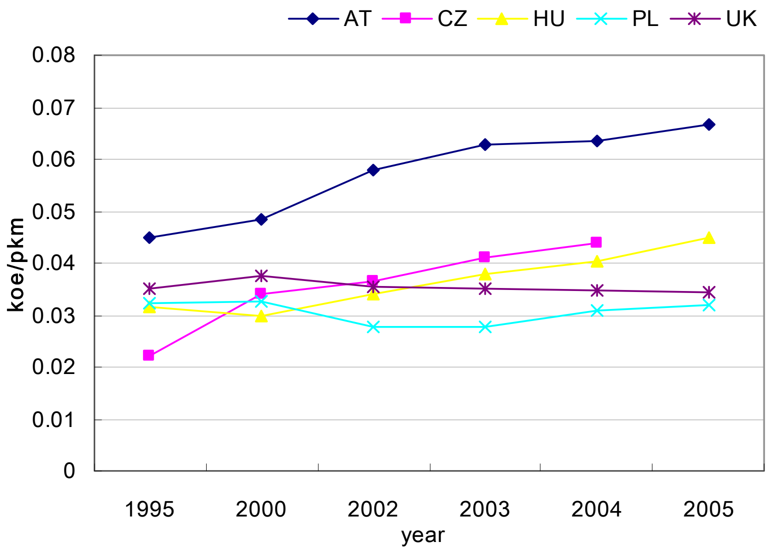


Figure 28: Energy intensity for the passenger road transport

:*excluding Slovakia for lack of the data.

Estimation based on data from ODYSSEE 2009, Eurostat 2009, and IEA 2008b

4.2. Freight transport

Japan

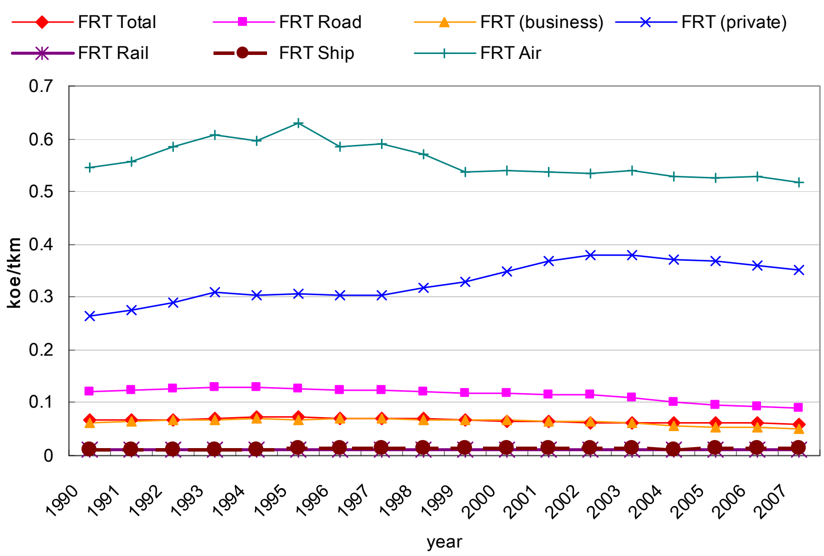


Figure 29: Energy Intensity for Freight Transport in Japan.

Source: ANRE 2009 and MLITT 2009

While the transport volume of the freight transport has slightly increased from 1990 to 2007, the energy consumption has slightly decreased. As a result, the average energy intensity for the freight transport has decreased (figure 29). Also all of modes except the private use road and the domestic navigation transport have decreased the intensities. The aviation is the most energy intensive transportation for the freight but the share is less than 1% and the energy intensity has decreased. The private use road transport has the second highest energy intensity and it had increased from 1990 to 2002, but both the transport volume and the energy consumption have decreased, Also the intensity have decreased since 2002. The navigation and rail transport is the least energy intense transport for the goods transport. The next table (table 7) represents the energy intensity (toe/tkm) for each freight transport mode. The road transport is several times more energy intensive than the railway and navigation. The intensity of the aviation is 50 times higher than that of the rail.

Road	0.0892	Rail	0.0107
(business)	0.0515	Ship	0.0129
(private)	0.3513	Air	0.5178
Total	0.0592		

Table 7: Energy intensity for the each freight transport mode in Japan in 2007 (unite: koe/tkm)
Data Source: ANRE 2009 and MLITT 2009. Own Calculation

The trend of CO_2 emission intensity has been very similar as that of the energy intensity like the passenger transport except the railway transport that has increased CO_2 emission intensity from 1990 to 2007 whilst decreased the energy intensity during the same period (table 8). It is due to the CO_2 emission coefficient change. All of CO_2 emission or energy use data for Japan is reallocated (consider the primary energy consumption for the electricity).

	1990	2007		1990	2007
Road	345	250	**Rail**	21	22
(business)	176	145	**Ship**	37	38
(private)	754	980	**Air**	1533	1456
Total	193	169			

Table 8: CO_2 emission intensity from the freight transport in Japan (unit: g CO_2 per tkm)
Data Source: Greenhouse Gases Inventory Office 2009 and MLITT 2009. Own Calculation.

Europe

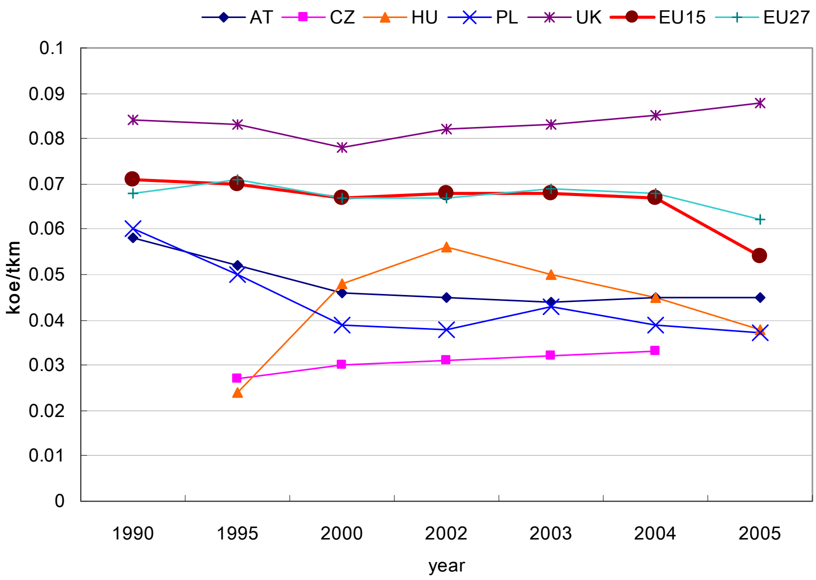


Figure 30: *Energy Intensity for Freight Road Transport* **in Europe**

Soure: ODYSSEE 2008.

Both the volume and energy consumption for the road freight transport have increased in general EU 27 and Central Europe as well. However, the trends of energy intensity for the road freight transport are different from the regions and countries as shown in Figure 30. The Western Europe (EU 15) and whole EU (EU 27) average energy intensity have decreased from 1990 to 2005; however, the decrease rate of EU 27 is smaller than that of EU 27 and it indicates that EU 12 (CEE + Cyprus and Marta) average intensity has very small reducing rate or might have increased. In fact, the energy intensity has increased in Czech Republic and Hungary, though Poland has declined it. The UK also has increased the energy intensity because the energy use growth ratio has larger than that of the volume increase.

For the freight transportation, the energy intensities of the pipeline and inland navigation have been calculated from some of the selected countries where these data are available besides the road transportation, and used for the decomposition analysis in the next chapter.

(a)

	1995	2001	2005	2006
AT	0.0162	0.0260	0.0318	0.0273
CZ	0.0090	0.0168	0.0149	0.0157
PL	0.0007	0.0052	0.0108	0.0141
SK		0.1147	0.1118	0.0733

(b)

	1995	2001	2005	2006
AT	0.0030	0.0028	0.0052	0.0055
CZ		0.0032	0.0029	0.0033
HU	0.0008	0.0009	0.0005	0.0005

Table 9: Energy intensity of (a) pipeline and (b) inland navigation (unit: koe/tkm)

Data Source: EC DG TREN 2009b and IEA 2008b

The energy intensity for the pipeline transport are very different from each reported country. In Austria, Czech Republic, and Poland, the intensities seem to have increased from 1995 to 2006 (table 9 a). The pipeline transport seems to be a bit more intensive than the railway or ship transport considering Japanese energy intensity data for the freight transport, though it is several times higher in Slovakia. The inland navigation has very small energy intensity and it seems to be even smaller than the railway or the sea transport (9 b). The changes in the energy intensity of the inland navigation also depend on the country. Austria has sharply increased the intensity while Hungary has considerably decreased it.

4.3. Total transport

The energy intensities for the total road transportation and railway transportation were calculated based on the concept of "net mass movement", which is introduced by Stead (2000) and converted passenger kilometer to tonne kilometer to integrate passenger and freight transport by harmonizing the unite. Again, this is just based on the assumption that one person with his/her belongings has 90kg weight and no other factors such as the use and kinds of the transportation are taken into account. Therefore, it may not precisely weight and present the total volume of both passenger and freight transport activities. Although this measurement is mostly used for the decomposition analysis in the next chapter, it should be considered as a guide.

The concept of the total transport intensity is used for the road and rail transportation which can be used for both but the data is not split into the two. The following graph (figure 31) shows that the energy intensity for the road transportation. As it can be observed, the range of the road energy intensity is wide among the countries. However, it can be said that

CE states has the lower energy intensity for the road transport than Austria and the UK. The decrease of the energy intensity can be seen for 4 out of 6 countries and only Austria and Czech Republic have increased the energy intensity. Poland, where the changes in both transport activity and energy use are large, has decreased the intensity by 26% from 1995 to 2005 and it is the largest decrease rate among the selected countries.

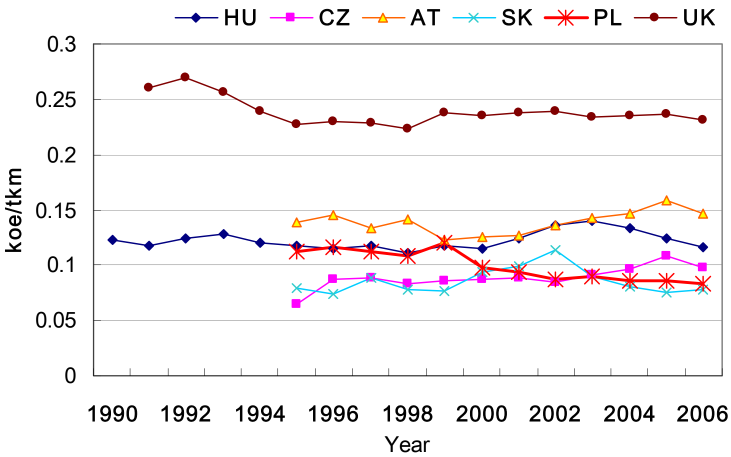


Figure 31: Energy intensity for the total road transportation (koe/net mass movement) in Central Europe. Data Source: EC DG TREN 2009b and IEA 2008b. Own calculation.

The energy intensity of the railway transportation is obviously much lower (3times to more than 10times lower depending on the countries) than that of the road transport for all selected states, and all of the countries except Czech Republic have decreased it between 1990 (or 1993 for Slovakia) and 2006 (figure 32) As the energy consumption and both the passenger and freight transport activity for the rail transport have sharply decreased, the energy intensity for the rail transport also had considerably decreased in Poland and Slovakia, though Hungary and Czech Republic where the drop rates of the energy consumption had slight changes in the intensity. Austria also have sharply decreased the intensity because the energy consumption slightly decreased while the transport volume have increased. Both the transport volume and energy consumption have increased in UK but the growth rates of the energy consumption is much smaller than that of the transport volume so that the energy intensity has decreased.

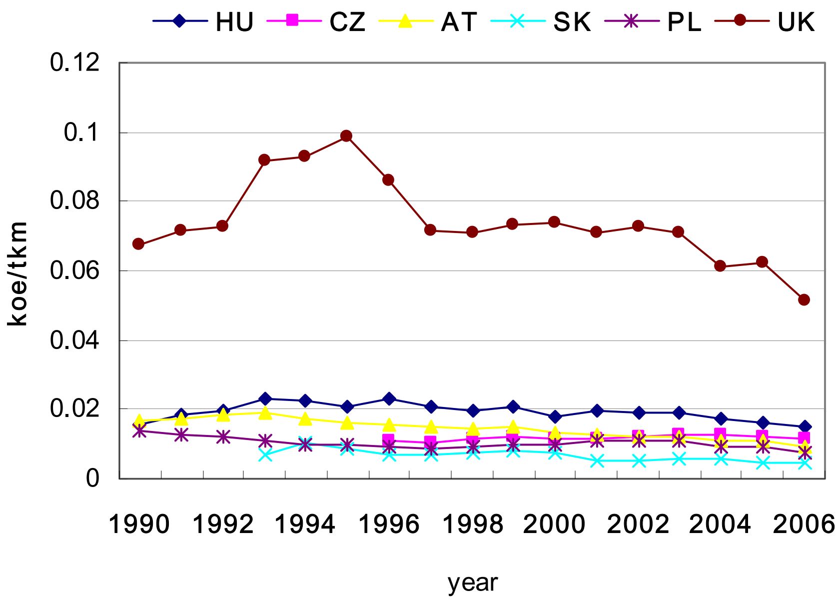


Figure 32: Energy intensity for the total rail transportation (koe/net mass movement) in Central Europe.
Data Source: EC DG TREN 2009b and IEA 2008b. Own calculation.

The trend of CO_2 emission intensity change from the road transportation is very similar as that of the energy intensity change as it can be seen in figure 33. The key findings on this graph are that both EU 15 and EU 12 have decreased their emission intensity but the decreasing rates of EU 12 is more rapid than EU 15 besides the emission intensity has had smaller in EU 12 than in EU 15. And all CE states except Poland does not follow EU 12 average trend. Austria and the UK also have not decreased the emission intensity as EU 15 has had.

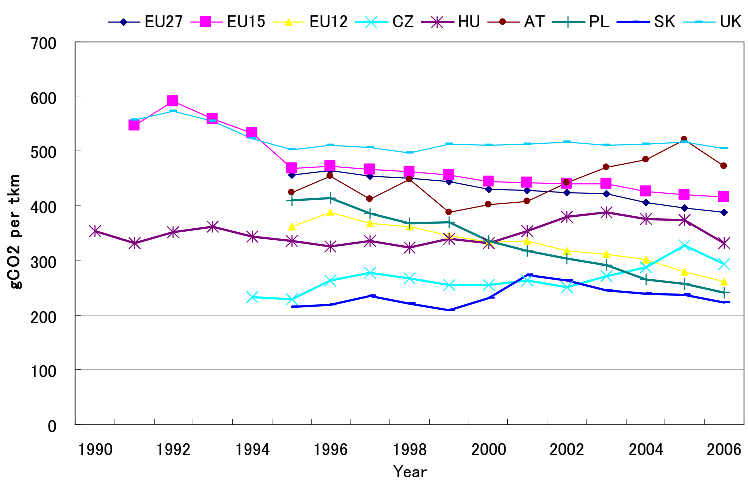


Figure 33: CO_2 emission intensity on the road transport in Europe.
Data Source: calculated by the author using data provided by EC DG TREN, 2009b.

Likewise the trend of CO_2 emission for the rail transport has close to that of the energy intensity (figure 34). The emission intensity in EU 12 has had smaller that in EU15 for the train transport and the decline rates are slightly larger. The trend of EU 12 and CE states are not that different from each other and the emission intensity has generally decreased. Austria has had less than half of EU 15 and even than EU 12 average emission intensities from 1990 to 2006. And UK has had three to four times' larger intensity than EU 15 average and the decrease rate is also smaller.

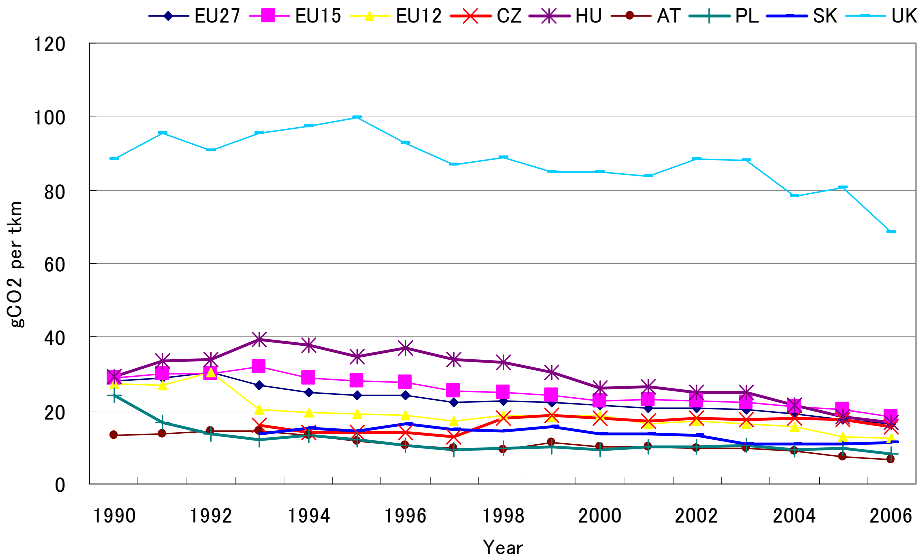


Figure 34: CO_2 emission intensity on rail transport in Europe.

Data Source: calculated by the author using data provided by EC DG TREN, 2009b.

5. Decomposition Analysis

To examine and properly weight the effects of transport volume, transport energy intensity, and the transport structure (modal split) on the total energy use, the index decomposition analysis using LMDI approach is used in this study. The detail about this LMDI method is discussed on the methodology chapter of this paper and relevant literatures including Ang and Liu (2001), Ang et al (2003), and USDE 2003. Unites States Department of Energy officially (2003) uses this methodology for its energy use analysis; for example, the following graph (figure 35) shows the decomposition of the total transport energy use in the US and it is the output of the LMDI analysis. The actual energy use index is the multiplication of three indexes, activity effect, structural (modal shift) effect, and energy intensity effect. The values on the y axes represent the level of the energy use and '1' is the level of the base year (1985 for this case). The energy intensity index on the graph is not the index of the actual energy intensity calculated from the energy consumption divided by the transport volume, called the aggregated energy intensity, but the output of the disaggregation of the aggregated energy intensity.

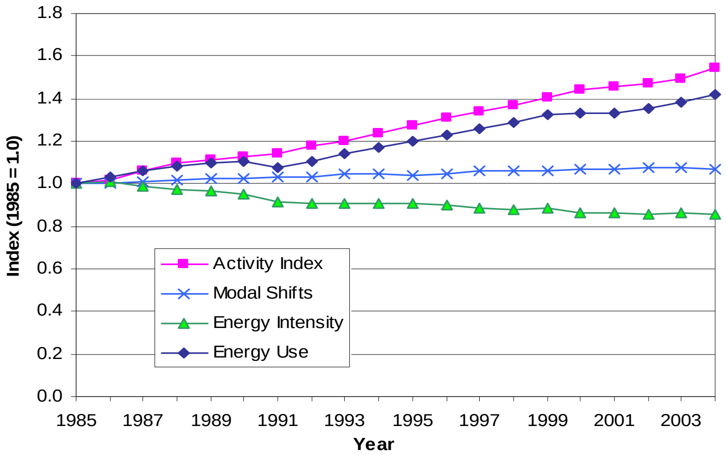


Figure 35: Decomposition of *total transport* energy use by LMDI method, USA

Source: USDE, 2009

The aggregated energy intensity can be defined as the energy consumption per passenger kilometer or tonne kilometer for all modes taken together (USDE 2003). And the index of the aggregated energy intensity can be split into the component energy index and the structural (modal shift) index because the changes in the energy intensity depend on not only the energy intensities of each mode but also the relative shares of the activities of each mode (USDE 2003). Therefore the aggregated energy intensity index and the component energy intensity index are usually different from each other unless there is no 'modal shift' (= '1').

The United States has increased the total energy use from 1985 to 2004 (figure 35) and the transport volume change mostly affect the increase of the energy use. The energy intensity has contributed to restraint the energy use growth but the effect is smaller than that of the transport activity and the modal shifts effect that is component of the aggregated energy intensity index has slightly offset the intensity effect.

The next graph (figure 36) represents the annual change of the energy use and the weight of each effect on it. This is an additive approach so that the sum of the changes in the transport activity effect (D_{act}), the modal shift effect (D_{str}), and the energy intensity effect (D_{int}) are equal to the changes in the actual energy use (D_{eng})

$$D_{eng} = D_{act} + D_{str} + D_{int},$$

The graph also indicates that the transport activity is the dominant effect on the energy use, but for the change between 1990 and 1991 the energy intensity effect has the largest impact on the change in the energy use. Modal shift has slightly contributed to the energy use growth and the effect is always within 2% change. Thus, both additive and multiplicative approaches are used to see the overall trends of the decomposed effect and the annual impacts of each effect on the energy use for Japan and selected European states.

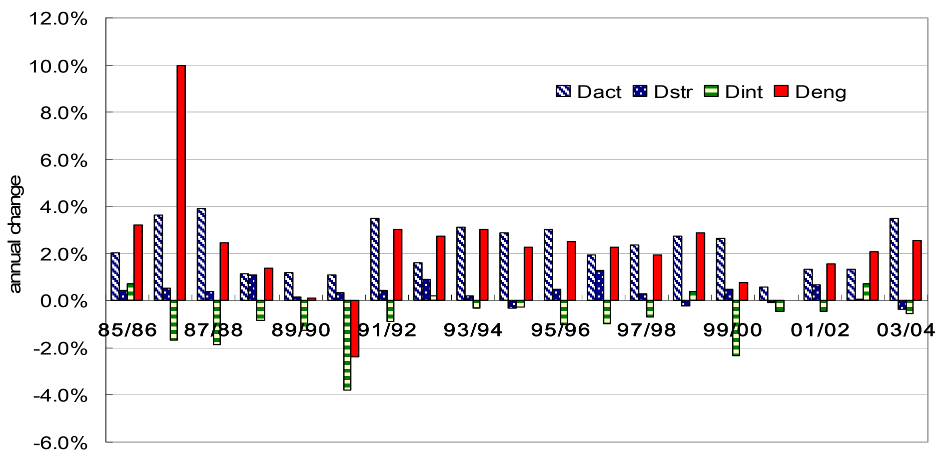


Figure 36: Decomposition of year to year energy use for total transport sector in the US.
Data Source: MLITT 2009 and ANRE 2009. Own Calculation

5.1 Japan

As discussed in the previous chapters, the energy use and the both passenger and freight transport activities have increased from 1990 to 2007 in Japan, The aggregated energy intensity for the total transportation has also increased, but the next graph (figure 37) indicates that the modal shift offset the component energy intensity effect and the total energy use as a result. However, the increase of the energy use had been still affected by the energy intensity more than the transport activity. The modal shift had rarely affected the changes in the energy use increase or decrease but has started improving since 1998 and contributing to the energy use control.

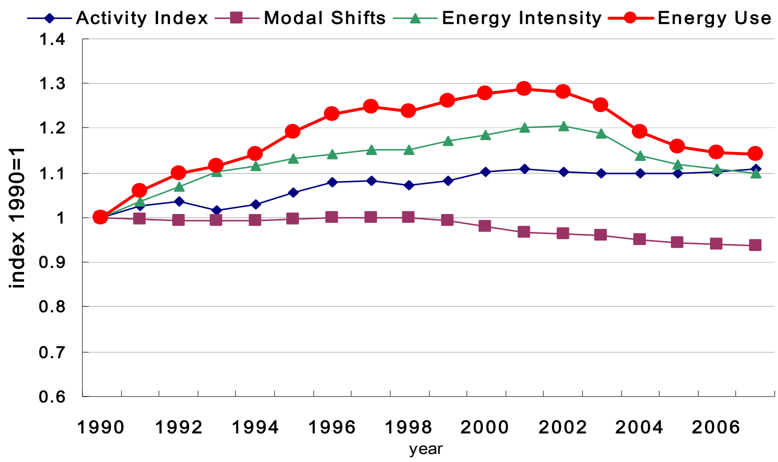


Figure 37: Decomposition of Total Transport Energy use by LMDI method, Japan

Data Source: MITT and ANRE 2009. Own Calculation.

The weight of the contribution of each effect on the annual changes in the total energy use has shifted from 1990 to 2007, but the dominant effect is the component energy intensity for the total transport (figure38). The growth rate of the energy use has decreased as the energy intensity has decreased. For instance, he largest annual growth was from 1990 to 1991 and the energy use had increased by 6% but 3.5 of 6% change was the energy intensity effect. Another example shows that the largest decline rate was 5% 2003-2004 but 4.3% was for the energy intensity effect. It indicates that decreasing energy intensity is the most effective to decrease the whole energy use. However, the activity effect has also accounted for the large part and it contributes to the increase of the energy use but not to the decrease for most of the times. Finally, the modal shift effect on the total transport sector is mostly slight but offsets the energy city effect. For the change 1999-2000, the negative change in the modal shift effect was larger than that of the positive change in the energy intensity effect As a result, the aggregated energy intensity have restraint the energy use growth. It indicates that the change in the modal share can have the large impact on the energy intensity and hence the total energy use.

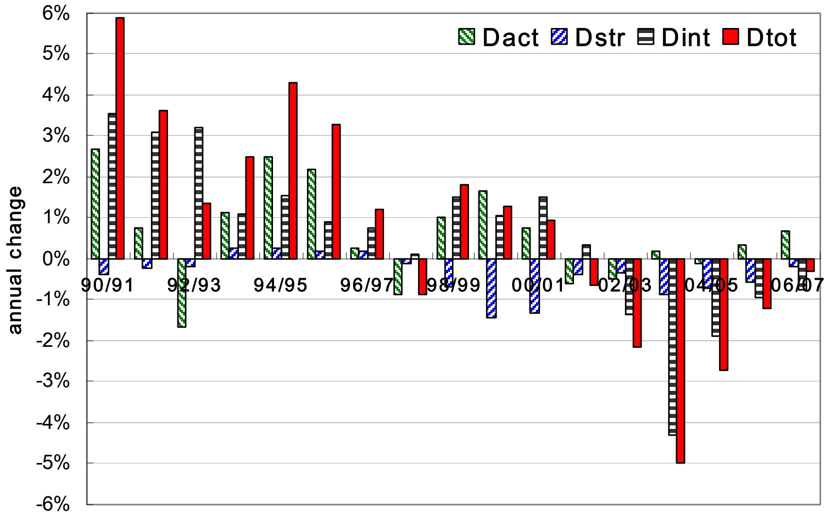


Figure 38: Decomposition of year to year energy use for total transport sector in Japan.

Data Source: MLITT 2009 and ANRE 2009. Own Calculation

For Japan, the energy use decomposition for the passenger and the freight transport are also analyzed because the detail data is available. First graph (figure 39) shows the decomposition of the passenger transport energy use. The energy intensity index has the similar trend line as the energy use but the activity index also had been close to the energy intensity level and it has had the highest level since 2005. The modal shift also affects the increase in the energy use.

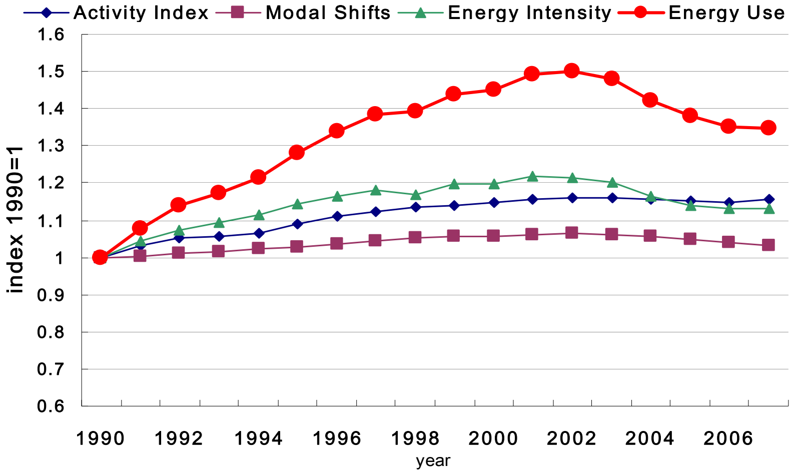


Figure 39: Decomposition of the passenger transport energy use by LMDI method, Japan

Data Source: MITT and ANRE 2009. Own Calculation.r

The annual change in the total energy use (figure 40) had been positive from 1990 to 2002 and changed to the negative since 2002. The energy intensity has again the highest weight on the total energy use for most of annual changes except the case of the period 1997-1998 and 2005-2006. The modal shift effect had kept contributing to the increase of the energy use from 1990 to 2001, but it has the largest weight to have the large decrease of the energy use from 2005 to 2006. And it seems that the energy intensity effect increase when the transport activity level increase.

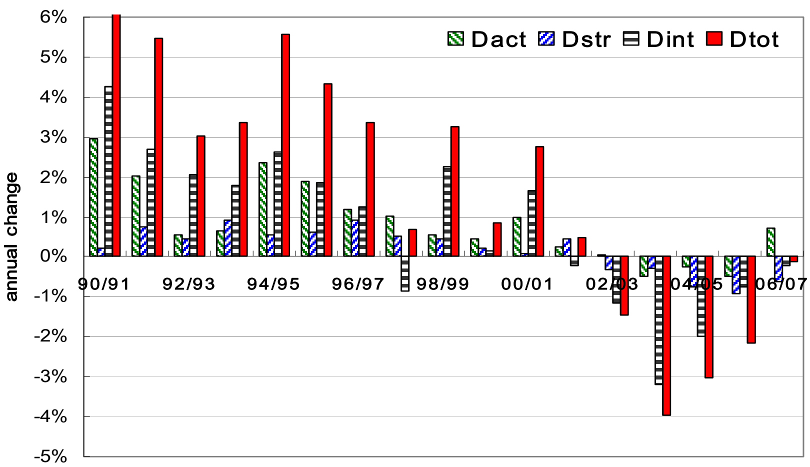


Figure 40: Decomposition of year to year energy use for the passenger transport in Japan.

Data Source: MLITT 2009 and ANRE 2009. Own Calculation

The energy use decomposition of the freight transport has the different pattern from that of the passenger transport (figure 41). Here the energy intensity and the modal shifts effect go to the opposite way, and the decrease of the modal shift index is relatively larger than that of the activity index and sometimes the energy intensity. It affects the decrease of the energy use very much especially after 2002 when the energy intensity effect reached the peak.

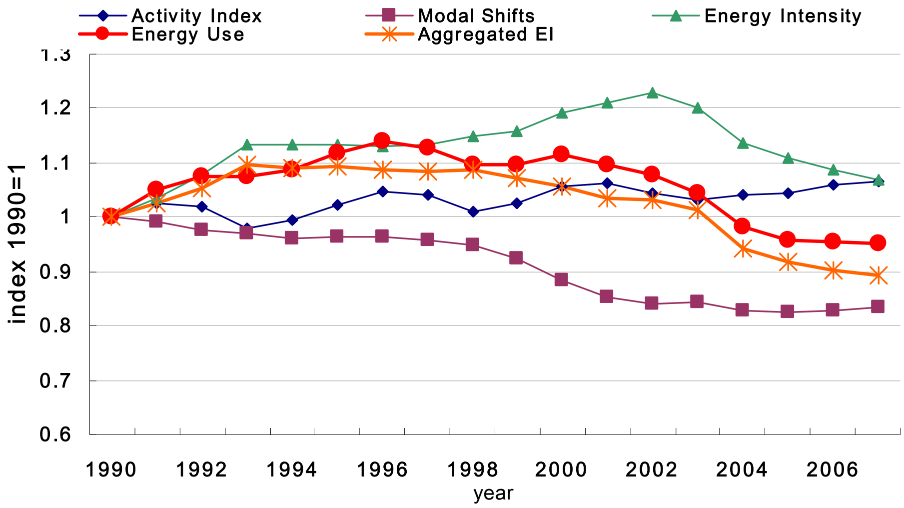


Figure 41: Decomposition of the freight transport energy use by LMDI method, Japan

Data Source: MITT and ANRE 2009. Own Calculation.r

The weight of the each effect on the energy use change depends on the year. The modal shift usually has the negative effect where the energy intensity has the positive effect (figure 42). Different from the passenger transport, the weight of the modal shift effect is large for some annual periods, even larger than the component energy intensity effect (from 1998 to 2002). The clear relationship between the activity index and the structure index cannot be seen here, but the transport activity change is always positive where the transport intensity change is negative except the case of the period 2002-2003.

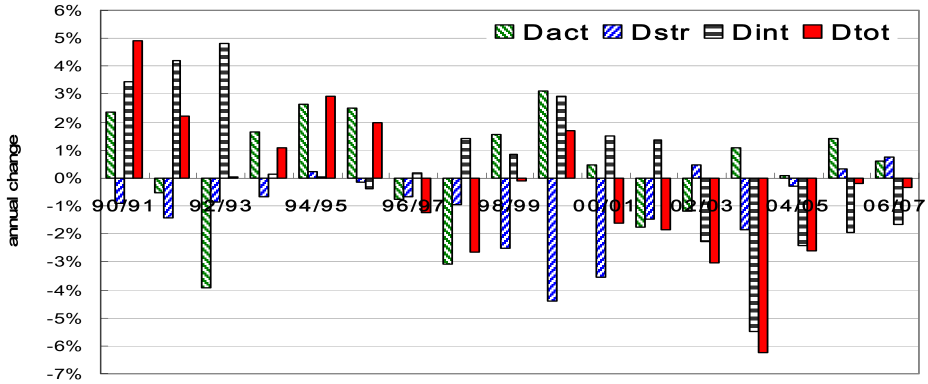


Figure 42: Decomposition of year to year energy use for the freight transport in Japan.

Data Source: MLITT 2009 and ANRE Energy 2009. Own Calculation

5.2 Europe

The transport is directly split into each mode for the selected European states and therefore the only total transportation is examined by the decomposition analysis for each country. Although the main purpose of the analysis for European countries is to disaggregate the energy intensity and examine the effect of the change in modal share to the aggregated energy intensity and the total energy use, the considered transport mode depends on the countries due to the data availability and it is the largest limitation of this study. For example, only the road and rail transport is taken into account for Slovakia although the pipeline transport seems to be also a large part of the energy consumption.

The sharp increase of the energy use originates from the increase of all factors levels especially after 2003 (figure 43). The increase of the transport activity level is one of the major reasons of the increase in the energy use but the effect of the modal change also contributes to the increase a lot, even more than the energy intensity. The energy intensity had been lower than 1997 level till 2002 but it has increased since then.

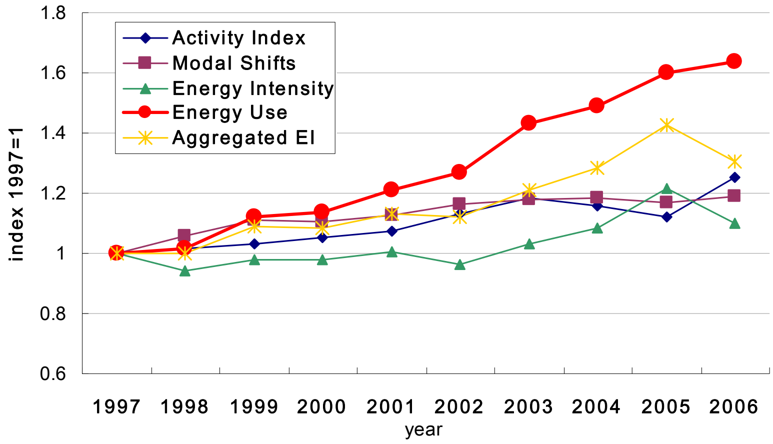


Figure 43: Decomposition of Transport Energy Use by LMDI method, Czech Republic

Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

The modal shift effect on the energy use is mostly positive and it was negative only when the energy intensity effect had large positive change (2004-2005). It sometimes sharply offset the energy intensity change and has the largest weight for the energy use growth (1998-1999). The total energy use has kept increasing from 1997 to 2006 and it has never had the negative annual changes, but the weights of each factor are very different from each year (figure 44).

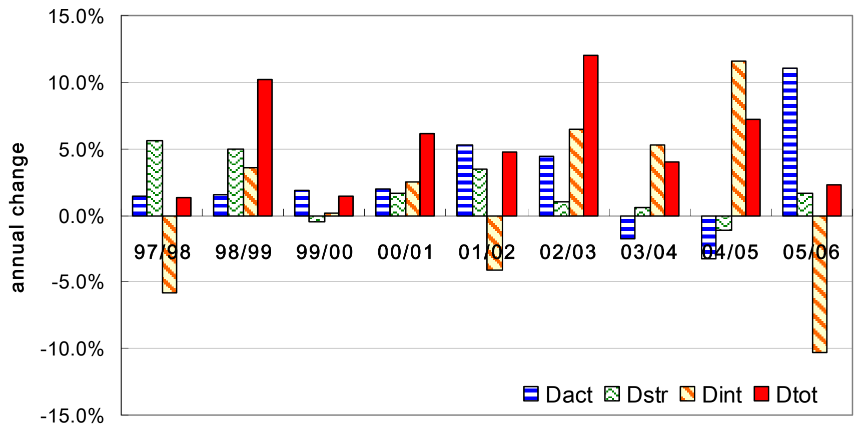


Figure 44: Decomposition of year to year energy use for total transport sector in Czech Republic.

Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

The trend of the energy use index is similar as that of the transport activity index in Hungary so that it can say that the energy use change mostly depends on the transport volume (figure 45). The modal shifts effect had constantly increased while the energy intensity effect has had zigzag changes. The energy use had sharply increased from 2000 to 2006, but it was due to the sharp growth in the energy intensity from 2000 to 2004 and in the transport activity from 20004 to 2006.

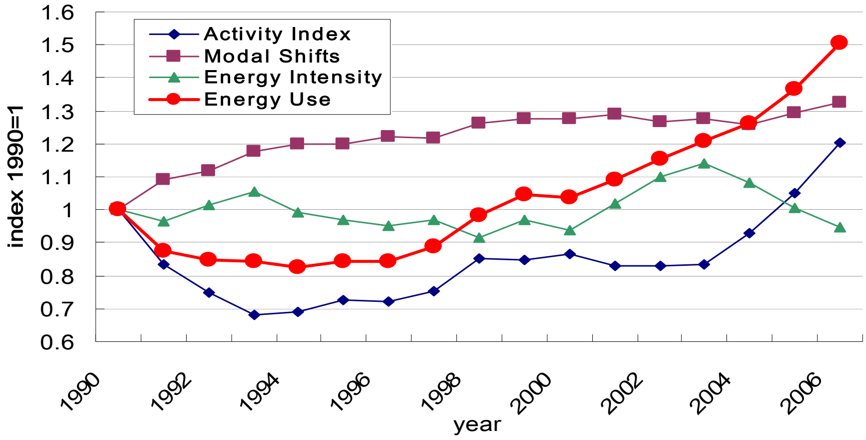


Figure 45: Decomposition of Transport Energy Use by LMDI method, Hungary.

Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

The weight of each effect on the energy use depends on the year, but the transport volume has the dominant impact on the changes in the total use except for a few years where the energy intensity has the largest weight (1998 to 2003). And the transport intensity usually decreases when the transport activity, at same time the modal shift effect is very small in these cases (figure 46). The modal shift has the large weight only for the periods 1990-1991 and 1992-1993. The modal shift effect is larger than that of the component energy intensity during those periods.

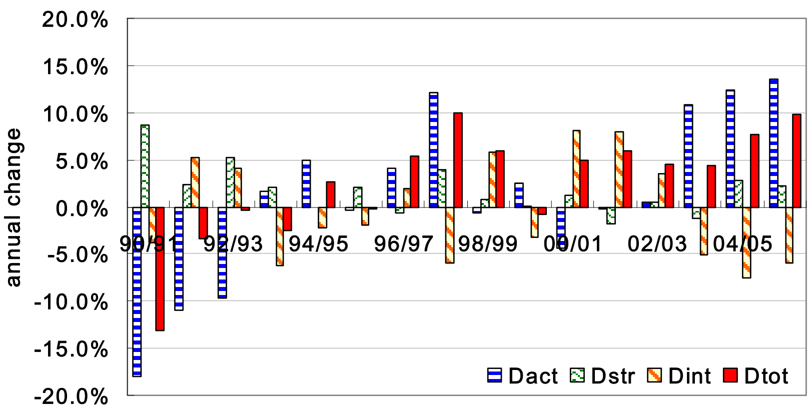


Figure 46: Decomposition of year to year energy use for total transport sector in Hungary.

Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

Poland also had the sharp increase of the energy use and these changes seem to be mostly controlled by the transport activity level (figure 47). The modal shift effect has also increased during the period and it supports the analysis on the chapter 2 that the modal shift towards the road transport has preceded. The aggregated energy intensity in Poland has increased from 1995 to 2006 but it was not because the energy intensity of each transport mode but because the increased share of the road transportation.

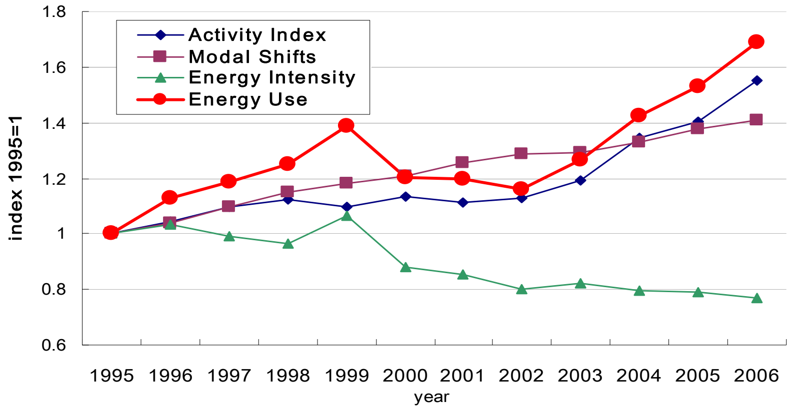


Figure 47: Decomposition of Transport Energy Use by LMDI method, Poland.

Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

Although the dominant effect on the total energy use is the transport activity, the component energy intensity also affects the energy use sharply from 1998 to 2000, as well as the modal shift effect has the largest weight for 1997-1998 and 2000-2001 (figure 48). Also the weight of each mode is almost same as each other for the period 1996 -1997. The modal mix effect is always positive and the transport activity level as well.

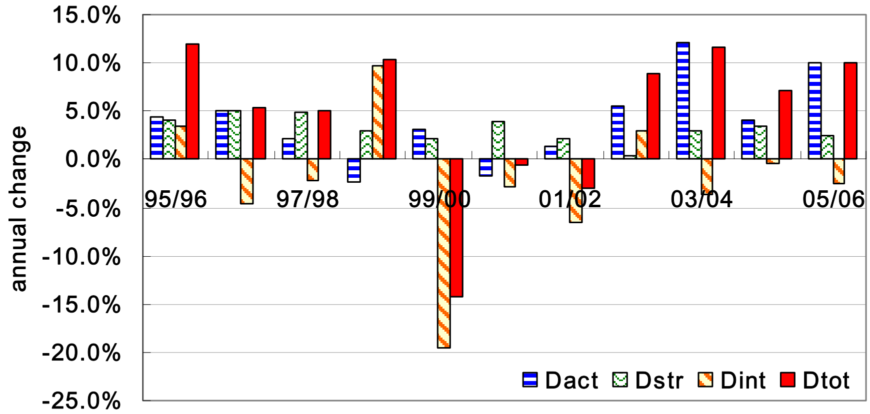


Figure 48: Decomposition of year to year energy use for total transport sector in Poland.

Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

Slovakia also has increased the total energy consumption as well as other CE states but the dominant factor of the energy growth are different from them and it seems to be the component intensity and modal shift (figure 49). It may be because only the road and rail transport are considered as the component (modes) for the data availability so that it almost depends on the change in the car share which account for more than 90% of the energy share.

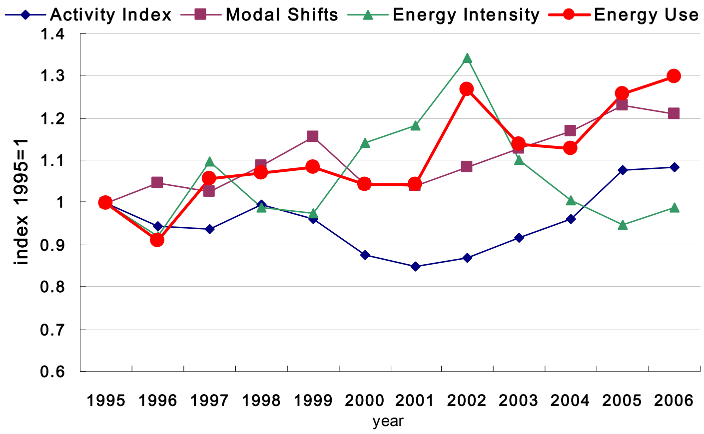


Figure 49: Decomposition of Transport Energy Use by LMDI method, Slovakia.

Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

The energy use changes in Slovakia were mostly driven by the changes in the transport energy intensity (figure 50). But the transport activity and the modal shift effect can also have the significant impact on the energy use. The modal shift effect was positive wherever the energy intensity effect was negative or vice versa except the case of the period 2001-2002

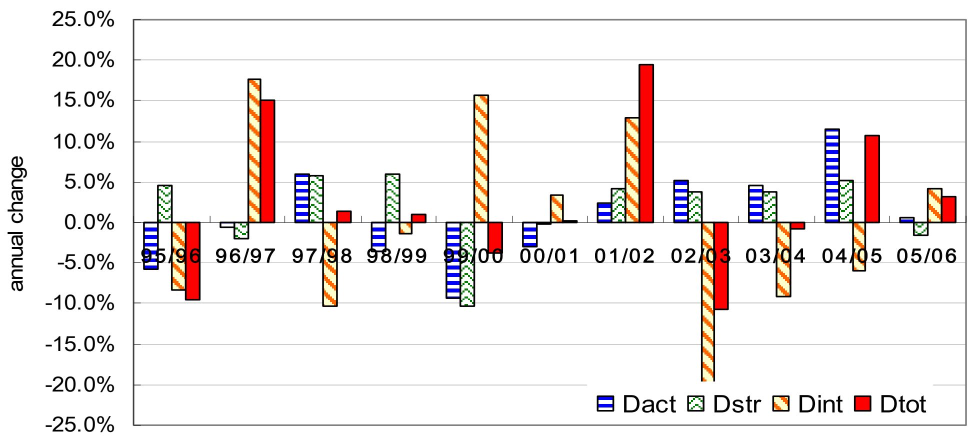


Figure 50: Decomposition of year to year energy use for total transport sector in Slovakia.

Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

Both the transport volume and the energy intensity seem to be the key effects of the sharp increase in the total energy consumption in Austria, while the modal shift effect seems to be very marginal (figure 51). The energy share of the road transport has been very high since 1995 and the modal split has not drastically changed during the period so that the energy use simply increased due to the increase in the transport activity.

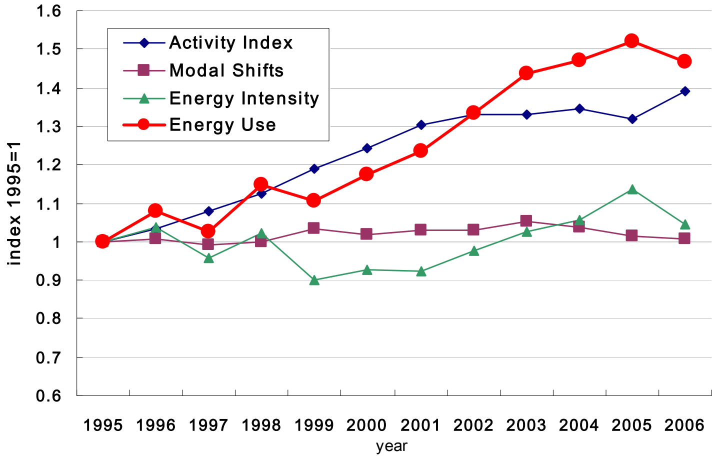


Figure 51: Decomposition of Transport Energy Use by LMDI method, Austria.

Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

The dominant effects on the increase of the total energy use are both the transport activity and the energy intensity (figure 52). However, the negative changes of the energy use are all due to the sharp decrease of the energy intensity effect. The effects of the modal share on the energy use change is very small in Austria but it sometimes offsets or enhance the component energy intensity effect probably when the log change of the road share is large (1998—1999).

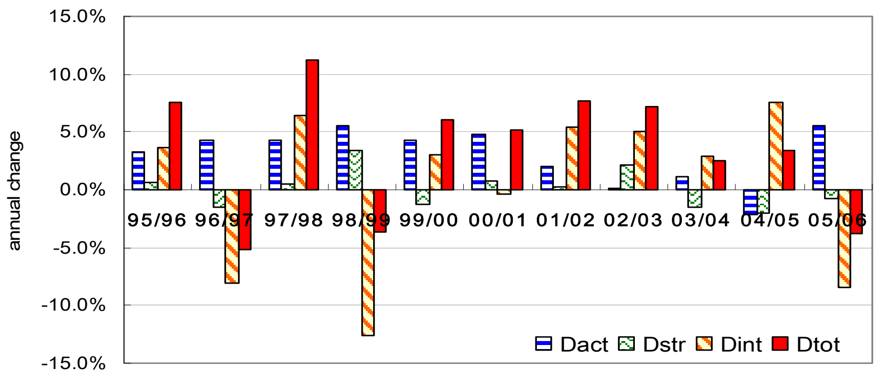


Figure 52: Decomposition of year to year energy use for total transport sector in Austria

Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

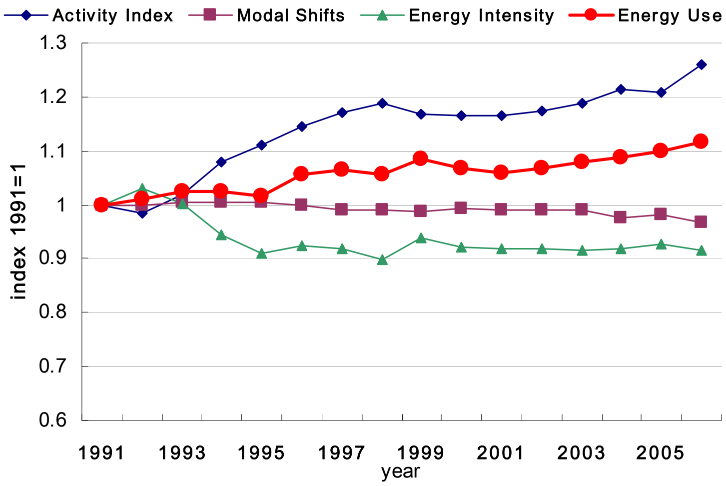


Figure 53: Decomposition of Transport Energy Use by LMDI method, the United Kingdom.
Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

The United Kingdom has more slightly increased the energy use compare to other countries, and the dominant effects seem to be both the transport volume and the energy intensity (figure 53 and 54). The transport activity has increased but the decrease in the transport intensity has controlled the growth in the energy consumption, though the increase rates of the transport activity is a bit larger than that of the energy intensity. The modal shift effect can rarely be seen for this country except the period 2001-2002 where the other effects had no change.

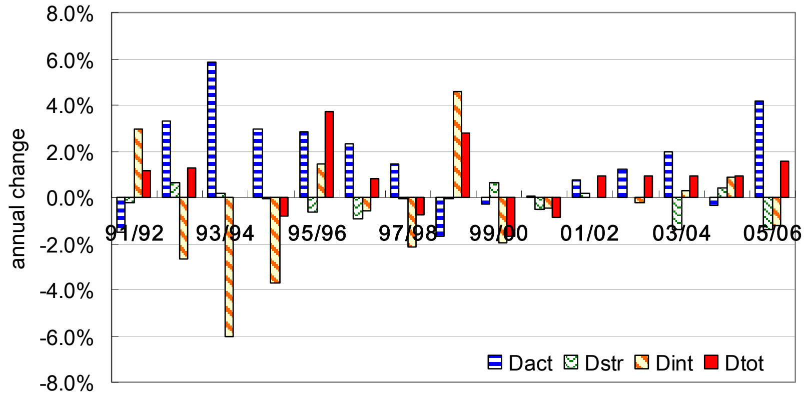


Figure 54: Decomposition of year to year energy use for total transport sector in the Untied Kingdom
Data Source: EC DG TREN 2009b and IEA 2008b. Own Calculation

6. Discussion

The results of the analyses on the last chapters are compiled and discussed, focusing on the importance of the effects of three main factors, transport activity level, modal shift, and energy intensity on the changes in the energy consumption in Japan, in Central Europe, and in general.

6.1 Summary of findings

The key results from the previous chapters are listed below for Japan and Europe.

Japan

Passenger Transport

- The transport volume has increased from 1990 to 2002 and then started decreasing but the 2007 level is **16%** in total with 26% for car, 5% for rail, 63% for aviation, and -20% for bus.
- The modal share of the passenger car has increased from 50.9% to 55.4%. 1990-2007 in2001 peak, while the railway transportation decreased from 34% to 31% and the lowest in 2002. the sharp increase for the aviation.
- The total energy consumption has increased by **32.7%** from 1990 to 2007 (peak in 2001) with 39% for road, 5% for rail, and 55% for the aviation.
- The energy share of the passenger transport; road 81%→84%, rail 9% - 7%, air 5% - 6%
- The energy intensity – the highest in taxi, the next is the passenger car, the lowest for the rail and the next lowest is ship. Car transport is more than 6 times energy intensive than the railway. 0.0057 koe/pkm for car, 0.001 koe/pkm for rail, and 0.0018 f or bus (2007)
- The energy intensity also has increased by 15% from 1990 to 2007 and reached the peak in 2001
- Energy intensity has the largest weight on the changes in the total energy use (the dominant effect on the total energy use).
- The transport volume also has the large impact on the increase of the energy use.
- The modal shift effect enhances the increase or decrease of the total energy use.
- The modal shift can have a significant impact on the energy use.

Freight Transport

- The total volume has slightly increased.
- The only road and aviation transport have increased their volumes (29% and 44%).
- The modal share of the road increased from 50% to 61%, while ship decreased 45% to 35%.
- The total energy consumption has slightly decreased from 1990 to 2007 with the highest in 1994.
- The energy shares of each freight transport mode have changed very little.
- The most energy intensive freight mode is private use road freight but the volume has decreased, while the least energy intensive mode, railway,
- The energy intensities of main freight modes are 0.08916, 0.01068, 0.51782, and 0.01292 (koe/tkm) for road, rail, aviation, and navigation respectively.
- The modal shift has the larger impact on the energy use for the freight than for the passenger.
- The component energy intensity effect has the significant impact on the energy use as well as the transport activity.

Europe

Passenger Transport

- The transport volumes in all selected countries have generally increased except Hungary.
- The road transport has sharply increased while the railway transport has drastically increased in CE states except the case of Hungary where the road transport has decreased the volume and the share as well. The train and metro/tram had very slightly increase the share instead in Hungary.
- Austria and UK also have increased their road transportation volume, but Austria has more slightly increased the car share and UK has decreased it. The uses of the railway and/or tram and metro have increased in these countries and especially UK have increased the train volume by 50% from 1990 to 2007.
- Energy consumptions for the passenger road transport have increased in all selected states

even including Hungary.

- Energy intensity of the passenger road transport has also increased in all examined countries except UK.
- The sharp increase of the passenger road energy intensity could be observed in Czech Republic and Hungary.
- Energy intensities for the passenger road transport for all examined countries are 0.067, 0.044, 0.045, 0.033, and 0.032 (koe/pkm) for Austria, Czech Republic, Hungary, Poland, and the UK in 2005 (in 2004 for Czech Republic). These are lower than that in Japan except Austria.

Freight transport

- The freight transport volume has increased by 28.% in Central Europe from 1995 to 2007 and each country also has increased the volume during the period
- The freight road transport has drastically increased the volumes in all CE countries, while UK and Austria has also increased the volume with smaller growth rates. Especially, Hungary and Poland had huge increase 160% and 195% respectively from 1995 to 2007.
- The railway freight transport has decreased the volume in CE states except Hungary, but the decrease rates are much smaller than that of the increase rates of the road transport.
- Austria and UK have considerably increased the railway transport volume with larger growth rates than that of the road transport.
- The pipeline transport has also increased in CE states while the inland navigation transport has decreased there.
- The pipeline transport accounts for 10% and 13 % of the modal share in Poland and Slovakia respectively.
- The energy consumption of the freight road transportation have sharply increased in Czech Republic, Hungary, and Poland by 80, 189, and 62% correspondingly from 1995 to 2005.
- Austria and the UK have also increased it but with smaller growth rates, 21% and 10%.

- Pipeline energy consumption has rapidly increased in Poland and Austria and it accounts for almost same share as the energy consumption from the railway in Poland in 2007. Also in Slovakia the pipeline transport consumes the energy more than the railway.
- Energy intensity of the freight road transport has been increased in Czech Republic, Hungary, and the Uk while it has been decreased in Austrian and Poland.
- The average road energy intensity of EU12 are lower than that of EU 15 and Central European states also have lower intensity than EU 15 including UK and Austria.
- The energy intensities for the freight road transportation in 2005 are 0.045, 0.033, 0.038, 0.037, and 0.088 (koe/tkm) for Austria, Czech Republic, Hungary, Poland, and the UK correspondingly. All of them are lower than that in Japan.

Total Transport

- Hungary, Poland, Slovakia, and the UK have decreased the total road transport energy intensity (toe/net mass movement (tkm)) till 2006, while Austria and Czech Republic increased it.
- Central European countries have lower total road energy intensity than that in Austria and the UK.
- The energy intensities for the total rail transport have been decreased in all of the analyzed countries except Czech Republic where the intensity have marginally increased.
- The intensity of the total rail transport is much lower than that of the total road transport in all selected countries (2 to 10 times lower).
- CO_2 emission intensity for the total road transport has very similar trends as the energy intensity. The EU 15 average intensity is higher than that of EU 12 and all CE states.
- CO_2 emission intensity for the total rail transport has been decreased in selected countries and all CE states except Hungary have had the lower energy intensity than EU 15 average and Austria and the UK.

6.2 Importance of three effects on the change in the energy use

Three factors which determine the energy consumption amount have been discussed separately in chapter 2, 3, and 4, and combined by the index decomposition analysis in chapter 5. As discussed in the earlier chapter, the total energy use (toe) for the transport sector is the multiplication of the total transport activity (tkm or pkm) and the energy intensity (toe/pkm or tkm). And “when two or more component or sub-sectors for which the activity is measured on a common basis are aggregated” (USDE 2003), the energy intensity that is calculated from the total energy consumption and the sum of transport activities of each mode is considered as the aggregated energy intensity and the index can be split into the component energy intensity and the structure effect. This structural effect is the change in the modal share.

Hence, the relationship between the energy intensity and the modal split is that the energy intensity can be affected by the modal shift which is caused by the relative change of the transport activities of each mode. Changes in modal split towards more energy-intensive modes like cars and trucks have increased the aggregated energy intensity and the total energy use as a result and vice versa. For example, the total transport energy consumption in Hungary has decreased by 12% from 1990 to 1991. This is mainly because the transport activity has decreased by 16% but the aggregated energy intensity has increased 4%. However, the increase of the aggregated energy intensity is not due to the growth in the component energy intensity effect but due to the increase in the modal shift effect. Actually the road transport share on the total transport in Hungary has increased from 51% to 57% during the period. The road, railway, and the inland waterway transport have been considered as the components of the inland total transport in Hungary for the LMDI analysis, but the previous trend analysis found that the component energy intensity of the road is the highest among three. Thus the modal shift towards the road transport contributes to the increase of the aggregated energy intensity.

The overall trend analyses of each country also prove that the changes in the modal split affect the changes in the energy use. The freight transport in Japan has decreased the energy use from 1990 to 2007 although the transport activity level has increased during the period. It is because the energy intensity has decreased but it can be disaggregated to the modal shift affect and the component energy intensity. The result of the analysis shows that the modal shift effect controls the increase of the aggregated energy intensity and the energy use, while the component energy intensity has increased. As shown in figure 2.2.4, the share of the freight road transportation has even increased. It is due to the sharp growth of the business use road transportation volume (60%), however, the share of the private road which is much more energy intensive (e.g. 0.05 and 0.35 koe/tkm for the business and private road respectively in 2007) than the business uses has decreased. Thus the modal shift away from the most energy-intensive mode has controlled the growth in the aggregated energy intensity.

The modal shift effect on the change in the energy use can be very significant. The degree and direction of the effect depends on the share of the energy-intensive modes, for this study, the road transport. This study found that Central European states have rapidly increased the road transportation for both the passenger and freight transport and decreased the other modes. As a result, the relative share of energy-intensive road transport among all transport modes have increased and it amplified the increase of the aggregated intensity and the total energy use. The results of decomposition analysis on chapter 5 as well as the analyses of transport activity and energy consumption show the evidence.

This study could not clearly find the general correlations among transport activity, transport intensity, and modal structure except the case between the energy intensity and modal split. But all of these three factors can be the dominant effect on the changes in the energy use and they also constrain or drive the effect each other; for example, transport activity level change of a specific component directly comes to the change in the modal split. Poland, where the transport activity has rapidly increased, has had the larger growth rate of the energy use than that of the transport volume, for the modal shift towards the road transport due to the huge increase of the road transport volume and the decrease of the railway transport. The modal shift accelerates the effect of the transport activity on the energy use in this case.

6.3. International comparison

This study examined the effects of the transport volume, modal share, and energy intensity on the energy consumption in Central Europe, UK and Austria, and Japan. Although all of these countries are the members of OECD, the economic and social situations as well as geographical location are different from each other; especially, Japan and Central Europe. In addition, this study only focuses on the numerical analysis of the three effects and did not consider the possible effect of economic measurement such as GDP on the energy use or the energy intensity as some researchers including Banister and Stead (2002) and Timilsina and Shrestha (2009). Hence, the comparison is only based on the energy intensities and the results of the decomposition analysis.

As it can be seen in the summary of the main findings and chapter 4, the energy intensity for both the passenger and freight road transport in Central Europe and Austria is lower than that of Japan although their road shares are higher than that in Japan. Even UK has lower intensity for the road freight transport.

The results of the decomposition analyses of the total transportation are compared to each other and it is found that the dominant effects on the change in energy use all depends on the country. The transport activity is the main contributor to the energy use change in Czech Republic, Hungary, and Poland, while the energy intensity is the dominant effect in Japan, Slovakia, and Austria. However, it can be said that Central European states have the larger impact of the modal shift effect on the energy use change compared to Japan, Austria, and UK where the impacts are relatively marginal (see also appendix). It may be because Central Europe has large increase rate in the transport activity and the modal shift towards the road transportation, while Japan and UK has started decreasing the road share since 2002 or 2003.

Conclusion

This study examines three factors which affect the change in the energy use in some selected countries in Europe and Japan. Likewise the general trends in the world, the energy consumption and relevant CO_2 emission from the transport sector has had the increase in all researched countries from 1990 to 2006 or 2007. To clarify the reasons behind the growth, the changes in the energy use is decomposed into the changes in the transport activity, modal share, and energy intensity effects and examined the trends and importance of each component.

The main finding in this study is that the dominant effect on the energy use depends on the country and region. For the total transport, the transport activity is the dominant effect on the change in the energy use in Czech Republic, Hungary, and Poland, while the energy intensity is the dominant effect in Japan, Slovakia, and Austria. However, the degree of the effect changes annually and there are no absolute effects which are always associated with the change in the energy use. The effect of the modal shift is smaller than other two effects overall, but it can have the significant impact on the change when the share of the road transport, which has the highest intensity among examined modes, sharply changed.

Also this study proves that the energy intensity of the total transport can be disaggregated into the component energy effect and the modal shift effect so that the change in the modal shift effect directly changes the aggregated energy intensity. Central European states have sharply increased the road transport volume but they also have increased the energy use even more sharply than that of the volume. And it is not only because the energy intensity of the components has increased but also because the relative shares of the activity (the road transport) increased. Poland has even decreased the component energy intensity but the rapid change of the modal share towards the road transport increased the aggregated energy intensity and it enhances the growth in the total energy use.

This study also tracks the trends of the transport activity, energy consumption, and energy intensity in Japan and Europe separately because of the geographical location and the difference in the data availability and quality.

In Japan, both the passenger and freight transportation have increased from 1990 to 2007 with the largest increase in the road transport although it have started decreasing since 2001 or 2002. The energy consumption has sharply increased for the passenger transport and decreased for the freight transport. The main reason for the growth in the passenger transport is the increase in both the transport activity and the energy intensity. And the main reason for the decline the freight transport is the modal shift away from the private use road transport which energy intensity is seven times higher than that of business use road. The analysis of Japanese transportation trends also finds the energy intensities for each mode for the passenger and freight transport mode which was hard to find for selected European countries. For the passenger transport, taxi is the most energy intensive and the railway was the least intensive. The private use road transportation is the most energy intensive for the freight transport and the railway was the least energy intensive. Indeed, the railway is also the least CO_2 emitting mode per travel volumes.

The trends of the transport activity in Central Europe are very clear. The overall volume for the passenger transport has sharply increased except the case of Hungary with the massive increase in the road transportation and the decrease in the railway. For the freight, the sharp growth in the road transportation can be seen in all CE states. The United Kingdom has the completely different pattern from CE states for both passenger and freight transportation and Austria is in between.

The trends of the energy consumption can be analyzed only by transport mode because the split data could not be found. But the estimated value shows that both passenger and freight road transport have increased the energy intensity and the energy share is much higher in passenger transport. And the total energy consumption and road transportation have increased in all selected countries. The energy and CO_2 emission intensities of the total road and rail transport are calculated based on the concept of net mass movement and it is found that Central European states have lower intensities compare to EU 15, Austria, and the UK for both for the road and rail transport.

Although the transport energy intensity in Central Europe is generally lower than that of the Western states and other industrialized countries like Japan, the massive growth of the transport activity and the modal shift towards the more energy-intensive road transportation accelerate the energy consumption and CO2 emission. To achieve the global aim of the CO2 reduction, the energy use reduction is essential because these two cannot be decoupled. This study proves that the growth in the energy use mainly depends on the transport activity and energy intensity but the modal shift also can affect the change. It seems to be very hard to reduce the transport activity because the transport is an essential demand of people and the more the globalization proceeds, the more transport activity people want. Hence, reducing the energy intensity combined with the modal split management seems to be the best way to tackle this challenging problem, which has more possibility to be successful with the proper policymaking.

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Appendices

The Results of LMDI analysis

Japan – Total

Annual change	Dact	Dstr	Dint	Dtot
90/91	2.69%	−0.32%	3.88%	6.25%
91/92	0.86%	−0.26%	3.38%	3.98%
92/93	−1.48%	−0.14%	3.31%	1.69%
93/94	1.10%	0.20%	1.05%	2.35%
94/95	2.49%	0.42%	1.48%	4.39%
95/96	2.15%	0.27%	0.89%	3.31%
96/97	0.36%	0.24%	0.79%	1.39%
97/98	−0.70%	−0.10%	0.09%	−0.71%
98/99	0.97%	−0.75%	1.68%	1.89%
99/00	1.54%	−1.65%	1.29%	1.18%
00/01	0.78%	−1.37%	1.60%	1.00%
01/02	−0.52%	−0.32%	0.41%	−0.43%
02/03	−0.44%	−0.02%	−1.60%	−2.06%
03/04	0.13%	−0.88%	−4.08%	−4.84%
04/05	−0.13%	−0.58%	−2.15%	−2.87%
05/06	0.26%	−0.44%	−1.21%	−1.40%
06/07	0.68%	−0.09%	−0.78%	−0.19%

Japan - Passenger

annual change	Dact	Dstr	Dint	Dtot
90/91	3.0%	0.2%	4.3%	7.4%
91/92	2.0%	0.7%	2.7%	5.5%
92/93	0.6%	0.5%	2.0%	3.0%
93/94	0.7%	0.9%	1.8%	3.4%
94/95	2.4%	0.6%	2.6%	5.5%
95/96	1.9%	0.6%	1.9%	4.3%
96/97	1.2%	0.9%	1.2%	3.4%
97/98	1.0%	0.5%	−0.9%	0.7%
98/99	0.6%	0.5%	2.2%	3.3%
99/00	0.5%	0.2%	0.2%	0.8%
00/01	1.0%	0.1%	1.7%	2.7%
01/02	0.3%	0.4%	−0.2%	0.5%
02/03	0.0%	−0.3%	−1.2%	−1.4%
03/04	−0.5%	−0.3%	−3.2%	−4.0%
04/05	−0.3%	−0.8%	−2.0%	−3.0%
05/06	−0.5%	−0.9%	−0.7%	−2.1%
06/07	0.7%	−0.6%	−0.2%	−0.1%

Japan - Freight

annual change	Dact	Dstr	Dint	Dtot	annual change	Dact	Dstr	Dint	Dtot
90/91	2.4%	−0.9%	3.4%	4.9%	99/00	3.1%	−4.4%	2.9%	1.7%
91/92	−0.5%	−1.4%	4.2%	2.2%	00/01	0.5%	−3.6%	1.5%	−1.6%
92/93	−3.9%	−0.9%	4.8%	0.1%	01/02	−1.7%	−1.5%	1.4%	−1.8%
93/94	1.6%	−0.7%	0.2%	1.1%	02/03	−1.2%	0.5%	−2.3%	−3.0%
94/95	2.6%	0.2%	0.0%	2.9%	03/04	1.1%	−1.8%	−5.5%	−6.2%
95/96	2.5%	−0.2%	−0.4%	2.0%	04/05	0.1%	−0.3%	−2.4%	−2.6%
96/97	−0.8%	−0.7%	0.2%	−1.3%	05/06	1.4%	0.3%	−2.0%	−0.2%
97/98	−3.1%	−1.0%	1.4%	−2.6%	06/07	0.6%	0.7%	−1.7%	−0.3%
98/99	1.5%	−2.5%	0.9%	−0.1%					

Czech

Annual change	Dact	Dstr	Dint	Dtot
97/98	1.5%	5.7%	−5.8%	1.3%

98/99	1.6%	4.9%	3.6%	10.2%
99/00	1.8%	−0.5%	0.2%	1.5%
00/01	2.0%	1.7%	2.5%	6.1%
01/02	5.3%	3.5%	−4.1%	4.7%
02/03	4.5%	1.0%	6.5%	12.0%
03/04	−1.8%	0.6%	5.3%	4.0%
04/05	−3.3%	−1.1%	11.6%	7.2%
05/06	11.0%	1.6%	−10.3%	2.3%

Hungary

annual change	Dact	Dstr	Dint	Dtot	annual change	Dact	Dstr	Dint	Dtot
90/91	−18.0%	8.6%	−3.8%	−13.2%	98/99	−0.6%	0.8%	5.8%	6.0%
91/92	−11.0%	2.4%	5.2%	−3.4%	99/00	2.4%	0.1%	−3.3%	−0.7%
92/93	−9.6%	5.2%	4.1%	−0.3%	00/01	−4.4%	1.3%	8.1%	5.0%
93/94	1.7%	2.0%	−6.2%	−2.6%	01/02	−0.2%	−1.8%	8.0%	6.0%
94/95	4.9%	−0.1%	−2.2%	2.6%	02/03	0.5%	0.5%	3.5%	4.5%
95/96	−0.3%	2.0%	−2.0%	−0.2%	03/04	10.8%	−1.2%	−5.2%	4.4%
96/97	4.1%	−0.7%	1.9%	5.4%	04/05	12.5%	2.8%	−7.5%	7.7%
97/98	12.1%	3.9%	−6.0%	10.0%	05/06	13.5%	2.2%	−5.9%	9.8%

Poland

annual change	Dact	Dstr	Dint	Dtot
95/96	4.4%	4.0%	3.5%	11.9%
96/97	5.0%	5.0%	−4.6%	5.4%
97/98	2.2%	4.9%	−2.2%	5.0%
98/99	−2.3%	2.9%	9.8%	10.4%
99/00	3.2%	2.1%	−19.5%	−14.2%
00/01	−1.6%	3.9%	−2.8%	−0.6%
01/02	1.3%	2.2%	−6.5%	−3.0%
02/03	5.6%	0.4%	2.9%	8.8%
03/04	12.1%	3.0%	−3.6%	11.6%
04/05	4.1%	3.4%	−0.4%	7.1%
05/06	10.1%	2.4%	−2.5%	10.0%

Slovakia

annual change	Dact	Dstr	Dint	Dtot
95/96	−5.8%	4.5%	−8.3%	−9.6%
96/97	−0.6%	−2.0%	17.6%	15.1%

97/98	6.0%	5.8%	−10.4%	1.4%
98/99	−3.6%	6.0%	−1.3%	1.0%
99/00	−9.3%	−10.3%	15.7%	−3.8%
00/01	−3.0%	−0.1%	3.3%	0.2%
01/02	2.4%	4.2%	12.9%	19.4%
02/03	5.3%	3.9%	−19.8%	−10.7%
03/04	4.5%	3.7%	−9.1%	−0.9%
04/05	11.5%	5.1%	−5.9%	10.8%
05/06	0.7%	−1.6%	4.1%	3.1%

Austria

annual change	Dact	Dstr	Dint	Dtot
95/96	3.3%	0.7%	3.6%	7.6%
96/97	4.3%	−1.5%	−8.0%	−5.2%
97/98	4.3%	0.6%	6.4%	11.2%
98/99	5.5%	3.4%	−12.6%	−3.7%
99/00	4.3%	−1.3%	3.0%	6.1%
00/01	4.7%	0.8%	−0.4%	5.1%
01/02	2.0%	0.2%	5.4%	7.7%
02/03	0.2%	2.1%	5.0%	7.2%
03/04	1.2%	−1.6%	2.9%	2.5%
04/05	−2.2%	−2.0%	7.6%	3.4%
05/06	5.5%	−0.8%	−8.5%	−3.8%

UK

annual change	Dact	Dstr	Dint	Dtot	annual change	Dact	Dstr	Dint	Dtot
91/92	−1.5%	−0.2%	2.9%	1.2%	99/00	−0.3%	0.6%	−2.0%	−1.7%
92/93	3.3%	0.6%	−2.7%	1.3%	00/01	0.1%	−0.5%	−0.4%	−0.9%
93/94	5.9%	0.2%	−6.0%	0.0%	01/02	0.8%	0.2%	0.0%	1.0%
94/95	3.0%	−0.1%	−3.7%	−0.8%	02/03	1.2%	0.0%	−0.3%	0.9%
95/96	2.9%	−0.6%	1.5%	3.7%	03/04	2.0%	−1.4%	0.3%	0.9%
96/97	2.3%	−0.9%	−0.6%	0.8%	04/05	−0.3%	0.4%	0.9%	0.9%
97/98	1.5%	−0.1%	−2.2%	−0.8%	05/06	4.2%	−1.4%	−1.2%	1.6%
98/99	−1.7%	−0.1%	4.6%	2.8%					

Europe - Passenger Modal Share in 2007

Mode/nation	AT	CZ	HU	PL	SK	UK
car	75.7%	69.9%	59.5%	82.3%	69.9%	86.1%
bus	10.3%	15.8%	24.6%	9.4%	23.3%	6.4%

Train	10.0%	6.7%	12.6%	6.7%	5.8%	6.3%
tram/metro	4.1%	7.6%	3.3%	1.5%	1.1%	1.2%

Europe - Passenger Modal Share in 1995

Mode/nation	AT	CZ	HU	PL	SK	UK
car	73.7%	61.4%	62.2%	62.8%	48.5%	88.2%
bus	10.4%	20.9%	22.8%	19.3%	39.0%	6.5%
Train	12.0%	9.0%	11.6%	15.1%	11.3%	4.3%
tram/metro	3.9%	8.7%	3.4%	2.8%	1.2%	1.0%

Europe - Freight Modal Share in 2007

	AT	HU	CZ	PL	SK	UK
Road	54.5%	70.1%	72.3%	65.9%	62.3%	82.4%
Railway	31.2%	19.7%	24.5%	23.7%	22.1%	12.7%
Pipeline	10.5%	5.9%	3.1%	10.3%	13.3%	4.9%
Inland Water	3.8%	4.3%	0.1%	0.1%	2.3%	0.1%

Europe - Freight Modal Share in 1995

	AT	HU	CZ	PL	SK	UK
Road	54.6%	53.9%	55.4%	38.3%	42.7%	86.8%
Railway	27.2%	32.8%	40.1%	51.0%	37.0%	7.1%
Pipeline	13.9%	8.5%	4.0%	10.1%	16.4%	6.0%
Inland Water	4.2%	4.7%	0.5%	0.7%	3.9%	0.1%

Passenger Modal Share in Japan

	1990	1995	2000	2007
Car	50.9%	53.9%	57.1%	55.4%
Private Car	49.5%	52.8%	56.2%	54.6%
Taxi	1.4%	1.1%	0.9%	0.8%
Bus	9.8%	7.9%	6.7%	6.8%
private	2.9%	1.9%	1.4%	1.3%
public	6.8%	6.0%	5.4%	5.5%
Rail	34.3%	32.5%	29.6%	31.0%
Ship	0.6%	0.5%	0.3%	0.3%
Air	4.6%	5.3%	6.1%	6.5%

Freight Modal Share in Japan

	1990	1995	2000	2007
Road	50.2%	52.7%	54.2%	60.9%
business	35.5%	39.9%	44.2%	53.3%
private	14.6%	12.8%	10.0%	7.7%
Rail	5.0%	4.5%	3.8%	4.0%
Ship	44.7%	42.6%	41.8%	34.9%
Air	0.1%	0.2%	0.2%	0.2%