UNDA Seventh Tranche

Project E:

Development and implementation of a monitoring and assessment tool for CO_2 emissions in inland transport to facilitate climate change mitigation

CO_2 emissions from inland transport: statistics, mitigation polices, and modelling tools

United Nations Economic Commission for Europe (UNECE)

Transport Division

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Executive summary

The Transport Division of the United Nations Economic Commission for Europe (UNECE), together with all UN Regional Commissions, initiated a new project to enhance international cooperation and planning towards sustainable transport policies that facilitate climate change mitigation.

The project is funded by the UN Development Account (UNDA) for 3 years, from January 2011 to December 2013.

The project aims at developing an information and analysis modelling tool based on a uniform methodology for the evaluation of the emissions of carbon dioxide (CO_2). Since the tool is meant to pave the way "For Future Inland Transport Systems", it was named ForFITS. It focuses on the inland transport sector (road, rail and inland waterways), while CO_2 emissions caused by international aviation and maritime transport are excluded from its scope.

In order to define the features of ForFITS, this report illustrates the main data requirements associated with the estimation of inland transport CO_2 emissions, it looks at the overarching strategies and targets set by countries for mitigating GHG emissions as a whole, it considers in more detail transport-specific policy measures suitable and frequently adopted for CO_2 emission mitigation, and it reviews the methodologies and modelling tools currently used for the estimation of CO_2 emissions. Building on this information, this report also provides recommendations for the improvement of statistics related to transport, energy and CO_2 emissions and the development of the ForFITS model.

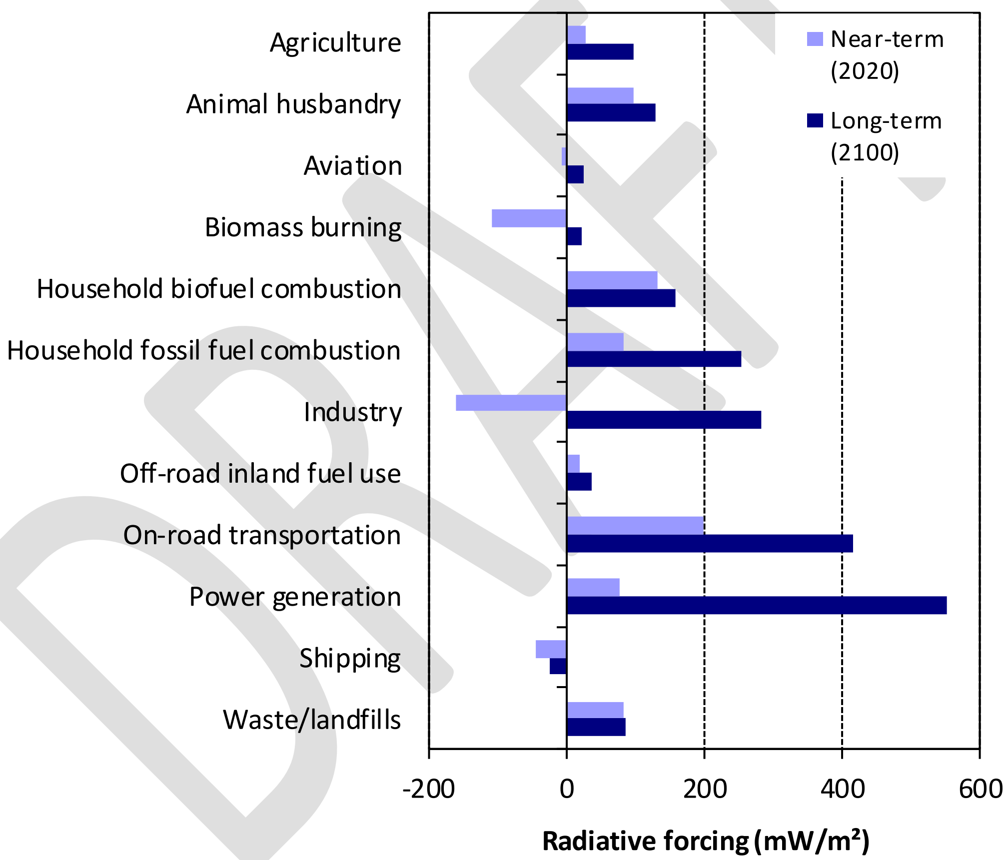
1. Introduction

Background

Virtually all the energy used in transport is obtained from the combustion of oil-based fuels (largely diesel and gasoline): this is why GHG emissions in transport are predominantly CO_2 emissions. Transport is responsible for about 13 % of GHG emissions (IPCC, 2007) and 22% of the total CO_2 emissions from fuel combustion (IEA, 2011a).

In addition, according to a recent multi-pollutant assessment of the total climate impact due to emissions from major anthropogenic economic sectors (Unger et al., 2009), the power sector and on-road transportation are estimated to exert the largest net positive radiative forcing[1] effect on climate (Figure 1).

Figure 1. Sectoral net radiative forcing due to perpetual constant year 2000 emissions



Source: Unger et al., 2009

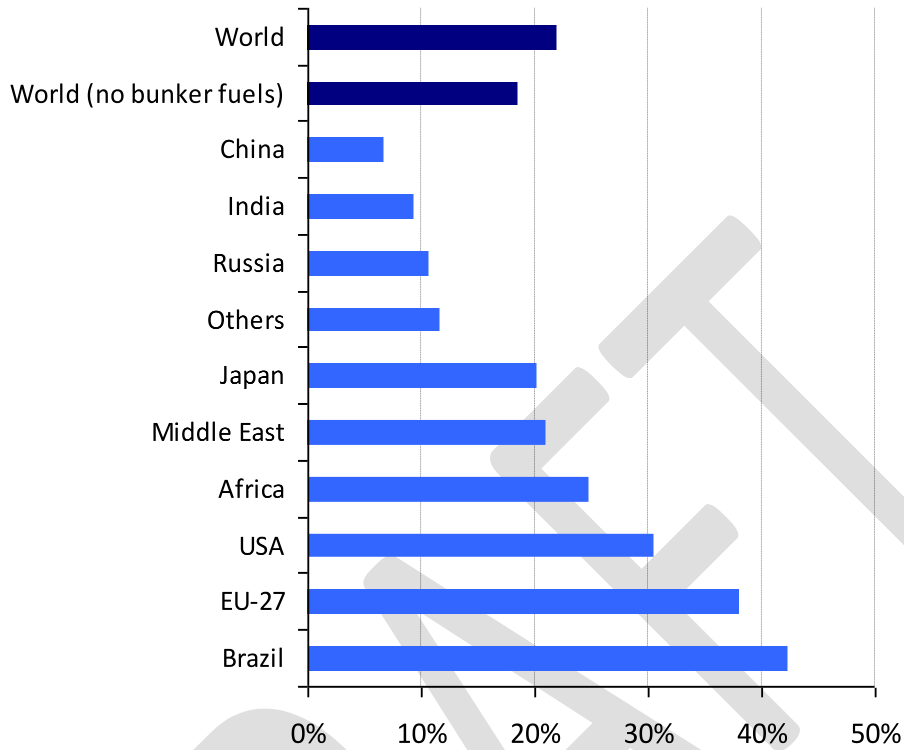
On-road transportation is predicted to be the economic sector responsible for most of the net forcing in the near term (2020), and the second largest in the long term (2100)[2]. The

[1] Radiative forcing is defined as the net energy flux difference at the top of the atmosphere caused by an imposed change in the pollutant loading relative to an unperturbed initial state. It was developed to quantify human and natural influences on the climate system.

[2] This is because the sum of the effects of short lived species (i.e. the air pollutants co-emitted with long-lived greenhouse gases like CO_2, CH_4 and N_2O: tropospheric ozone and fine aerosol particles like

same study also underlines that shipping has an overall net cooling effect both in the near term and the long term, while the radiative forcing of the aviation sector is positive and consistent with smaller (but quickly growing) fuel use, relative to other activities.

Figure 2. Share of transport CO_2 emissions in selected world regions and countries



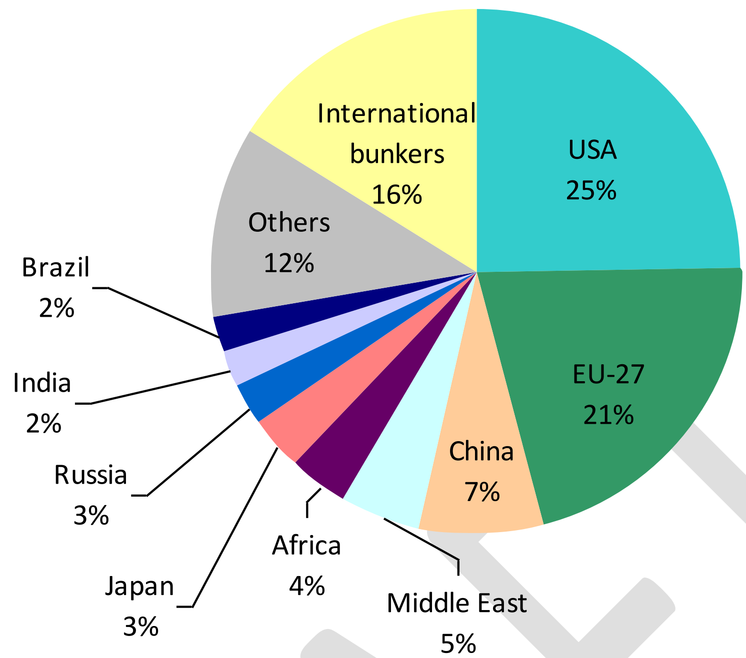
Source: IEA, 2011b

Transport's share in the total CO_2 emissions from fuel combustion is not uniformly distributed across the world. Figure 2 illustrates that transport-related CO_2 emissions are more prevalent in OECD (Organisation for Economic Cooperation and Development) countries, where transport activity and its intensity are higher, as well as countries where the electricity generation is predominantly obtained from low-carbon sources. Transport-related CO_2 emissions are lower than the global average in developing countries and regions where a large portion of electricity is produced from carbon-intensive fossil fuels.

In absolute terms, the United States of America is the leading emitter of transport-related CO_2, followed by the EU-27, China and the Middle East (Figure 3). Additionally, EU-15 emissions represent a dominant share of EU-27 emissions.

sulphate, nitrate, black carbon, organic carbon, all affecting global climate in complex ways involving both warming and cooling) is estimated to have about the same as the CO_2 effect, in road transport, while the effect of the short lived species results in a lower net radiative forcing for other economic sectors.

Figure 3. Shares of CO_2 emissions from fuel combustion in selected world regions and countries



Source: IEA, 2011b

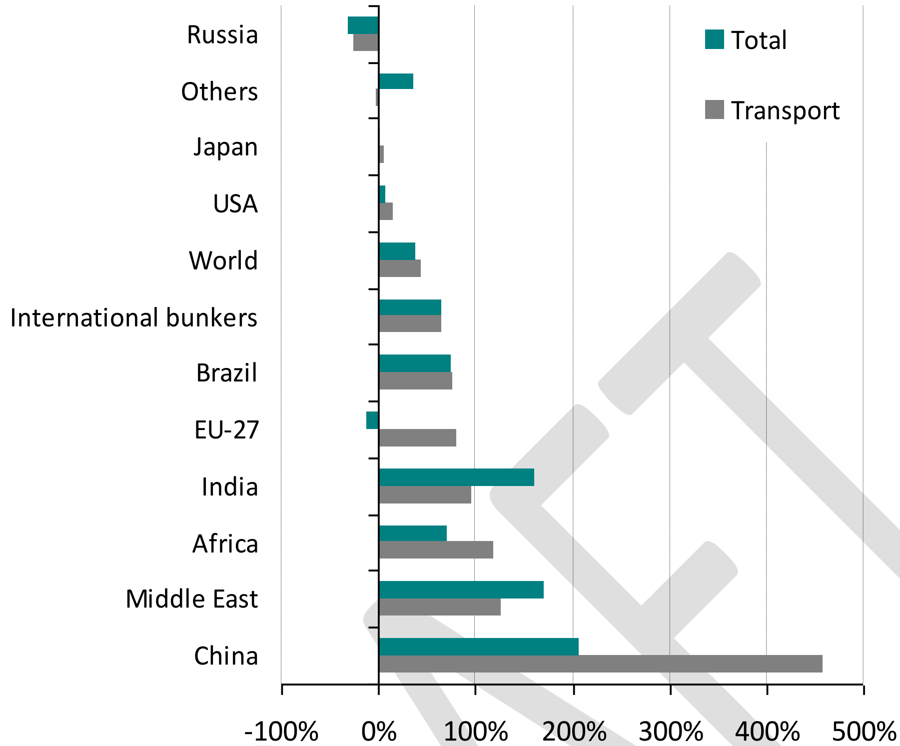
Since 1990, global CO_2 emissions from fuel combustion in the transport sector increased more than 40% (Figure 4). This increase is largely due to the growth of passenger and freight transport activity, the lack of structural changes (such as shifts to more efficient transport modes) and limited reductions of CO_2 emission intensities within each transport mode.

The growth of transport activity is underpinned by:

- a tendency to travel farther if people have access (either because of increased income or other factors) to faster modes of travel;
- the allocation of a growing share of the available income to transportation in countries with a motorisation rate lower than 300 cars per 1000 inhabitants, only partly mitigated by the stability of the share of available income allocated to transportation when motorisation rates are higher;
- the subsequent increase of the stock of light duty vehicles, which reached 800 million in 2005 (IEA, 2009a), driven by the growth of real household disposable income, resulting an increase in passenger transport activity and a decrease in the portion of passenger transport taking place through less energy-intensive modes;
- the strong linkage between freight transport activity and economic growth, since economic growth stimulates transport demand, creating opportunities for the increased availability of transport options, which ultimately reinforces itself by facilitating specialization and trade (IPCC, 2007a).

In addition, during the last several decades, consumers also showed a significant preference for larger vehicles with more powerful engines.

Figure 4. Growth of CO_2 emissions in transport and in total, 1990-2009



Source: IEA, 2011b

The growth of transport-related CO_2 emissions has been especially prevalent in rapidly developing countries and world regions (namely in China, but also the Middle East, India and Brazil). However, CO_2 emissions in the transport sector have also been growing in OECD countries. In the EU-27, the increase of transport emissions is in stark contrast with the mitigation of overall emissions that took place since 1990, which was driven by emission reductions in other end-use sectors and power generation. In the United States and Japan, transport-related CO_2 emissions also increased more than other sectors (but less than in Europe, since the average income per capita in Europe led to lower motorisation rate increases).

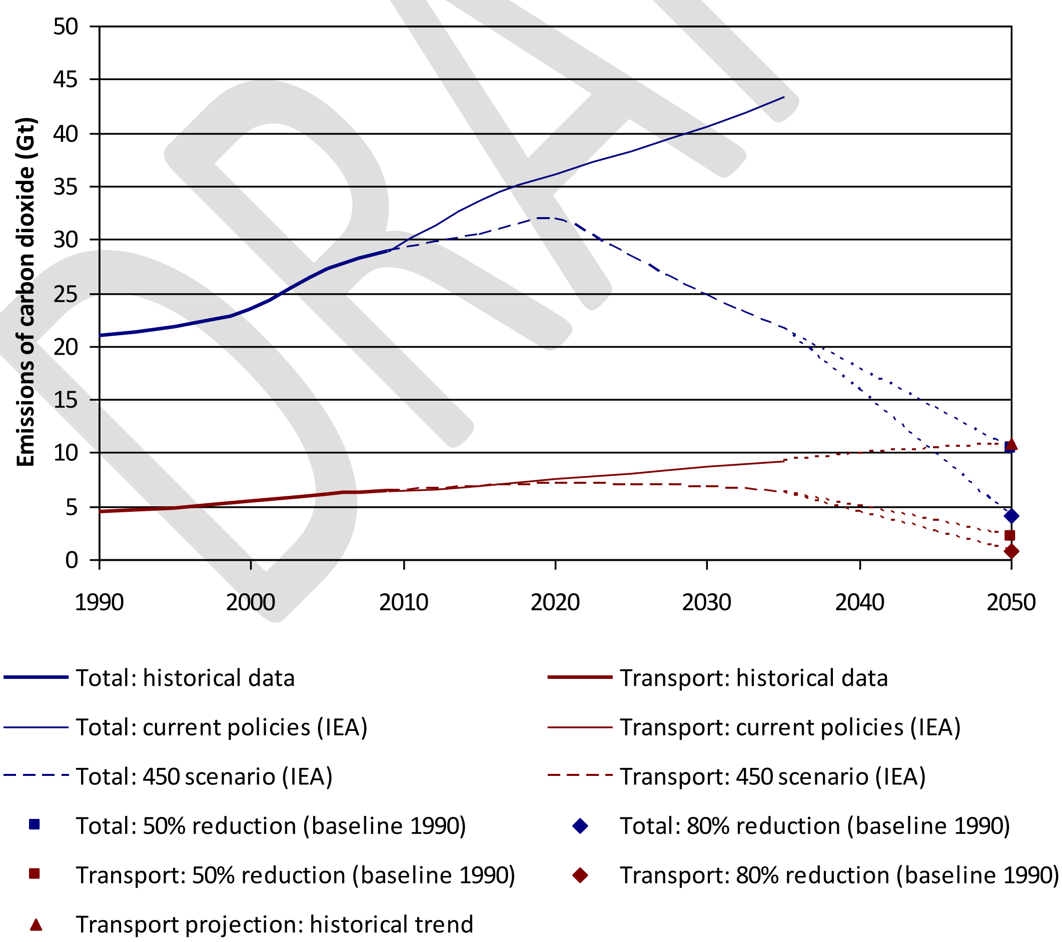
Notwithstanding the slow recovery in advanced economies, weakened and uneven global activity, large increases in fiscal and financial uncertainty, and a slowdown in global economic growth in 2011 (IMF, 2011), the global economy is expected to continue to grow over the next decades, with the highest rates of growth in emerging economies (e.g. Ward, 2011 and Hawksworth and Tiwari, 2011). If real household disposable income continues to grow at a faster rate than the real cost of transport, and barring a major shift away from current patterns of energy use in transport, world transport CO_2 emissions are projected to attain nearly 10 Gt by 2035 (IEA, 2011b).

Prolonging this trend would lead to more that 10 Gt by 2050 (Figure 5). If emissions of GHGs, and in particular CO_2, continue unabated, the enhanced greenhouse effect is very likely to induce changes in the global climate system during the 21st century (IPCC, 2007b). This would result in impacts that would likely impose increasing net annual costs for society as global temperatures increase (IPCC, 2007c).

Figure 5 shows historical CO_2 emissions, the projected emissions by the International Energy Agency (IEA) and long-term CO_2 mitigation targets for total and transport-related CO_2 emissions due to the combustion of fossil fuels (IEA, 2011b). Clearly (even if the representation of years beyond 2035 is deliberately simplistic), maintaining the historical rate of growth of CO_2 emissions in transport is not compatible with long-term overall GHG emission reduction targets, which would be compatible with an average global temperature increase in the range of 2°C to 3°C.

Reducing CO_2 emissions in transport has been widely recognised as a priority (and a challenge) by all transport stakeholders: road vehicle manufacturers (e.g. OICA, 2010), their components suppliers, the shipping industry (e.g. ICS, 2009), the rail industry (e.g. Sándor and Obenaus, 2011), aviation-related businesses (e.g. IATA, 2009), companies working on the construction and maintenance of transportation infrastructure (e.g. ENCORD, 2009), energy and fuel producers (e.g. Shell, 2008), intergovernmental organisations, consumer protection associations and environmental advocacy groups.

Figure 5. Global CO_2 emission trajectories against transport emissions



Source: elaboration based on IEA, 2011b

The establishment of the United Nations Framework Convention on Climate Change (UNFCCC, 1992) and the subsequent decisions concerning international agreements and documents, i.e. the Kyoto Protocol (UNFCCC, 1998), the Bali Action Plan (UNFCCC, 2007), the Copenhagen Accord (UNFCCC, 2009), the Cancun Agreement (UNFCCC, 2010) and the recent establishment of the Durban Platform for Enhanced Action (UNFCCC, 2011a), are overarching steps representing global efforts toward the reduction of GHG emissions to limit climate change (mitigation) and the adaptation to its consequences.

These steps encompass all economic sectors. For the transport sector, these agreements, as well as actions going beyond them and following the recommendations of the IPCC in terms of GHG emission mitigation, can be implemented through a variety of policies and measures. In order to support the wider objective of promoting the sustainable development of the transport sector, policies addressing GHG emissions must also be coupled with measures addressing other transport externalities, health-related concerns, environmental problems (such as those due to local pollution and noise, or those related to the management of waste at the end of the useful life of products), long-term resource availability issues (e.g. for oil and other materials, like rare earths), as well as social and economic questions. All these measures could, in turn, ultimately lead to increased opportunities to better address climate change, since future vulnerability depends not only on climate change, but also on the pathway of global development (IPCC 2007c).

Policy options that could reduce growth in transport sector CO_2 emissions (as well as polices aimed at the promotion of sustainable transport) can generally be associated with three main areas that are clearly identified by the keywords Avoid-Shift-Improve (ADB, 2009a):

- managing travel demand, e.g. avoiding or reducing the need for travel (Avoid);
- shifting travel to more sustainable transport modes (Shift); and
- improving the sustainability of vehicles, fuels and infrastructure concerning all modes, leveraging technologies capable of reducing or eliminating GHG emissions and noxious pollutants (across the entire life cycle of products), as well as noise (Improve).

The cost-effectiveness of policies (i.e. the cost of implementing a given measure with respect to the social benefits it delivers), as well as the cost effectiveness of the actions they stimulate (i.e. the mitigation of CO_2 emissions favouring the lowest cost per tonne of CO_2 abated, first) are also fundamental determinants for their adoption.

The prerequisites for implementing the appropriate policy actions are the availability of information for the characterisation of the situation (both in the present time and in the past) and the policy definition, as well as the ability to process them in a way that allows evaluation of their impacts, their costs and the benefits they are expected to deliver.

Information on transport activity, vehicle and fuel characteristics, as well as fuel usage has a fundamental importance when evaluating the past, present and future status of CO_2 emissions. Similarly, a wider range of inputs (spanning from demographic and macroeconomic figures to technological characteristics and costs, amongst other information) is needed for the evaluation of CO_2 emission mitigation policies in transport.

Such data should not only characterise the past and current timeframes, but also the future, since policy measures need to be evaluated for their expected effects after introduction.

A number of tools for measuring CO_2 emissions are already available, as well as some models designed to analyze the effects of policy changes on transportation. However, none of them currently combines the reliance on a fully transparent, uniform and harmonised methodology, unimpeded accessibility guaranteed by its free availability on the web, and offers a flexible approach capable of adapting to the availability of statistics in different situations, while being suitable for a diverse range of users. This is what the UNECE is attempting to achieve through the development of ForFITS, a modelling tool that is meant to pave the way for future inland transport systems[3] by providing policy makers an opportunity to evaluate the impacts of different policies aimed at the reduction of CO_2 emissions.

Objectives of the study

This analysis is primarily developed to provide a basis of information to undertake the development of the ForFITS model.

The analysis builds on desk research on existing activities concerning data collection practices, existing policy initiatives in the field of transport and climate change, and existing modelling efforts aimed at the estimation of their impacts.

It also benefits from information collected through a questionnaire aiming to gather information on worldwide measures and actions that reduce inland transport CO_2 emissions and facilitate climate change mitigation. In order to enable a global assessment, the questionnaire was developed by the UNECE Transport Division, jointly with the other United Nations Regional Commissions, including the Economic Commission for Africa (ECA), the Economic Commission for Latin American and the Caribbean (ECLAC), the Economic and Social Commission for Asia and the Pacific (ESCAP), and the Economic and Social Commission for Western Asia (ESCWA). It was circulated to all member countries of the United Nations and to a number of international and non-governmental organisations. The areas that were addressed by the questionnaire targeted the following topics:

- approaches used for the collection of statistical data concerning CO_2 mitigation in inland transport;
- strategies aiming to reduce inland transport CO_2 emissions, including specific polices and legal instruments in use; and
- existing assessment tools for the estimation of inland transport CO_2 emissions and the impacts of polices that attempt to mitigate them.

The data collection was initiated in June 2011 and was concluded in September 2011. Overall, data were received from 58 countries and organisations, listed in Annex 1.

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[3] This tool focuses on the inland transport sector (road, rail and inland waterways) because these are the fields where the United Nations Economic Commission for Europe, which is developing the tool, has the mandate to operate and a recognized expertise. CO_2 emissions caused by international aviation and maritime transport are excluded from the scope of the model.

Structure of the report

Further to this introductory chapter, the report is structured as follows:

- Chapter 2 illustrates the main data requirements associated with the estimation of inland transport CO_2 emissions and the evaluation of policies attempting to mitigate them. In addition, it provides information on the main databases available, existing uncertainties and availability limitations;
- Chapter 3 looks at the overarching strategies and targets set by countries for mitigating GHG emissions as a whole, and then considers in more detail, transport-specific policy measures suitable and frequently adopted for CO_2 emission mitigation, attempting to figure out what are the most relevant ones and how they have been used by different countries;
- Chapter 4 presents the methodologies and tools currently used for the estimation of CO_2 emissions in transport and the evaluation of policies attempting to mitigate them. It evaluates the strengths and weaknesses of these approaches, attempting to extract information capable of guiding the development of the ForFITS tool; and
- Chapter 5 conveys the key messages resulting from the assessment and provides final recommendations on the improvement of statistics concerning transport, energy and CO_2 emissions, as well as the development of ForFITS.

2. Sources of information

Data requirements

Statistics and other numerical data have a fundamental importance for evaluating the past and present status of socio-economic phenomena. They provide information in a clearly defined framework and help explain which parameters should be monitored when looking at future developments in a given field.

A range of variables can influence the reduction of inland transport CO_2 emissions. Building on information provided by databases, publications, modelling efforts and the UNECE questionnaires, it is possible to identify the statistics that are relevant for CO_2 emissions in transport and to classify them in three main groups:

- the first includes information concerning the manufacture and use of fuels, vehicles and transportation infrastructure, with a primary focus on energy use and CO_2 emissions (amongst other issues);
- the second focuses on transport activity and how it is linked to the amount of fuels consumed, the amount of vehicles produced and sold, and the network required for transportation services; and
- the third concerns data linking transport activity with the drivers of transport demand.

In addition, a further distinction is needed. It concerns:

- data focusing on past developments (historical data), necessary to understand the current status of the transport sector, its energy use, its CO_2 emissions and how they developed in the past; and
- information on future developments, which are particularly needed to characterise policies in order to evaluate their impacts.

Historical data for the characterisation of CO_2 emissions in transport

The statistical data describing the current status of CO_2 emissions in transport have been considered here according to the classification suggested earlier.

Characteristics of transport fuels, vehicles and infrastructure

The data included in this group include information characterising fuels, vehicles and transportation infrastructure with respect to the energy and emissions associated with their production (or construction) and use.

In particular, they encompass:

- the consumption of fuels and other energy carriers, considering transport as an end-use, independent from other activities (at least as an aggregate, and possibly by fuel, by mode and with further disaggregation);

- the technical characteristics of fuels (such as the properties of fuels and other energy carriers in terms of energy content and tank-to-wheel CO_2 emissions per unit energy);
- the life-cycle energy requirements and CO_2 emissions associated with
  a) the fuel production (well-to-tank);
  b) the vehicle manufacture, maintenance and disposal; and
  c) the construction, maintenance and disposal of the transportation infrastructure.

Transport activity and vehicle characteristics

This set of data is the widest. It incorporates information on transport activity according to transport mode, including:

- statistics on the number of vehicles circulating by class and powertrain group;
- information on their average annual travel; and
- data on their average load (for freight, resulting from the average load on laden trips and empty running).

This enables the expression of transport statistics in terms of passenger-km and tonne-km, which are the two most relevant indicators for passenger and transport activity.

In addition, this group includes data on the technical characteristics of the vehicle stock. This refers to information like their consumption per km, including data on different powertrain technologies, as well as other non-engine technologies. These also include information on the efficiency of conventional gasoline and diesel engines and the introduction of more advanced technologies including hybrids, plug-in hybrids, electric and fuel cell vehicles.

Data on vehicle sales and their characteristics are also part of this set of information, since they can explain changes occurring in the characteristics of the vehicle stock over time. This is also the case for the evolution of vehicle travel once the vehicle age increases, as well as the average scrappage rate of vehicles over time (scrappage curves).

Finally, transport activity is related to the extent of the infrastructures (roads, rail, waterways, and pipelines) of the inland transport network and their capacity. Such information also allows the determination of (in combination with transport activity data) the infrastructure usage rate.

Drivers of transport demand

Variables providing demographic, macroeconomic, geographic information, as well as data concerning prices, are extremely important to understand the evolution of transport activity and energy use. Even if they do not contribute directly to the calculation of CO_2 emissions, they have a fundamental role for the definition of the socio-economic context where they take place and for the characterisation of policies. They are also necessary to separate the impacts of policy measures over time against the background of changes in transport activity, energy use and emissions driven by higher incomes, demographic and geographic changes (partly reflected in variations of land use).

This group of data also includes parameters like the average travel time, or (for passenger travel) the average number of trips per day and the average trip length, since they play a key role in the determination of the characteristics of passenger transport demand (for instance concerning the modal selection).

Information on fuel and vehicle costs (including cost figures on different powertrain technologies, as well as other non-engine technologies) have a similar importance, since they influence individuals' decisions on issues such as the selection of vehicle powertrains, the selection of a specific transport mode for a particular trips, acceptable tradeoffs between loads and delivery time, amongst other relevant decisions.

The percentage of taxes, both for vehicles and fuel, is also a requirement for the understanding of the current and past policy contexts.

Finally, information on the interaction between transport activity and available infrastructures (which may be expressed through the level of use, speed limits characterising different segments, and congestion levels) is important for understanding some of the dynamics of transport demand, as well as their influence on specific fuel consumption levels of vehicles.

Future context and policy characterisation

The evaluation of policies requires using projected future data, since policy measures need to be evaluated for their expected effects in the same timeframe.

The information needed should characterise the context where polices play a role, as well as specific policy features.

The data required for the characterization of the transport-related context where the CO_2 emissions are going to take place comprise:

- projections of demographic, macroeconomic, and geographic characteristics;
- assumptions on the linkages between demographic, macroeconomic, and geographic characteristics on one hand and on the other hand, the vehicle stock (car ownership), vehicle characteristics (fuel consumption, load capacities, production cost for each powertrain group) and travel activity (average travel per vehicle and average load per vehicle, or passenger travel on collective passenger transport modes rather than individual modes);
- assumptions on the development of networks (extension, speed limits and congestion components) with respect to demographic, macroeconomic, and geographic characteristics;
- inputs on the expected vehicle and fuel production costs.

The numerical data capable of characterising policy measures that are relevant in this context include:

- the expected evolution of vehicle and fuel taxes;

- the introduction mandates on the characteristics of fuels (e.g. the requirement for a minimal amount of bio-components);
- the introduction of legislation regulating the fuel consumption of vehicles (e.g. expressed in grams of CO_2 per kilometre travelled);
- the development of transport networks (e.g. due to particular development concerning the construction of new infrastructure or the conversion of existing transport connections), and the effect it may have on parameters, such as car ownership;
- the effect on the average vehicle fuel consumption due to the promotion of eco-driving;
- the expected evolution of parameters, for instance the average travel per vehicle, due to measures promoting urbanisation;
- the effect on the average travel per vehicle, the vehicle ownership and the average load per vehicle (for different modes) of initiatives such as access restrictions to some parts of the transport network or road pricing measures as a means to reduce traffic congestion.

Main sources of transport and CO_2 emissions statistics and data

A number of different institutions collect and publish statistics that are relevant for the estimation of CO_2 emissions in transport. Typically, entities collecting these data include local, national and international governmental institutions, individual companies, industry associations, research institutes, academia and consulting groups (either under the direction of public institutions, for the purposes of selling the information contained in the database to private and public sector operators, or to sell them as a part of a larger package, including analytical work).

The following sections attempt to provide an overview of the information currently collected and published on inland transport vehicles, travel, activity, fuel use and CO_2 emissions.

This section focuses on annual statistics and information relevant for assessments that span a period of time measurable in years. It is largely based on desk research, and partly complemented by the limited information obtained from the circulation of the UNECE questionnaires developed explicitly for this exercise. The following analysis takes into account the most relevant sources of statistical information providing international data, as well as a selection of national and local sources that provide a wide range of data, ranging from historical information contained in time series (e.g. the number of vehicles, transport activity, fuel use and CO_2 emissions) to more specific and analytical information (e.g. on the elasticity of vehicle travel with respect to fuel price changes) that results from research activities.

The review of this information is presented following the classification suggested in the previous section and already adopted for the illustration of the historical data characterising CO_2 emissions in inland transport.

Fuel usage, fuel characteristics and CO_2 emissions

Fuel combustion and associated CO_2 emissions

Fuel combustion

The IEA publishes on a regular basis, data concerning the annual consumption of transport fuels, classified by product and flow, including different transport modes (for inland transport, the modes comprise road, rail, inland navigation and pipelines) and other end-use and energy transformation activities (IEA, 2011c). The data are provided for a large number of countries, including the OECD members, as well as many others. Aggregates based on the same detailed data are sometimes included in other OECD publications and databases (e.g. OECD, 2011a). More aggregated energy statistics are also published by the IEA on a monthly and quarterly basis.

Table 1. Transport fuels reported in the IEA statistics

Coal and peat	Anthracite Coking coal Other bituminous coal Sub-bituminous coal Lignite Coke oven coke BKB/peat briquettes
Natural gas	
Crude oil	
Oil products	Liquefied petroleum gases Motor gasoline Aviation gasoline Gasoline type jet fuel Kerosene type jet fuel Other kerosene Gas/diesel oil Naphtha White spirit & SBP Lubricants Bitumen Non-specified oil products
Biofuels and waste	Primary solid biofuels Biogases Biogasoline Biodiesels
Electricity	
Heat	

The IEA data on annual fuel supply and consumption are collected through 5 questionnaires covering different energy carriers (IEA, 2012a). Such questionnaires are developed and collected jointly by the IEA, Eurostat and the UNECE. Their methodology is periodically discussed and updated every five to six years to increase the comprehensiveness of the questionnaires, to improve data quality, as well as for collection and reporting purposes. UNECE is particularly important for Eastern Europe and Russian figures, since Russia and some Eastern European countries are not members of the European Union, the IEA or the OECD.

According to the definitions established in the IEA publications (e.g. IEA, 2011c), the fuels relevant for transport (including domestic aviation, domestic navigation, international aviation bunkers, international marine bunkers, pipeline transport, rail, road and non-specified transport) in accordance with recent data from the IEA dataset, are listed in Table 1, while Table 2 gives an overview of the share of each fuel in the overall consumption under each transport flow.

Table 2. Overview of the consumption by main fuel in transport sub-sectors

Domestic aviation	Mainly kerosene type jet fuel. Small share of aviation gasoline, gasoline type jet fuel, fuel oil, motor gasoline and gas/diesel oil.
Domestic navigation	Mainly gas/diesel oil. Small share of fuel oil and motor gasoline. Sub-bituminous coal, other kerosene, lubricants, biodiesels, liquefied petroleum gas, coking coal, coke oven coke and non-specified oil products represent a tiny share.
International aviation bunkers	Mainly kerosene type jet fuel. Aviation gasoline, other kerosene and gas/diesel oil represent a tiny share.
International marine bunkers	Mainly fuel oil and gas/diesel oil. Lubricants, non-specified oil products and motor gasoline represent a tiny share.
Pipeline transport	Mainly natural gas. Small share of electricity. Gas/diesel oil, crude oil, liquefied petroleum gas and motor gasoline represent a tiny share.
Rail	Mainly gas/diesel oil. Small share of other bituminous coal and fuel oil. Lignite, other kerosene, biodiesels, primary solid biofuels, BKB/peat briquettes, coke oven coke, coking coal, liquefied petroleum gas, anthracite and white spirit & SBP represent a tiny share.
Road	Mainly motor gasoline and gas/diesel oil. Small share of biogasoline, liquefied petroleum gas, natural gas, biodiesels and other liquid biofuels. Fuel oil, biogases, other kerosene, white spirit & SBP, electricity, naphtha and primary solid biofuels represent a tiny share.
Non-specified	Mainly electricity and gas/diesel oil. Small share of natural gas, liquefied petroleum gas, fuel oil, kerosene type jet fuel, heat, motor gasoline and other bituminous coal. Other kerosene, bitumen, coke oven coke, non-specified oil products, biogases and coking coal represent a tiny share.

Statistics on the annual fuel consumption by fuel and by end-use (including transport) are also published by a number of international organisations that focus primarily on activities of global macro-regions or on selected member countries, even if the level of detail they provide is not always consistent.

This is the case of the following organisations:

- APEC (Asia Pacific Economic Cooperation) (APEC, 2012);
- Eurostat (Eurostat, 2012a);
- OAPEC (Organization of Arab Petroleum Exporting Countries) (OAPEC, 2010);
- OLADE (Organización Latinoamericana de Energía, Latin American Energy Organization) (OLADE, 2012);
- OPEC (Organization of the Petroleum Exporting Countries) (OPEC, 2011a).

These data are used by the IEA, amongst others, as a basis for its statistics on non-OECD countries. Some of the IEA data are also reported in the IRF (International Road Federation) publication on World Road Statistics (IRF, 2011), as well as in the World Bank's World Development Indicators database (World Bank, 2011a).

The Energy Statistics Database of the UNSD (United Nations Statistics Division) also contains annual energy statistics (including consumption of energy carriers in road, rail, inland and coastal waterways and other modes) for more than 215 countries/territories (UNSD, 2012a). The UNSD Annual Questionnaire on Energy Statistics is the primary source of information for the database (UNSD, 2012b).

The United Nations Framework Convention on Climate Change (UNFCCC) also gathers a wealth of statistics and other information on energy use in transportation (as well as other date). This stems from the fact that signatory Parties of the UNFCCC (currently 195 countries) are obligated to submit national communications containing information on emissions and the removal of GHGs to the UNFCCC Secretariat.

Parties that have also ratified the Kyoto Protocol (Annex I) must include supplementary information in their national communications. In particular, they need to compile and submit annual inventories on emissions and the removal of GHGs to demonstrate compliance with the Protocol's commitments. This comprises a National Inventory Report, with explanation of the efforts undertaken, and Common Reporting Format (CRF) tables (UNFCCC, 2012a). Table 1.A(a) of the CRF contains sectoral background data for energy related to fuel combustion activities. This includes detailed information on the amount of energy consumed on an annual basis by fuel and by transportation sub-sector (civil aviation, road, rail, navigation and other transportation) in each Annex I country. The national communications submitted by Annex I Parties (including the CRF tables) and non Annex I Parties are available on the UNFCCC web site (UNFCCC, 2011b and 2012b).

The assessment of fuel demand of countries around the world is also carried out by some national administrations. The US EIA (United States Energy Information Administration) assembles and disseminates information through its website on energy consumption by country and by fuel type collected from a wide number of primary sources (such as national statistical offices) (US EIA, 2011a).

Some consulting firms also provide information on energy consumption statistics. One example is Enerdata, which publishes data with a level of detail that is very similar to the one offered by the statistics previously noted (Enerdata, 2010).

National statistical offices, ministries, tax administrations, local authorities and other institutional sources (such as specific agencies dealing with energy-related issues) are some of the providers of primary data on energy use by fuel. This is especially true in countries where the fiscal treatment of fuels leads to large revenues for governments.

Some relevant examples of publications and statistical databases reporting the energy used in transportation for an individual country include:

- in Canada, the report on transportation in Canada (Transport Canada, 2011), as well as the statistics of fuel use by different vehicle types included in the transport data published by Statistics Canada (Statistics Canada, 2012a);
- in the USA, the annual Energy Review of the US EIA (US EIA, 2011b), also including estimates on other end-use and energy transformation sectors, as well as tables on fuel-use included in the statistics of the Bureau of Transportation Statistics of the United States of America (US BTS) (US BTS, 2012); and
- in Brazil, the statistical yearbook of the ANP (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, National Agency of Oil, Natural Gas and Biofuels) (ANP, 2012).

Other sources of primary data (with a main focus given to the supply side, by product) are the fuel producers, such as oil companies (including refiners) or biofuel producers. For large corporations quoted on the stock market and dealing with the production and refinement of crude oil, fuel transport and fuel distribution, information is typically provided in Annual Reports or Sustainability Reports (e.g. Shell, 2010). In some cases, companies issue specific statistical publications on fuel production and consumption, as well as other related information (e.g. BP, 2011 and ENI, 2011). When fuel production is not concentrated in large scale facilities (as in the case of biofuels), the dissemination of statistics on fuel production may take place through specific bulletins issued by industry associations (e.g. UNICA, 2012, for Brazilian ethanol).

Specific research efforts may also attempt to provide detailed estimates of the energy needed by different end-uses (including transport), drawing upon official sources, specific literature, availability of technology and additional materials. One important example, focusing specifically on China, is provided by the China Energy Databook of the LBNL (Lawrence Berkeley National Laboratory) of the United States (LBNL, 2011). Another one, from the same research laboratory, looked specifically at residential and transport energy use in India (LBNL, 2009).

<u>CO_2 emissions from fuel combustion</u>

The IEA publishes annually data concerning CO_2 emissions from fuel combustion with the same classification, which is used for its energy data (IEA, 2011a). The same data are used for the analysis of future CO_2 emission trends published annually in the IEA World Energy Outlook (IEA, 2011b).

The transport-related statistics extracted from the IEA dataset have also been used and disseminated in 2010 by the ITF (International Transport Forum) (ITF, 2010). This excludes emissions associated with fuel production, vehicle manufacturing and the construction of the transport network.

Table 1.A(a) of the UNFCCC Common Reporting Format (CRF) (UNFCCC, 2011b) contains detailed information on transport-related CO_2 emissions due to fuel combustion, as well as other GHG emissions. This dataset includes detailed annual data that are classified by fuel and by transportation sub-sector (civil aviation, road, rail, navigation and other transportation). It covers Annex I Parties to the Kyoto Protocol. The national communications submitted by non-Annex I Parties to the Kyoto Protocol, available on the UNFCCC web site (UNFCCC, 2012b), also contain information on CO_2 and other GHG emissions in transport, but this information is not submitted on a regular basis, or with a consistent format.

In the United States, the Carbon Dioxide Information Analysis Center (CDIAC) is the primary climate-change data and information analysis center of the Department of Energy. It publishes data on the emissions of CO_2 from fossil-fuel consumption and land-use changes. For fossil fuels, it estimates emissions for all countries distinguishing between gaseous fuels, liquid fuels and solid fuels, without giving specific information on the share of transport-related emissions (CDIAC, 2011). On the other hand, this database also includes estimates of emissions derived from the production of cement. These data are also used in the World Bank's World Development Indicators database (World Bank, 2011a).

The Climate Analysis Indicators Tool (CAIT), developed by the World Resources Institute (WRI), provides a database of GHG emissions based on information published by other sources. For CO_2 emissions, the key data sources are the CDIAC and the IEA. Transport data are shown as a single aggregate.

Aggregated data on CO_2 emissions from oil and oil products, by country, are also available from the US EIA (US EIA, 2011a). The US EIA also publishes information on annual CO_2 and other GHG emissions in the United States (US EIA, 2011c).

In Europe, the European Environment Agency (EEA) is in charge of the publication of CO_2 emissions estimates, as well as their submission to the UNFCCC (EEA, 2011a). These data correspond to those available from the UNFCCC and are submitted according to the UNFCCC CRF. For transport as an end-use, they distinguish between emissions from domestic civil aviation, road transportation, railways, domestic navigation, other transportation, international marine bunkers and international aviation (further distinction on a product basis for transportation fuels is only available in the CRF submitted to the UNFCCC).

As in the case of fuel use, some consulting firms also provide information for CO_2 emissions from fuel combustion. In the case of Enerdata, the information provided (by country, fuel and sector) has a level of detail that is very similar to the one offered by the IEA statistics, also for end-use transport (Enerdata, 2010).

As in the case of energy consumption, national statistical offices, ministries, local authorities and other institutional sources also provide estimates of CO_2 emissions. When these estimates are not explicitly available, a detailed methodology to estimate emissions from energy data is provided by the IPCC (IPCC, 2006).

Finally, a number of data is released by private and public companies into their annual reports, in their environmental reports or in documents dealing with corporate social responsibility, since they may also address environmental issues. The data included in these sources, however, depend on the selection made by individual companies. In addition, some of them may not be released systematically, but only on an ad hoc basis. Finally, they are not necessarily calculated following methodologies that are consistent over time and across companies. As a result, they require time to be assembled in a way that is comparable to the information sought in this section. On the other hand, the content of some of these reports may turn out to be a very useful source of information for life-cycle assessments.

Fuel characteristics

Fuel characteristics with respect to CO_2 emissions, energy contents and other fuel properties are available from a number of different sources.

Default information on the tailpipe CO_2 emission factors per unit of energy of fossil fuels is specified in the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). Emission factors from these guidelines are also adopted by the IEA for the estimation of CO_2 emissions from fuel combustion (IEA, 2011a), in combination with a set of data on net calorific values for different fuels.

For Annex I countries that signed the Kyoto Protocol, tailpipe CO_2 emission factors (as well as emission factors for other GHGs) for transport fuels are also included in Table 1.A(a) of the CRFs (UNFCCC, 2011b).

Fuel properties for liquid and gaseous fuels used for transportation across the world depend on the legislation enforced in each country.

Conservation of Clean Air and Water in Europe (CONCAWE), defined as a non-profit making, scientific association whose member representing practically 100% of the total crude oil refining capacity within the European Union, published three comprehensive reports on the worldwide legislation and regulations governing motor vehicle emissions, fuel specifications and fuel consumption. The first report details existing and proposed legislation (as of 2006) on emissions limits and emissions testing (CONCAWE, 2006a), the second summarises the changes that took place between 1999 and 2005 (CONCAWE, 2006b) and the third targets the changes that occurred between 1970 and 1999 (CONCAWE, 1999).

Another initiative promoting greater understanding of the fuel quality characteristics and their relationship with the needs of motor vehicle technologies (also designed to harmonize fuel quality word-wide, in accordance with the need for innovative vehicle emission control technologies) is the World-Wide Fuel Charter. The Charter was first established in 1998 by automobile and engine manufacturers from around the world. It matches fuel specifications to the needs and capabilities of engine and vehicle technologies designed for various markets around the world in a periodically updated publication (ACEA et al., 2006).

In 2007, the United Nations World Forum for Harmonization of Vehicle Regulations (WP.29) also considered the link between fuel quality and pollutants emissions from motor vehicles (UNECE, 2007a) and recognized that further reduction of emissions required that cleaner fuel be available to consumers. In 2011, WP.29 also adopted a set of recommendations for minimum market fuel quality, which were annexed to the Consolidated Resolution on the Construction of Vehicles (UNECE, 2011c).

Some consultancies, like for instance the International Fuel Quality Center, also provide, on a regular basis and for a significant fee, information on worldwide automotive fuel specifications.

Life cycle analyses

In addition to fuel specifications and tailpipe emission factors, several studies focus on the life-cycle energy requirements and emissions that are associated with fuel production, vehicle manufacturing and the construction of the transport network (sometimes including its maintenance and operation)[4].

Fuel production

For fuels, the estimation of energy requirements, CO_2 and other GHG emissions on a life-cycle basis is typically performed based on (Delucchi, 2010):

a. the amount and type of fossil fuels used in the fuel production process;

b. the amount of nitrogen fertilizers applied (especially relevant for N_2O emissions);

c. the effects resulting from the co-products of the fuel production process (e.g., animal feed for corn ethanol); and

d. carbon emissions from land-use change (an important emerging issue).

In transport, such studies frequently refer to well-to-wheel emissions, also distinguishing between well-to-tank for upstream emissions, and tank-to-wheel for emissions associated with fuel use in vehicles (e.g. nearly exclusively due to the combustion processes).

These analyses are particularly important for transport fuels and energy carriers that do not lead to tailpipe emissions, like hydrogen and electricity, since their contribution to GHG emissions depends on the way they are produced. These analyses are also important for biofuels, since only a fraction of their tailpipe emissions are actually re-absorbed with plant growth.

Looking exclusively at an energy balance (and therefore neglecting the effects of fertilizers, co-products and land-use change), this approach is equivalent to the allocation to the transport sector of:

- part of the emissions taking place in the energy transformation sector (e.g. in processes converting primary energy sources into fuels and energy carriers);

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[4] The life cycle approach typically looks beyond energy, CO_2 and other GHG emissions. However, the discussion here will only focus on energy requirements and CO_2 emissions because this is the primary focus of the present analysis.

- part of the emissions originating in the agricultural and forestry sectors, if the biomass is used as a feedstock for the transport fuel or energy carrier;
- part of the emissions originating in the mining sector, if the primary materials needed for the production of fuels require mining; and
- part of the emissions initially allocated to the transport sector, since fuels and other energy carriers need to be moved from the production sites to the end-use location.

Other reallocations may also be possible, depending on the materials and energy required for specific fuel production pathways. One example (albeit small, in the case of fuels) is energy use and emissions from coal transformation, since coal is required for the production of materials used in most fuel production plants – like iron.

A selection of some important analyses carried out in this field (targeting the European Union, the United States and Japan, respectively) includes:

- the joint study developed by the Joint Research Centre (JRC) of the European Commission, European Council for Automotive R&D (EUCAR) and CONCAWE (JEC, 2011);
- a North American study on energy use, greenhouse gas emissions, and pollutant emissions (Brinkman et al., 2005).

A wealth of scientific publications and reports continue to contribute to this research subject, focusing often on specific fuel pathways (e.g. IHS CERA, 2010 and Mui et al., 2010 for tar sands) or on particular geographical locations (e.g. Brazil, for sugar cane ethanol). Research can result in divergent points of view (as in the case of the publications quoted earlier for tar sands, for instance). Broadly speaking, however, the analysis of most fuels progressed to a point allowing for overall assessments. This is the case, for instance, in the of Delucchi (2010) for biofuels.

The results published to date vary mainly according to the different technologies. In addition, they also depend on assumptions and constraints in the application methodologies, suffering in some cases from the limited availability of data. A relative consensus has been reached on process emissions, even though some important discrepancies still exist. Most of the uncertainties regarding the fuel production process (especially for biofuels) are related to N_2O emissions. On the other hand, strong discrepancies remain on the effects due to land-use change because, even though life cycle assessments can detail the effects of direct land conversion to evaluate the performance of fuels based on biomass, they have limited capability to assess GHG emissions and other environmental impacts resulting from indirect land use change (UNEP, 2010a).

A recent IEA report (IEA, 2009a) provides some estimates of current global emissions expressed on a well-to wheel basis, together with information on possible future scenarios. Similar estimations, further outlined for a selected list of countries and regions, were published one year later by the IEA as part of a wider report (IEA, 2010a).

Vehicle manufacturing, maintenance and disposal

In order to perform life cycle analyses for the estimation of energy requirements and emissions characterizing the vehicle manufacturing, maintenance and disposal phases, it is necessary to consider the energy requirements and emissions associated with the extraction of raw material required for these purposes, as well as the energy and emissions caused by the transformation of the raw materials into intermediate products and components in industrial processes. The energy requirements for the assembly and transport of these products and components, as well as their disposal and waste treatment once the vehicle is scrapped must also be taken into consideration.

This is normally performed relying on life cycle inventories, i.e. databases containing a wide range of information regarding energy requirements and CO_2 emissions (amongst other information) on process characteristics and materials[5].

In addition, they need to take into account parameters affecting the recycling rates of materials. Such parameters typically depend on existing legal obligations regulating the environmentally friendly treatment of end-of-life vehicles (ELVs) (for instance EC, 2009a and EC, 2011b in the European Union, and Japan, 2007 in Japan) and the recycling infrastructure available in a particular region. Their estimation may also be further complicated by the practice of exporting used vehicles (very prevalent in some parts of the world).

A recent comprehensive report of the JRC focused on the estimation and comparison of the environmental impacts of passenger cars through a life-cycle perspective (Nemry et al., 2008). The study was implemented by applying the process chain approach to quantify the more relevant environmental impact categories for passenger cars from the production to the disposal phase. It included the analysis of energy requirements and CO_2 emissions, assessing their impact on issues like climate change. Two generic car models – one petrol car and one diesel car – were used as benchmarks for the analysis.

Another study addressing energy needs and GHG emissions is currently being developed for the European Commission. To date, this effort led to the production of an draft report containing a review of existing data sources and analyses targeting life cycle emissions from transport vehicles (from manufacture to disposal) in different modes (road, rail, aviation and shipping) (Hill, Branningan et al., 2011).

A number of industry associations also commissioned work that targeted the life-cycle analysis of transport vehicles. In some cases, this resulted in the provision of life cycle analysis tools. One example is the World Auto Steel (WAS), with the GHG Material Comparison Model (WAS, 2010), which also contains emissions factor information for some of the other key materials.

Some vehicle manufacturers also provide detailed life cycle analyses of their vehicles (e.g. Volkswagen, 2010).

[5] An overview of the Life Cycle Inventory (LCI) databases available across the World was published by the US EPA (United States Environmental Protection Agency) in 2006 (US EPA; 2006). One of the most renowned ones is the Ecoinvent database, whose methodology has been illustrated by Frischknecht et al. (2007).

In addition, a wealth of work on life cycle analyses applied to vehicles and their components (e.g. fuel cells, or batteries) is carried out in research laboratories and academic institutions. Results from this work are typically published in scientific journals.

Overall, even if the actual emissions depend on the vehicle segment and lifetime travel, life cycle analyses suggest that, in the case of passenger cars, manufacturing accounts for 15-20% of the passenger car life cycle CO_2 emissions, while disposal accounts for roughly 1%. The remaining fraction is associated with the vehicle use (Ricardo, 2011). The shares that can be attributed to vehicles are lower in shipping (about 2%) and air (about 3%) and relatively variable in the rail sector, since the emissions due to vehicle use depend on the power generation mix for electrified lines (Hill, Branningan et al., 2011).

<u>Network construction</u>

The life cycle approach can also be followed for evaluating energy requirements, CO_2 and other GHG emissions resulting from construction, maintenance and operation of transport networks.

A draft report containing a review of existing data sources and analyses targeting life cycle emissions from vehicle manufacturing, maintenance and disposal previously mentioned is also looking at a similar assessment for transport infrastructure, covering different modes (road, rail, aviation and shipping) (Hill, Brannigan et al., 2011). The same study provides an extensive literature review on the topic.

As in the case of the life cycle assessment of vehicles, some industry associations have also developed tools that to evaluate GHG emissions from the construction of transport infrastructures. The primary example in this respect is provided by the Changer greenhouse gas calculator, focusing on roads (including pavement, drainage systems, road signs, line painting and construction machines) and developed by the International Road Federation (IRF) (IRF, 2010). A report describing a methodology for an ecological assessment of transport infrastructure of high-speed railway has also been issues by the Union Internationale des Chemins de fer, International Railway Union (UIC) (UIC, 2009).

Similar efforts can be found in international organizations: a toolkit for the evaluation of GHG emissions of a road construction or rehabilitation project (the ROADEO Calculator) has been developed by the World Bank (World Bank, 2010), while the Asian Development Bank published recently a methodological report, focusing on India, on the estimation of GHG emissions from road construction (ADB, 2010).

Hill, Brannigan et al. (2011) suggest that the GHG emissions related to road construction, maintenance, operation (including, for instance, road lighting) and end-of-life may range from just a few per cent to over 10% of total life cycle GHG emissions for road modes. A 15% estimate (essentially due to the operation of ports, rather than their construction) has been published for transoceanic shipping (Walnum, 2011, cited by Hill, Brannigan et al., 2011), while the percentage of emissions due infrastructure is higher in the case of rail (the exact value is heavily affected by the power generation mix). In Sweden, the construction and operation of railway and metro stations are estimated to account for 28% and 36%, respectively, of the total energy needed (on a life cycle basis) by the rail sector

(Jonsson, 2005, cited by Hill, Brannigan et al., 2011). In addition, significant differences characterize (as in the case of roads) open networks from tunnels and bridges.

Transport activity and vehicle characteristics

International databases

At the international level, statistics on several transport-related parameters are collected by Eurostat, the ITF and the UNECE. The data are collected mainly through four questionnaires covering all inland transport modes: road, rail, inland navigation and pipeline transport (UNECE, 2009a to UNECE, 2009d). The statistical data required in the questionnaires include:

- the extension of the transport network infrastructure (for all inland transport modes) and its capacity (for pipelines only);
- the number of registered transport vehicles (except for pipelines) and the number of newly registered vehicles (for roads only);
- the total transport activity: vehicle km (except for pipelines), passengers and passenger-km for passenger transport, tonnes and tonne-km for freight transport;
- employment statistics and information on investment and maintenance expenditures for transport vehicles (for rail, road freight and freight transport on inland waterways and pipelines); and
- investments and maintenance expenditures for transport infrastructure (all inland transport modes).

The development of such questionnaires is managed jointly by Eurostat, the ITF and the UNECE in the Intersecretariat Working Group on Transport Statistics, which is mandated to contribute to the development of a coordinated statistical system for transport, so users can have access to high quality data (UNECE, 2010a). All the definitions and terms used for these statistics are explained in the *Glossary for transport statistics*, a publication issued jointly by Eurostat, the ITF and the UNECE, which is periodically updated and released on-line (UNECE, 2009e).

In addition, the UNECE also collects data for road traffic injury accidents through another specific questionnaire. Recently, the UNECE also attempted to gather statistics on passenger transport by buses and coaches (UNECE, 2011a) through a pilot questionnaire specifically developed for this purpose (UNECE, 2009f).

The information included in these international questionnaires is provided by national administrations (e.g. transport ministries, national statistical offices or official transport research institutes) and correspond to official data. For EU Member States, reporting their data to Eurostat and the compilation of several transport-related statistics (including road freight, rail and freight on inland waterways, etc.) is mandatory[6]. This results in better coverage of transport statistics in Europe comparison with other United Nations regions.

[6] A compendium of the legal acts on transport statistics is available on the web site of the European commission (EC, 2012a).

The availability of data outside the EU ranges from nearly complete datasets (as in the case of other OECD countries that are members of the ITF, such as Canada and Japan) to very poor ones. An overview of recent data availability was carried out by the UNECE in 2009 (UNECE, 2009g). The same organisation also issued a road map on the collection and dissemination of transport statistics in 2010, highlighting the need to improve the status of these processes (UNECE, 2010b). In 2011, the UNECE also issued an encouraging note on the progress following the road map initiative (UNECE, 2011b), but further improvements are needed.

Another important source of transport-related statistics at the international level is the North American transport Statistics Database, hosted by the Mexican Secretaría de Comunicaciones y Transporte (SCT). It assembles data collected by statistical agencies from Canada, United States and Mexico (NATS, 2012). This dataset contains selected indicators on issues related to transportation and the economy, safety, energy and the environment, domestic and cross-border goods transport and passenger travel, transportation infrastructure and transportation vehicles.

The Interstate Statistical Committee of the Commonwealth of Independent States (CIS) is also disseminating statistics (including information on transport activity) through publications and its website (CISSTAT, 2012).

Primary sources

Notwithstanding the importance of data collection at the international level, only a limited part of the information available on transport activity is actually reported on international statistical databases. More information exists at the national and local levels, although the actual data availability varies significantly across countries and regions.

The primary data on transport activity are derived from the collection of information through travel-related surveys, vehicle-related databases, network-related instruments to gather data and, in recent years, the wide proliferation of wireless means of transmitting data, as well as the increased availability and affordability of data processing tools.

Travel-related assessments have a fundamental importance to explain parameters related to vehicle usage and travel habits. They include origin-destination surveys, investigations on commodity flows and logistics, surveys of individual vehicle use and odometer readings.

Origin-destination surveys are suitable to explain:

- drivers of trip generation (such as employment, schooling for children, shopping, etc.);
- number of trips per day;
- modal choice;
- trip distance and time, subject to the modal choice and the actual route taken; and
- distance and average network speed, which can provide information on travel times.

Investigations on commodity flows and logistics have a similar role for freight. They provide data on:

- drivers of trip generation (e.g. purchase of goods, demand of construction materials, disposal of waste);
- haulage length in km and in time;
- modal choice;
- load per laden trip and empty runnings (capacity utilization); and
- characteristics of the load (type of goods, value of goods transported, etc.).

Surveys of individual vehicle use provide statistics on:

- distances covered by vehicles in different time periods (e.g. on weekdays or weekends, in winter or summer, etc.);
- number of trips per day (with the same distribution over time);
- daily travel time (also with the same distribution);
- amount of fuel used, as well as the average vehicle fuel consumption;
- unit cost of the fuel, as well as its average cost per km;
- information on other costs, such tolls and parking; and
- information on traffic conditions (average speed and congestion).

Odometer readings give information on:

- actual distances covered by vehicles; and
- relationship between vehicle travel and vehicle age, class, and fuel type.

Data from fleet and public transport operators (taxis, buses, trucks, metros, trains) also provide statistics on the distances travelled by vehicles and vehicle loads.

Vehicle-related databases are necessary to understand the scale of these habits and usage patterns. They include data sets targeting:

- vehicle registrations, typically available from public authorities;
- information on the production and sales of new vehicles, typically released by vehicle manufacturers and component suppliers, or their associations;
- statistics reporting information on vehicle trade, complied by some international organisations; and
- numerical information on vehicles and their main characteristics (for instance fuel consumption), put together based on legal requirements.

Network-related instruments include visual observations, traffic counts and speed measurements. These instruments provide information on:

- speed distribution on the network over time, congestion (speed measurements);
- vehicle flows over time (vehicle counts);

- vehicle characteristics within a mode (typically road), such as the share of trucks or cars, eventually detailed in sub-categories (visual observation, vehicle counts); and
- vehicle utilization (based on vehicle flows, network extension and speed).

They also relate to traditional traffic engineering and transport planning.

Some of the tools typically grouped under the Intelligent Transport Systems (ITS) label can gather and use information suitable for real-time data and long-term analyses on transport activity, with special considerations for congestion. Some examples of such tools are:

- Global Positioning Systems (GPS) for vehicle navigation, suitable for any land transport mode and particularly relevant for road vehicles, but also used (with different arrangements and characteristics) for other transport modes; and
- personal devices such as smartphones, which have recently proliferated in use.

The widespread diffusion of wireless means of transmitting data, combined with the development of specific software for the collection and interpretation of data, have the potential to significantly contribute to the improvement of the knowledge of several transport-related parameters. One interesting example in this context is given by an application capable of identifying the transportation mode selected by users of smartphones based on the interpretation of accelerometer traces, while GPS data together with online map queries establish their actual travel pattern (Manzoni et al., 2010).

A number of commercial initiatives have started to emerge in this area: wireless electronic devices are already being used by telecommunication operators and software providers to gather information on network conditions, ultimately contributing to the provision of services and information to other users. GPS devices, for instance, can gather information on the vehicle speed in different network areas. These data can be processed and converted into real time updates on traffic conditions and transmitted to the users of similar electronic tools (TomTom, 2011).

The opportunities offered by ITS-related devices are not limited to OECD countries, since the diffusion of these devices (especially smartphones) means they are quickly spreading beyond their borders.

Collecting traffic data from wireless devices such GPS and smartphones also seems to be a very cost-effective alternative to conventional surveying methods (Leduc, 2008). Tools based on information and telecommunication technologies have the capacity to greatly reduce the cost of monitoring traffic, transport, and fuel use, especially in comparison with the early efforts that started in OECD countries in the 1960s (ADB, 2009a). This is further corroborated by the fact that handling large data sets is also much cheaper today, thanks to the diffusion of calculators.

An important reference-base providing information on initiatives aiming to the enhance the quality and usefulness of transportation surveys done at the local, state, and national levels (including a subcommittee working on new technologies) is the Travel Survey Methods Committee of the Transportation Research Board (TRB) of the United States. Eurostat has also published important reference reports on freight transport by road (Eurostat, 2011a and Eurostat, 2011b).

Passenger and freight transport activity

Looking at passenger and freight transport activity, the North American Transport Statistics Database (NATS, 2012) includes data on:

- passenger-km by mode (domestic, within North America, and international); and
- freight volumes (expressed in tonne) and transport work (expressed in tonne-km) by mode (domestic, within North America, and international).

In Canada, transport-related statistics (including activity data) are also published in an annual report, Transportation in Canada (Transport Canada, 2011). Transport-related figures are also part of the Comprehensive Energy Use Database (NR Canada, 2012). For rail (passenger and freight), transport activity data were published as a result of the rail-related activities of the ecoFREIGHT Program (RAC, 2010).

In Mexico, the Instituto Mexicano del Transporte/Mexican Institute of Transport (IMT) under the Secretaría de Comunicaciones y Transporte/Ministry of Transport and Communications (SCT) publishes a comprehensive manual on Mexican transport statistics. It includes information on the transport activity for all transport modes (IMT, 2009). Specific publications also target heavy trucks and buses (SCT Mexico, 2011a), as well as the federal rail transport (SCT Mexico, 2011b).

The Bureau of Transportation Statistics of the United States of America (US BTS) continuously updates a database of its national transportation statistics (US BTS, 2012). Such databases include detailed data at the federal level on passenger travel and goods movement on all transport modes, including statistics on transport activity (t km) and volumes (t) by commodity transported.

Statistics on passenger and freight transport activity are also part of the figures that are systematically collected by Eurostat, the ITF and the UNECE through their joint questionnaires.

Even if the variables required in the questionnaires are rather detailed (including travel expressed in tonne-km, for freight modes, as well as travel expressed in vehicle km, and as freight transport volumes expressed in tonnes), disaggregated data are only published by Eurostat for EU Member States.

The ITF (ITF, 2012a) only publishes relatively aggregated data on passenger and freight transport:

- for passenger transport, it provides figures on passenger-km on rail vehicles, private cars, as well as buses and coaches; and
- for freight transport, it contains data, expressed in tonne-km, on rail, road, inland waterways and oil pipelines.

In addition, the ITF also publishes data on the volumes of intermodal transport (containers), both for rail vehicles and sea vessels.

The ITF databases cover most OECD countries (including, in addition to the European members, Canada, Mexico and Japan), several Eastern European countries that are not in the OECD, as well as some of the countries of the former Soviet Union (including the Russian Federation).

The UNECE databases (UNECE, 2012a) also provide information on passenger and freight transport, giving more details than the ITF and evaluating certain items more closely:

- for passenger transport, the UNECE databases include information on passenger-km by vehicle type (motorcycles, passenger cars, buses and coaches, and rail vehicles). For rail transport, it also includes the number of railway passengers and differentiates between national and international transport.
- for freight transport, the databases include figures on road, rail and inland waterway freight transport by type. For road, it focuses on vehicles registered in the reporting country and distinguishes amongst national transport, dispatched and received international transport, cross-trade transport (loading and unloading in two different countries outside the declaring country) and cabotage (loading and unloading in the same country, but outside the declaring country). For rail and inland waterways, it provides a similar distinction amongst national transport, international transport (dispatched and received), and transit, including all vehicles and vessels, irrespective of the country of registration.

In addition, the UNECE database also provides data on road motor vehicle movements within national territories, expressed in vehicle km. These data are differentiated by vehicle type, distinguishing amongst motorcycles, passenger cars, buses and coaches, lorries and road tractors. Most of the data available in this dataset, however, are for OECD countries.

The country coverage provided by the UNECE databases is very similar to the ITF country coverage.

The Eurostat database (Eurostat, 2012a) focuses on all EU Member States and includes a large amount of detailed information. It covers:

- road traffic (passenger and freight), expressed in vehicle km, road passenger transport (expressed in passenger-km);
- road freight transport activity (expressed in tonne-km), road freight transport volumes (in tonnes), and journeys, including data concerning different commodities transported (also reported by distance class) and the service provider (on hire or own account), as well as information classified by the nature of the transport (national, cross-trade, international, or cabotage), eventually including details on the country of origin and destination of the carriage;
- passenger rail transport in terms of vehicles (trains, tractive vehicles and hauled vehicles), vehicle km (for the same categories), passengers, and passenger-km;
- freight rail transport in terms of vehicles (trains, tractive vehicles and hauled vehicles), vehicle km (for the same categories), volumes (tonnes) and activity (tonne-km), also including information by type of commodity transported and figures on intermodal transport and;

- annual data on transport occurring on inland waterways, with most of the figures expressed in tonnes and tonne-km, including data on transport activity (tonne-km) and volumes (t) by type of commodity transported (since 2007, data on the number of vessels and their vkm, as well as details on the flows of container transport are also available); and
- tables on the oil pipeline transport within the national territories of EU Member States by type of transport operations and products, in tones and tonne-km.

The full content is accessible for free on the Eurostat website.

For EU countries, the Odyssee database also includes information on transport activity for all modes (road, further distinguished by vehicles, rail, water and air) (Enerdata, 2012).

Transport activity data for the EU are also published annually in a specific pocketbook (EC, 2011a), eventually coupled with energy and environmental statistics. The figures included in this publication focus on EU countries and build on the information provided by Eurostat, but also on other sources. For transport activity, this publication reports passenger-km on tramways and metros (based on national statistics and a study of the International Union of Public Transport the European Commission) separately from other railway transport. Some aggregated data are also presented in this publication for the United States, Japan (except for tramways and metros, as well as oil pipelines), China (except for tramways and metros) and Russia, relying on statistics from the Japan Statistics Bureau, the US BTS, Rosstat, and the National Bureau of Statistics of China (NBSC).

These organizations are the most relevant institutions gathering information on transport statistics in each of these countries. Besides the information released by the US BTS (already mentioned earlier), the key publications and datasets provided by these institutions (all available for free) are listed below:

- the transport-related section of the Japan Statistical Yearbook (Japan Statistics Bureau, 2012);
- the transport-related section of the Statistical Yearbook of Russia (Rosstat, 2011); and
- the transport-related section of the China Statistical Yearbook (NBSC, 2010).

As in the case of energy-related information, other publications complement this information; leveraging data compiled from surveys, censuses, accounts and other statistical publications. In the United States, one important example is given by the Transportation Energy data Book (ORNL, 2011).

Similar work is undertaken in most OECD countries. Selected examples are listed below:

- in Australia, statistics are also available in the transport-related section of the Year Book Australia (ABS, 2010), which builds on the information collected through surveys, vehicle census, and industry associations. The Bureau of Infrastructure, Transport and Regional Economics (BITRE), also publishes transport statistics, including data on transport activity for inland transport modes (BITRE, 2011);

- in Canada, Statistics Canada (Statistics Canada, 2012a) and Transport Canada (Transport Canada, 2011) publish detailed statistics on vehicle travel, passenger and freight transport activity (in vehicle km, passenger-km and tonne-km, respectively);
- in Chile, the national statistical office (Instituto Nacional de Estadística) publishes annual information on the passenger and freight transport activity by rail. For road transport, the information collected on transport activity is only limited to vehicle counts in specific locations (INE Chile, 2011a); and
- in Israel, the Central Bureau of Statistics releases data on the number of road vehicles and the corresponding average annual travel, freight and passenger transport volumes (tonnes, passengers) and activity (tonne-km, passenger-km) by rail, passenger transport vehicles, their capacity and their average mileage (CBS, 2011).

Within the OECD, the level of detail available in different countries is not always the same. In some cases, transport activity data for some modes may not be available at all. Outside the OECD, regularly updated statistics on transport activity are available from national statistical offices and, in a few cases, by regulatory authorities. The level of detail is generally less accurate as compared to OECD countries:

- sometimes the statistics available on transport activity are limited to the number of passenger transported rather than the passenger-km;
- for freight, tonnes transported may be the only available information reported;
- for the transport activity of vehicles, the information collected may only concern some modes, and it may only be partial within these modes;
- little detail may be given beyond the main modal level (road, rail, water and air transport), eventually demonstrating a relative weakness of the aggregate estimation;
- the statistical availability may be better in specific urban areas and regions (like for instance the capital and the largest cities only): data at city levels may be available from research agencies, but they may be unrelated to the statistics released at the national level;
- statistics on commercial transport activity (rail, road freight, and public road passenger) have a higher likelihood of being available, since they can be collected through surveys targeting commercial companies (or published directly by the companies) rather than surveys of individual vehicle use and widespread vehicle counts; and
- specific assessments may be available for some urban areas, some countries or some groups of countries.

Some of the non-OECD countries where national statistical offices provide transport activity data (at least for some transport modes), include Algeria (excluding road) (ONS, 2009), Bolivia (volumes only) (INE Bolivia, 2010), Brazil (Ministerio do Transporte, 2011), China (NBSC, 2010), Indonesia (BPS, 2011), and the Russian Federation (Rosstat 2011).

Cooperative projects amongst statistical offices may also lead to the improved collection and dissemination of transport-related information. In the Mediterranean regions, the EuroMed and Medstat projects yielded a number of results, including:

- the publication of country overviews of the transport conditions of Mediterranean countries (including information on transport activity) (EuroMed, 2007);
- the setup of an on-line database on the Eurostat web site (Medstat) (Eurostat, 2012b); and
- the publication of ad-hoc statistical reports (Eurostat, 1999 and Eurostat, 2009).

African data are much harder to find than data for other world regions, and transport activity data are even harder to collect and publish than other transport-related parameters. Nevertheless, some information on transport activity are included in a dataset (ADBG, 2012) developed in the context of the Africa Infrastructure Country Diagnostic (AICD), a project designed to expand the world's knowledge of physical infrastructure in Africa. This includes information on daily traffic on different roads (vehicles/day), freight transport activity (tonne-km/year), passenger transport activity (passenger-km/year) and vehicle usage (vehicle km/year) on the road network (the latter also differentiated according to the road type).

As in the case of energy, some companies and industry associations may also publish information and statistics on transport activity. For passenger transport, most of the information collected and released by the private sector on activity concerns modes and vehicle categories performing public services, like buses, coaches, tramways, metros and railways. For rail transport (passenger and freight), this information is likely to be provided by rail operators in their annual report. Examples include DB (2010), Indian Railways (2011a and 2011b) and JSCo Russian Railways (2011).

Three important sources of information related to the private sector which provide country-level data for multiple sets of countries are the International Road Federation (IRF), the UIC and the Union Internationale des Transports Public/International Union of Public Transport (UITP):

- the IRF annually updates the World Road Statistics database, available for purchase (IRF, 2011). It includes annual data on transport volumes per vehicle category (passenger cars, buses, lorries and vans, motorcycles) and country, expressed in vehicle km, as well as data on transport activity (expressed in passenger-km and tonne-km) for inland surface freight transport modes (road, rail and waterways);
- the UIC publishes and annually updates a dataset, available for purchase, on statistical indicators, including information for its member companies on passenger traffic - including high speed - and freight traffic, as well as intermodal transport, amongst other variables (UIC, 2011). It contains data on passengers, passenger-km, tonnes, tonne-km and train km. For freight, it includes details on the revenue-earning wagonload volumes and traffic by commodity transported; and
- the UITP publishes ad-hoc reports, available for purchase, including data on transport activity on public transport modes and vehicles, with a specific focus on

urban areas. Its most relevant publications produced to-date, including information on transport activity in a wide range of cities, are the Millennium Cities Database for Sustainable Transport (UITP, 2001) and the Mobility in Cities Database (UITP, 2006). It also contributed data to the European pocketbook on transport figures (EC, 2011a).

The World Bank's World Development Indicators database (World Bank, 2011a) also includes figures on passengers carried and goods hauled on roads and railways, drawing on the IRF World Road Statistics database for road data and on a World Bank database based on UIC figures for rail. The World Bank's World Development Indicators figures are available for free on the web.

The Organization for Co-operation between Railways (OSJD) also collects data from its 25 members (of which 20 belong to the UNECE) (OSJD, 2011).

For inland waterways, the CCNR (Central Commission for the Navigation of the Rhine) carries out regular observation and analysis of the inland waterway transport sector for the European Commission. It publishes annually a report that contains information on European inland navigation vessels, including a thorough analysis of the evolution of freight transport activity on European inland waterways by product group (CCNR, 2012).

Specific assessments on transport characteristics may also focus on the local level. Such research may complement official statistics with information collected on an ad hoc basis (e.g. Schipper et al., 2008 or WBCSD, 2009). Finally, even if they are not necessarily released in detail to the public in national publications (and therefore not part of this review), regional data are a necessary asset for any analysis targeting the local level.

Transport vehicles

Statistics on transport vehicles are collected by official sources, such as national statistical offices, transport research institutes and other agencies, and (at least in part) reported to international organisations.

At the international level, they are included amongst the parameters systematically collected by Eurostat, the ITF and the UNECE through their questionnaires, previously mentioned.

In some cases (this is especially relevant for cars and other light duty road vehicles), statistics related to transport vehicles are also the focus of interest for a number of other institutions: vehicle manufacturers and their associations (especially for new road vehicles), research institutes analysing material flows across the economic system and their disposal in the environment, as well as research groups looking at the flow of second hand vehicles within a country (e.g. for the analysis of the second-hand car market) and across the globe.

Some governments and research groups also pay specific attention to transport vehicles in the context of waste-management, since their disposal can have significant impacts on the environment and differences in existing waste-related legislations may result in an incentive to trade second-hand vehicles across the globe (e.g. in order to bypass the burden associated with the end-of-life management obligations that exist in OECD countries). The interest in recycling vehicles may also be an important driver for the availability of some data on the vehicle scrappage rates over time.

New vehicle sales and new vehicle registrations

Road vehicles

Most of the information available on new vehicle sales and registration concern road vehicles:

- the ITF publishes data on the "first registration of brand new private cars" and "first registration of brand new goods vehicles" for its member countries (ITF, 2012b);
- the UNECE publishes information (for its member States) on new passenger car registrations by country, fuel used (gasoline, diesel, liquefied petroleum gases (LPG), natural gas and others), and engine size (only for gasoline and diesel vehicles); and
- the Eurostat database (Eurostat, 2012a) includes a large amount of detailed information on new road vehicle registrations. For road vehicles, it covers motorcycles, passenger cars, buses and coaches, lorries and road tractors (by motor energy - including gasoline, diesel, LPG, natural gas, electricity and others), as well as trailers and semi-trailers. The data on road passenger vehicles are also reported by engine size. Goods vehicles (lorries, trailers and semi-trailers) are distinguished by load capacity, and special purpose road vehicles are reported separately over the last several years[7].

The level of data available for the datasets just mentioned is definitely not homogeneous across all countries: data for EU members tend to be significantly more complete than those for other countries.

For EU countries, the Odyssee database also includes information on new road vehicle registrations for cars, two-wheelers, bus, light commercial vehicles, and trucks (Enerdata, 2012). This database builds on a collection of information compiled from a variety of sources. Some of the data are freely available, while others need to be purchased.

As in the case of energy-related information and statistics on transport activity, data on new road vehicle registrations are also released to the public by national statistical offices and ministries. They are often coupled with information on the stock of vehicles, namely in the case of road vehicles, such as two-wheelers, passenger cars, buses, lorries and road tractors. Similar to energy-related data (and unlike transport activity ones), they may also be available from tax administrations, since vehicle sales taxes and vehicle circulation taxes can be important sources of government revenues. One example of statistics on vehicle sales is the monthly release of tables on new motor vehicle sales (by province) of Statistics Canada (Statistics Canada, 2012).

Vehicle manufacturers also keep track of the vehicles they produce and those they sell. They may publish some of this information in their Annual Reports (e.g. PSA, 2009 and PSA, 2011), or even release them systematically on-line, together with other market-related data (e.g.

[7] Passenger cars are also reported by unloaded weight, buses and coaches by seat capacity, lorries by kind of transport (own account or hire or reward).

Toyota, 2012). The data released directly by manufacturers, however, tend to have a limited degree of detail, since they tend to be aggregated either across countries or for all the vehicles produced and/or sold.

Detailed statistics on road vehicle production and sales by country and by vehicle class are typically released by regional associations of manufacturers or equipment providers, as well as their global organisation.

The information on vehicle production and sales is typically classified according to agreements between relevant groups of manufacturers in a given region. It also changes from one global area to another. The international questionnaire distributed by Eurostat, the ITF and the UNECE are an important reference that define adopted classifications. Other classifications may have drawn on the criteria used in the United States, or from approaches that were adopted by prominent vehicle market analysts.

Organisation Internationale des Constructeurs d'Automobiles, International Organisation of Vehicle Manufacturers (OICA), publishes annual statistics on the road motor vehicle production by country, by manufacturer (also by make), and by vehicle type (passenger cars, light commercial vehicles, heavy trucks, buses and coaches) (OICA, 2012a). OICA does not release a corresponding database on new vehicle sales.

OICA groups a number of regional vehicle manufacturers and vehicle importers associations (trade associations). The full list of OICA members is available on the OICA website (OICA; 2012b).

Many regional associations of motor vehicle manufacturers and motor vehicle importers publish a number of statistical bulletins containing information that go well beyond the data released by OICA. Typically, they include statistics on vehicle sales, distinguishing between different vehicle categories. In some cases, sales are differentiated by vehicle class and fuel used. Sometimes, they include more information, such as estimates on the vehicle stock and other considerations on the status of the vehicle market, as well as a summary of new registrations of passenger cars and commercial vehicles in a wide rang of countries (this is the case, for instance, of JAMA, 2011). Table 3 provides a list of selected regional associations of motor vehicle manufacturers, as well as an indication of the statistical datasets they release. Examples of associations of vehicles importers (not listed in the table) include, amongst others, Danske Bilimportører, Danish Car Importers Association (DBI), and the Israel Vehicles Importers Association.

Similar data may also be released from the association of component producers. One important example of detailed statistics is provided by a publication that details information on the Brazilian autoparts industry performance, which also contains information on the country's road vehicle market (including sales) (Sindipeças and Abipeças, 2011).

And overview of new vehicles registrations (divided in passenger cars, light commercial vehicles, medium and heavy trucks), based on publicly available datasets (including references on the source of data that have been used), is assembled and distributed by the Economist Intelligence Unit (EIU, 2012).

Table 3. Selected associations of motor vehicle manufacturers publishing data on sales

Association acronym	Association long name	World region	Reference
ACEA	Association des Constructeurs Européens d'Automobiles - European Vehicle Manufacturers Association	European Union	ACEA, 2012
ACEM	Association des Constructeurs Européens de Motocycles - European Motorcycles Manufacturers Association	European Union	ACEM, 2012
ADEFA	Asociación de Fabricas de Automotores - Association of Automotive Factories	Argentina	ADEFA, 2012
ANFAVEA	Associação Nacional dos Fabricantes de Veículos Automotores - Association of Motor Vehicle Manufacturers	Brazil	ANFAVEA, 2011
AMIA	Asociación Mexicana de la Industria Automotriz - Mexican Assocation of Automotive Industry	Mexico	AMIA, 2012a and AMIA, 2012b
FCAI	Federal Chamber of Automotive Industries	Australia	FCAI, 2012a and FCAI, 2012b
GAIKINDO	Gabungan Industri Kendaraan Bermotor Indonesia - Association of Indonesian Automotive Industries	Indonesia	GAIKINDO, 2012
IVMA	Iran Vehicle Manufacturers Association	Iran	IVMA, 2012
JAMA	Japanese Automobile Manufacturers Association	Japan	JAMA, 2012 and JAMA,2011
KAMA	Korean Automobile Manufacturers Association	Korea	KAMA, 2012
NAAMSA	National Association of Automobile Manufacturers of South Africa	South Africa	RGT, 2012
OSD	Otomotiv Sanayii Derneği - Automotive Manufacturers Association	Turkey	OSD, 2011a and OSD, 2011b
SIAM	Society of Indian Automobile Manufacturers	India	SIAM, 2012
TAIA	Thai Automotive Industry Association	Thailand	TAIA, 2012
UKRAUTOPROM	Association of Ukrainian Motor Vehicle Manufacturers	Ukraine	UKRAUTOPROM, 2011 and UKRAUTOPROM, 2012
VAMA	Hiệp Hội Các Nhà Sản Xuất Ôtô Việt Nam - Vietnam Automomobile Manufacturers Association	Vietnam	VAMA, 2012

The World Road Statistics database, sold by the IRF, also includes some annual data on first registration of passenger cars and all motor vehicles, together with other information on vehicle production, imports and exports (IRF, 2011).

For passenger cars, highly detailed data on vehicle sales (combined with other information on the vehicle characteristics) can also be derived from specific detailed studies carried out by public institutions.

Two important examples of public efforts in this respect are:

- an annual publication of the United States Environmental Protection Agency (US EPA), on fuel economy trends for light duty vehicles, also providing a wealth of information on the characteristics of the new vehicles (US EPA, 2011); and
- an annual publication issued by the European Environment Agency, containing data for new passenger car registered, together with several other specifications.

Several consulting firms also offer services on the automotive sector. They assemble statistics based on specific methodologies each of them established over time. They then eventually sell the statistical datasets to their customers in combination with analytical and other services. Selected examples of forms providing this sort of information include IHS, Polk, McKinsey and PriceWaterhouseCoopers.

For buses, a specific analysis containing figures on the urban bus fleet in the European Union was released by the UITP in 2007 (UITP, 2007).

Rail and inland waterways

Statistics on new vehicle registrations from public sources are not as complete for rail vehicles (trams, trains, distinguishing between tractive and non-tractive units) and for inland waterway vessels.

Estimates on new rail vehicles (rolling stock) can also be derived from the information released in annual reports by rail vehicles suppliers. One example is provided by the Annual Report from Bombardier Transportation, containing details on major orders received, their value, the type of product or service that they concern, the number of cars involved, and the market value of the product and service, as well as estimations of the total market value and the market share covered by a given company (Bombardier, 2011). This information can be further complemented by specific press releases that give additional information on some of the major orders.

Railway operators may also provide information on new acquisitions and dismissals of rolling stock, as in the case of India (Indian Railways, 2011a).

In Japan, data on the production and exports of rail vehicles are regularly released by the Japan Association of Rolling Stock Industries (JARI, 2011). In the United States, data on locomotives constructed in the most recent year are published annually by the US BTS (US BTS, 2012).

Specific studies, developed by consulting companies and commissioned by the European Rail Industry (UNIFE), also address the subject, focusing mainly on the market value. The two most recent, available for purchase, concern the global rail market to 2016 (RolandBerger, 2008) and to 2020 (BCG, 2010).

Other studies, developed on an ad-hoc basis, focus on specific markets and may be available for free if they are commissioned by public institutions. One example is provided by the analysis on locomotives and rail cars carried out by the International Trade Commission for the United States (US ITC, 2011), also including a market overview for Canada, China, Mexico, and Russia.

Finally, a number of published datasets contain information on the stock of these vehicles (further details are given in the next section). Since the lifetime of rail vehicles and inland waterway vessels tends to be much longer than the lifetime of road vehicles, it is possible to use the information available on vehicle stocks (eventually combined with information from industrial sources) to deduce estimates on the amounts new registrations of these vehicles.

For inland waterways, information on European inland navigation vessels, including data on new cargo capacity on the market, are published in the annual market observation of the CCNR (CCNR, 2012).

Vehicle stock

Some of the statistics on transport vehicle stocks that are collected via the joint questionnaire are published by the UNECE, but not by the ITF. These statistics include, in particular:

- data on the annual road vehicle fleet at year-end by country (for UNECE member States), type of vehicle (distinguishing between mopeds, motorcycles, passenger cars, buses and coaches, lorries, and road tractors, plus trailers and semi-trailers)[8];
- information on the annual rail locomotive fleet at year-end by country, distinguishing amongst electric, diesel and steam-powered units; and
- the annual number of self-propelled inland waterway vessels in service at year-end by country and date of construction class.

The Eurostat database (Eurostat, 2012a), focusing exclusively on EU countries, includes a larger amount of information on the stock of vehicles for all inland transport modes:

- For road, it includes the total registration data for mopeds, motorcycles, passenger cars, buses and coaches, lorries and road tractors, with the same disaggregation used for new vehicle registrations. In addition, it provides a further characterisation of this information by age class for passenger cars, buses and coaches, and lorries;
- the vehicle stock of trams is also available, and is reported under road vehicles;
- for railways, the database contains statistics on the number (and the total tractive power) of locomotives, and railcars by source of power, the number (and capacity)

[8] Passenger cars, buses and coaches, lorries, and road tractors are also divided by age group (less than 2 years, 2 to 5 years, 5 to 10 years and more than 10 years). Buses and coaches in the vehicle stock are also distinguished on the basis of the fuel they use (gasoline, diesel, LPG, natural gas, electricity – for trolleybuses – and other fuels). Lorries are also characterised on the basis of their capacity.

of passenger coaches (or railcar trailers) by class, the number (and capacity) of freight wagons by type (and by status of the railway enterprise, either private or public), and the number of trainsets (indivisible block of railcars and railcar trailers or locomotives and passenger railway vehicles) by speed category; and

- for inland waterways, the data provided focus on the number (and power) of self-propelled vessels and the number of dumb and pushed vessels. The information is classified by date of construction and load capacity of vessels.

For EU countries, the Odyssee database also includes statistical data on the stock of vehicles. For road, vehicles are characterized on the basis of their fuel use. Data are available for cars, two-wheelers, bus, light commercial vehicles, and trucks. The Odyssee database also contains information on rail, water and air transport vehicles (Enerdata, 2012).

The North American Transport Statistics Database contains information on the number of transportation vehicles and other transport equipment in air, public transport, road, rail, and water modes. (NATS, 2012). More details are provided by each national administration that contributes to it:

- in Canada, Statistics Canada publishes detailed information on the vehicle stocks for several vehicle types used in different modes, including road and rail (Statistics Canada, 2012a). In addition, the Comprehensive Energy Use Database that has been developed (and is being updated) by Natural Resources Canada also includes information on the stock of road vehicles (NR Canada, 2012). For freight transport, the ecoFREIGHT Program led to a collection of studies and reports targeting the reduction of GHGs and other pollutants from freight transport. For rail, these reports included also an assessment of the number of diesel-powered locomotives and diesel mobile units (RAC, 2010).
- in Mexico, the statistical manual issued by the IMT includes information on the vehicle stock for all transport modes (IMT, 2009). It includes references to periodically updated data sources analyzing different transport modes and vehicle categories in more detail. Data on the vehicle stock for road, rail and other modes are also reported in the Mexican Annual Statistical Yearbook (INEGI, 2010). Specific statistics on the registered road motor vehicles by type are also released separately by the Mexican national statistical office (INEGI, 2012a).
- vehicle, aircraft and vessel inventories are regularly included amongst the detailed information reported in the National Transportation Statistics issued by the US BTS (US BTS, 2012). The same publication includes data on railroad locomotives by year of construction.

Statistics on the vehicle stocks of all modes are also collected by other OECD countries:

- the National Statistical Office (Instituto Nacional de Estadística) annually publishes a report on the road vehicle stock in Chile, but no information on the rail vehicle stock (INE Chile, 2011b);
- the national statistical office (Central Bureau of Statistics) in Israel publishes data on vehicle stocks for all transport modes (CBS, 2011);

- the Japan Statistical Yearbook includes data on motor vehicle registrations by class and the number of vessels by type (transport by sea), but not on rail transport vehicles (Japan Statistics Bureau, 2012); and
- in Turkey, the national statistical office (Türkiye İstatisitk Kurumu, Turkish Statistical Institute) publishes data on the road vehicle stock, as well as the number of locomotives and wagons in use for rail transport (TÜİK, 2012).

Non-OECD public institutions also provide information (with varying degrees of details and different classification criteria) on the road vehicle stock. Selected examples of data providers in different world areas are included in Table 4.

Table 4. Selected data sources on the road motor vehicle stock

Country	Source	Reference
Algeria	National statistical office (Office National des Statistiques)	ONS, 2009
Bolivia	National statistical office (Instituto Nacional de Estadística), building on the registry of the tax administration (Registro Único para la Administración Tributaria)	INE Bolivia, 2010
Brazil	Department of transport of the Ministry of Cities in Brazil (Departamento Nacional de Trânsito)	DENATRAN, 2011
Cameroon	National statistical office (Institut National de la Statistique du Cameroun)	INSC, 2011
China	National statistical office (National Bureau of Statistics of China)	NBSC, 2010
Dominican Republic	General directorate for taxation (Dirección General de Impuestos Internos)	DGII, 2011
Guatemala	Tax administration (Sistema de Administración Tributaria)	SAT, 2011
India	Ministry of Road transport and Highways	Government of India, 2011
Indonesia	National statistical office (Badan Pusat Statistik)	BPS, 2011
Iran	National statistical office (Statistical Centre of Iran)	SCI, 2007
Russia	National statistical office (Rosstat)	Rosstat, 2011

Statistical offices of non-OECD countries also publish data on the vehicle stock for other inland transport modes. For rail, this is the case in Brazil (Ministerio do Transporte do Brasil, 2011) and China (NBSC, 2010).

Vehicle manufacturers and component producers may also evaluate vehicle stocks and, on some occasions, publish their assessments. For road vehicles, one important example in this area is the annual estimation of the Brazilian vehicle stock made by Sindipeças (Sindicato Nacional da Indústria de Componentes para Veículos Automotores) and Abipeças

(Associação Brasileira da Indústria de Autopeças), in Brazil (Sindipeças and Abipeças, 2012), since it differs significantly from official statistics.

For road vehicles, the World Road Statistics database, sold by the IRF, also includes some statistics on the number of vehicles in use, distinguishing between passenger cars, buses, lorries and vans, and motorcycles (IRF, 2011). These data are also used by the World Bank to estimate passenger cars per capita in the World Development Indicators database (World Bank, 2011a). Consulting firms also provide estimations of the road vehicle stocks, (e.g. IHS, 2012).

For rail vehicles, the UIC annual database, available for purchase, provides information on the rolling stock, drawing on the data collected for its member companies (UIC, 2011). It uses a classification system that is very similar to the one adopted by the Eurostat, ITF, and the UNECE. In the rail sector, railway operators also provide information on the rolling stock in their annual reports. Two relevant examples are the annual reports issued by the Indian Railways (Indian Railways, 2011a and 2011b) and the Russian Railways (JSCo Russian Railways, 2011).

For inland navigation, information on the number of active vessels in the European inland waterways is included annually in the market observation of the CCNR (CCNR, 2012).

In Europe, the EX-TREMIS project includes updated information on non-road transport data concerning the vehicle fleet. In addition, it considers also data on transport activity, emission and energy consumption factors, as well as total energy consumption and emissions data (T&T et al., 2008).

Finally, it is also possible to calculate estimates of the vehicle stock on the basis of new vehicle registration statistics and scrappage rates. This is important when older vehicles are out of service, but still registered in official documents (something that is likely to be the case in Brazil and India). A methodological approach that was used for the National Communication of Greenhouse Gases to the UNFCCC in the case of Brazil is illustrated in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). A review of statistical and analytical information on scrappage rates of road vehicles used in the EU, Japan and the United States is included in Pelkmans et al. (2003), while Pridmore at al. (2010) contains an assessment of the average and maximum vehicle scrappage age for all modes. Meanwhile, Dray (2011) presents a discussion of assumptions suitable for different transport modes.

Second hand vehicle flows

Second hand vehicle flows are particularly important in the road modes, namely for light duty passenger transport. However, finding data and reliable statistics on this subject is very difficult. Some information can be deducted from the analysis of new registration figures (typically issued by governmental entities) and sales data (typically released by the industry), since the differential between them may be due to the re-matriculation of vehicles that were formerly registered in another country. In addition, further information can be derived from trade databases on the national level, but the availability and quality of data varies and may be dispersed between various national authorities.

Two main types of vehicle flows can be identified: the first one concerns free-market areas, where no trade restrictions exist, the other concerns trade beyond the borders of free market areas. The first type of trade is generally more poorly documented than the second.

A few analyses have addressed the issue of second hand vehicle trade across the globe:

- the IEA identified the primarily used light duty vehicles (LDV) flows around the world, distinguishing between intra-OECD and outer-OECD flows (IEA, 2009a). This analysis builds extensively on published literature. The estimates published suggest that second-hand imported vehicles represent a significant market share of newly registered vehicles in a number of world regions and countries including, Eastern Europe, Mexico, New Zealand, Russia, several African countries and the United Arab Emirates (also used as a platform for second hand vehicles distribution in other regions), amongst others in the Middle East.
- a study from the European Commission (Melhart et al., 2011) provides an overview of the trade of second hand vehicles for EU member countries, looking at intra-EU and extra-EU trade. It consolidates information on vehicle cross-border trade obtained from international and national sources, illustrating that most new EU Member States are net importers and suggesting a threshold of 12.5 thousand EUR of final consumption per capita, above which export activities start to exceed imports;

Legislative processes introduced norms in Europe (in 2000) and Japan (in 2002) to regulate the environmental friendly treatment of end-of-life-vehicles (ELVs) (EC, 2009a, EC, 2011b and Japan, 2007). Following these initiatives, Asian countries also introduced ELV-legislation or started political and technical discussions on this issue. China, India and Russia have also started working on such regulations, and Canada, Mexico and Brazil are now looking into this issue (OICA, 2011). Following these initiatives, work on a United Nations Regulation on the type-approval of motor vehicles (passenger cars and light commercial vehicles) with regard to their reusability, recyclability and recoverability is expected to start soon (OICA, 2011).

Scientific literature focusing on waste materials and recycling, as well as specific studies on ELV, resulted in a number of analyses that address:

- the assessment of the amount of ELV; and
- the estimation of the share of ELVs joining the international trade flows of used vehicles in countries where waste management legislation is in place, rather than being scrapped in these countries according to the legal requirements on waste treatment.

Some papers focus on Japan (e.g. Fuse et al., 2007), others are related to the EU and single countries within the EU (e.g. Sander et al., 2002 and Kollamthodi et al., 2003). In the EU, the reporting requirements and targets set out in the ELVs Directive also led to Eurostat's collection of ELVs statistics (Eurostat, 2012c). These data represent several types of materials and the waste treatment processes that they are subject to. They concern all EU countries and are expressed in mass units.

It is also important to mention that the scientific literature also includes a number of articles that focus specifically on the used vehicle market cross-border trade. A selection of the most recent and the most relevant works dealing with used vehicle markets includes Clerides (2004), Joost Beuving (2006), Pelletiere and Reinert (2006), Fuse et al. (2009), and Davis and Kahn (2010).

Some of these articles address the subject in combination with trade-related or environment-related considerations. Others also analyse societal cost and benefits stemming from the trade of hand vehicles. In parallel, some studies focus on specific markets and flows (e.g. between the United States and Mexico), while others have a broader target. Most of these analyses provide statistical data and estimations on the magnitude of the cross-border used vehicle market. A few of them build on international databases, such as the United Nations Commodity Trade Statistics Database (UN COMTRADE, 2012). Overall, they tend to identify EU countries (namely Germany), the United States, and Japan as the main sources of most used vehicles traded around the world, with exports from Japan particularly relevant for countries with left-hand driving. A few papers even suggest modelling approaches to understand their main trade flows.

The UNEP published three information tables containing a review of the existing import regulation on cross-border used vehicle markets trade in Central and Eastern Europe, the Middle East, West Asia and North Africa, as well as the Asia-Pacific region and Latin America and the Caribbean (UNEP, 2008a; UNEP, 2008b; UNEP, 2011a; and UNEP, 2011b). The same tables also contain some quantitative and qualitative information on the vehicle fleet characteristics.

The ELV legislation does not target non-road inland transport modes, and very little information (if any) exists on the cross-border trade of rail and inland navigation vehicles. However, factors like the significantly longer vehicle lifetimes, the more frequent practice of vehicle refurbishing rather than scrapping and the much lower order of magnitude of vehicles in comparison with road all support the idea that the trade of used rail and inland waterway vehicles is nearly negligible and limited to very specific cases.

Vehicle characteristics

The bottom-up analysis of energy consumption and GHG emissions in transport requires information capable of characterizing different types of motorized vehicles according to their specific features, including their transport capacity (either in terms of passengers or freight), fuel consumption and CO_2 emissions. Other information, like those on the vehicle weight and size and the type of fuel used, are also necessary to distinguish amongst vehicle sub-categories and to further characterize the fuel consumption of vehicles.

Information on vehicle size, mass and load capacity are generally used to identify different vehicle classes. For passenger road transport, motorized vehicles are generally classified amongst two wheelers (motorbikes and mopeds), light duty vehicles, and buses and coaches (including trolleybuses). Freight transport vehicles are typically identified based on classes associated to their carrying capacity (e.g. distinguishing between light commercial vehicles, lorries and road tractors plus the associated trailers). Similar considerations can be extended to rail vehicles: passenger trains can be characterized based on their carrying capacity (in terms of passenger), as well as freight trains (in terns of tons). For inland navigation, classification based on the carrying capacity is also feasible. In addition, all vehicle categories can be further split according to the fuel they use (e.g. gasoline, diesel, LPG, natural gas and electricity).

It is not easy to associate each vehicle class to its representative fuel consumption (and, indirectly, to its CO_2 emissions) with a strong level of accuracy. Some of the reasons for this include:

- the lack of a legal obligation to test the fuel economy of vehicles in several countries, since this is generally in place only in countries that are enforcing fuel efficiency standards (Australia, Canada, China, the European Union, Korea, and the United States for light duty vehicles, as well as Japan and the United States for medium- and heavy-duty vehicles), or at least requiring the provision of transparent consumer information through labeling practices;
- the existence of variables, in countries where fuel efficiency standards are in place, amongst existing official procedures aimed at the estimation of the fuel consumption for road vehicles associated with the lack of harmonization on test procedures designed to evaluate fuel consumption and CO_2 emissions[9];
- the uncertainties associated with the existing test procedures concerning the estimation of fuel consumption of vehicles, which typically result in lower estimations of the fuel consumption in comparison with the actual on-road performances (Plotkin, 2007). This is due to issues related to ambient conditions, the mix of driving cycles and trips, road conditions and topography, the state-of-maintenance of the vehicle, driver behavior, vehicle accessories and actual loads (ECMT/IEA, 2005). Another element that is likely to contribute to the discrepancy is the tendency to exploit opportunities given by the existence of inertia classes in some of the regulations defining the test procedures (ICCT, 2011a);
- the lack of systematic and comprehensive assessments for different types of rail and inland waterway vessels, notwithstanding the voluntary standard developed by the

[9] For light duty vehicles, the main driving cycles currently used to evaluate the fuel consumption of vehicles are the JC08, the FTP-75 and the NEDC test cycles, used respectively in Japan, the United States and the European Union. A proposal for the development of a new UN GTR (Global Technical Regulation) concerning Worldwide harmonized Light Vehicle Test Procedures (WLTP) – including provisions for the evaluation of fuel consumption, CO_2 and other GHG emissions – has been submitted to the World Forum for the Harmonization of Vehicle Regulations (WP.29) in 2009, and a draft UN GTR is expected in 2013 (UNECE, 2009). A globally harmonized measurement procedure, concerning gaseous pollutants as well as CO_2 emissions and fuel consumption, has been already developed for two-wheeled motorcycles (UN GTR No. 2) (UNECE, 2005 and UNECE, 2012b). For heavy duty road vehicles, the existing UN GTRs (No. 4) does not include provisions for the evaluation of fuel consumption, CO_2 and other GHG emissions, but it focuses mainly on the emissions of gaseous pollutants (UNECE, 2007b and UNECE, 2012b). The fuel efficiency standards for heavy duty vehicles introduced in the United States and Japan are associated to country-specific test procedures. Details for the United States are available from the USE EPA (2012). For Japan, they are briefly outlined in Wani (2007). An overview on worldwide engine and vehicle dynamometer test cycles used for emission and fuel economy measurement is available from Dieselnet (2012),

rail industry on technical recommendations for the specification and verification of energy consumption of the railway rolling stock (UNIFE, 2010); and

- the strong dependency, especially for freight transport, of fuel consumption on the actual loads transported, combined with the limited availability of detailed information coupling vehicle loads and transport patterns.

However, a number of studies provide information on fuel consumption and CO_2 emissions of vehicles, building on the available test procedures, leveraging on existing methodologies and, eventually, developing specific analyses and case studies.

For light duty vehicles, the most relevant publications containing information on fuel consumption and CO_2 emissions by vehicle category and fuel used (as well as other characteristics) include the following:

- a regularly updated database containing the data required by the European Commission for the calculation of the average specific emissions of CO_2 from new passenger cars entering the EU market and for setting the specific emissions targets that shall be met by car manufacturers. It includes information on vehicle manufacturer, type, variant, version, make and commercial name, emissions of CO_2, mass in running order, wheel base and track width (EEA, 2011b); and
- a publication released every year by the US EPA containing information on vehicle manufacturer, engine type, fuel economy, CO_2 emissions, weight, footprint and technological characteristics (drivetrain type, number of valves, acceleration time, top speed, engine power, fuel distribution type) for new vehicles entering the market in the United States (US EPA, 2011).

In Japan, detailed data on the average fuel economy of new gasoline-powered passenger cars by vehicle weight class coupled with sales data are available from the Japan Automobile Manufacturers Association (JAMA) and the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) (Sano, 2008), but this information is not regularly released to the public in the form of a publication or database.

The automotive divisions of consulting companies like IHS, Polk, McKinsey and PriceWaterhouseCoopers are also active in the collection and provision of information on vehicles and their characteristics (including fuel consumption, weight and size-related parameters, amongst others).

Building on the data provided by one of the consulting companies active in this field (Polk), and complementing these data with other information, the IEA recently published a draft analysis on passenger light duty vehicle sales with some of their characteristics (such as weight, engine displacement and fuel consumption) (Cuenot and Fulton, 2011). This report, developed for the Global Fuel Economy initiative (GFEI), includes estimates of the fuel consumption of light duty vehicles for the years 2005 and 2008 in Argentina, Australia, Brazil, Chile, China, Egypt, France, Germany, India, Indonesia, Italy, Japan, Malaysia, Mexico, Russia, South Africa, Thailand, Turkey, Ukraine, United Kingdom, and the United States of America.

Similarly, the International Council on Clean Transportation ICCT published a report (focusing only on Europe), including numerical information on technical characteristics, emission levels and registration volumes at a car variant level. The dataset underlying the report was developed building on data obtained by Polk, various registration authorities, car manufacturers' and importers' associations, data from the United Kingdom Vehicle Certification Agency (VCA), the German Kraftfahrtbundesamt (KBA), the Automobil Revue magazine and other information provided directly by manufacturers and suppliers (ICCT, 2011b).

Other analyses and datasets provide specific information on the fuel efficiency (and either directly or indirectly CO_2 emissions) of passenger light duty vehicles. Some of them look at fuel efficiency standards that are (and expected to be) enforced in different countries, others are coupled with labeling schemes aimed at improving consumer information on the vehicle fuel efficiency. The latter typically focus on a specific country. The level of detail included in this type of analyses may vary: some only contain aggregated figures for passenger light duty vehicles at the country level, others may give more information on vehicle sub-categories.

One of the most well-known reports summarizing fuel efficiency standards was published by the ICCT (2007). This is regularly updated when new announcements are available. For country-specific analyses, a good example is provided by the regular update on the French passenger light duty vehicle market characteristics, which is published by the French agency for energy and energy efficiency, ADEME (ADEME, 2011).

Looking at light commercial vehicles, it is important to mention another ICCT report (ICCT, 2011c) that contains statistics on their fleet distribution in the EU in 2010. The report includes information on technical characteristics, emission levels and registration volumes at a vehicle variant level. The primary sources of information used are similar to the ones listed earlier for passenger cars. In the United States, some information on vehicles with a similar size and purpose max be deduced from the US EPA report on fuel economy trends (US EPA, 2011), but specific information is not available because, amongst other reasons, the vehicle classification in use differs from the European one.

When the global dimension is considered, it is clear that the availability of detailed information capable of describing the characteristics of light commercial vehicles is significantly more limited than for passenger light duty vehicles. Similar considerations (actually even stronger) should be extended to other road freight vehicles, like medium- and heavy-duty lorries and road tractors. One reason for the limited availability of assessments on the vehicle fuel efficiency for medium- and heavy-duty road vehicles (transporting passengers or goods) is the lack of procedures to measure fuel consumption and CO_2 emissions in the current globally harmonised cycle for heavy duty vehicle certification (UNECE, 2007b and UNECE, 2012b): to date, test procedures including instructions for the evaluation of fuel consumption, CO_2 emissions and the emissions of other GHGs and associated fuel efficiency standards have only been developed in Japan and the United States[10].

In addition, it is important to mention that vehicle loads have a greater importance for the determination of the vehicle's fuel consumption with respect to heavy duty vehicles than in the case of light duty passenger vehicles, since the percentage of the load in the total vehicle weight is much larger for trucks and buses than it is for cars. The greater importance of loads is one of the elements that makes vehicle testing more complex for heavy-duty vehicles than for light duty vehicles (Steven, 2011).

Notwithstanding the existing hurdles encountered in the determination of the performance characteristics of heavy-duty vehicles, information on the heavy-duty vehicle market, the heavy-duty vehicle characteristics, their fuel use, as well as strategies for testing and reducing GHG emissions from heavy duty vehicles have been published in a number of reports. Some of the most relevant ones include:

- ICCT (2009), on the heavy-duty vehicle market, the heavy-duty vehicle characteristics and their fuel use (focusing on the United States);
- AEA (2011), on strategies for testing and reducing GHG emissions from heavy duty vehicles (focusing on the EU);
- NRC TRB (2010) and TIAX (2011a), on technologies capable of improving their fuel efficiency (also focusing on the United States); and
- TIAX (2011b), on the available potential for GHG emission reduction in the EU.

Detailed information on the characteristics of non-road inland transport vehicles (used on railways and inland waterways) is even less frequent than for heavy-duty road vehicles. This may be due to the relatively low priority given (in the analysis of issues related to energy efficiency) to rail vehicles and navigation vessels, since both tend to perform significantly better, in term of energy requirements per unit of transport work, than road vehicles. In addition, there is a lack of standards, even for testing the vehicle's fuel efficiency: the only technical standard for the specification and verification of energy consumption in the rail sector is of railway rolling stock and was developed by the rail industry (UNIFE, 2010).

Some information on the performance of non-road inland transport vehicles are included in detailed studies focusing on the analysis of energy demand. These analyses not only include information on road vehicles, but also typically expand their focus to other transport modes and even to other energy end-use sectors. Such assessments are generally carried out by institutes working on energy efficiency and are disseminated in the form of databases. They build on technical analyses on vehicle technologies, the overall energy consumption in transport subsectors, and the corresponding transport activity data. Two relevant examples are:

[10] Japan (MLIT, 2011) and the United States (ICCT, 2011d) have also implemented fuel efficiency standards for medium- and heavy-duty engines and vehicles (for road modes), while the European Union is currently preparing a strategy for reducing the fuel consumption and CO_2 emissions of heavy-duty vehicles (EC, 2011). In Europe, the Finnish VTT has also developed methodology to measure the fuel consumption of heavy duty vehicles (Nylund and Erkkila, 2007).

- the Comprehensive Energy Use Database that was developed (and is being updated) by Natural Resources Canada (NR Canada, 2012), including estimates of energy consumption for different vehicles in different modes. This is accompanied by detailed information on the number of vehicles, their energy use and other characteristics released by Statistics Canada (Statistics Canada, 2012a); and
- the Odyssee database, targeting EU countries, which links information on new road vehicle registrations to the average fuel consumption of cars, two-wheelers, bus, light commercial vehicles, and trucks (Enerdata, 2012). These data are coupled with information on the average annual distance travelled. This database includes estimates of the average consumption of the vehicle stock of road vehicles, and provides similar information for all other transport modes: rail, water and air.

A few studies developed in the European context include a relatively detailed characterization of rail vehicles with respect to energy consumption (Halzedine et al., 2009, Andersson et al., 2011a and Andersson et al., 2011b). In addition, the rail industry contributed to the development of an integrated project co-funded by the European Commission, aimed at addressing the energy efficiency of the integrated railway system. This led to the assessment of a number of innovative traction technologies, components and layouts to the development of rolling stock, as well as strategies on the operation and management of the infrastructures. Unfortunately, little information on benchmarking the existing system (including vehicles) is available from this project, while most of the focus is on future development (Railenergy, 2012).

Information on active vessels of the European inland waterways is included annually in the market observation of the CCNR (CCNR, 2012).

The characterization of vehicles may also include detailed information on the contribution of different materials to the composition of transport vehicles, as well as other information with relevance for the life-cycle analyses concerning the manufacture and use of vehicles. Some of the analyses publishing data on the materials used for the manufacture of vehicles were commissioned by specific industrial associations (or other interest groups) and focus on the contribution of specific materials (e.g. aluminium) on vehicles (e.g. Ducker, 2008). Alternatively, they may focus on selected vehicle categories, materials and technological solutions: this is the case of the latest engineering report commissioned by World Auto Steel, the automotive group of the World Steel Association (WAS, 2011), as well as a number of previous reports (WAS, 1998, WAS, 2001a, WAS, 2001b and WAS, 2002). Pelkmans et al. (2003) contains a review of vehicle characteristics, including information on materials. More recently, a study commissioned by the ICCT also provided an assessment of the materials that are typically used on light duty vehicles and expected future developments, building on a review of existing vehicles (Lotus, 2010). Nemry et al. (2008), already mentioned in the section on life-cycle assessments, is also relevant here, since it contains an estimate of the materials in use on typical European light duty passenger vehicles.

Other relevant information is also available in studies analyzing vehicle technologies and their costs, like in McKinsey (2011) or the technical information included in IEA (2009A), but also detailed analyses on single vehicles with specific technological configurations like Olszewski (2007).

Travel and loads

Travel per vehicle

Vehicle usage is required to evaluate transport activity when it is expressed in vehicle km. Vehicle usage is not uniform for all users. It is not the same across transport services, modes and vehicle types. Vehicles for the transport of passengers, such as cars, tend to travel much less than trucks, buses, and other vehicles used for collective passenger transport (such as tramways and trains). Beyond the aggregations concerning type of service, mode, and vehicle categories, groupings that provide meaningful information for the analysis of transport activity per vehicle are typically those based on the type of fuel used (e.g. diesel vs. gasoline) and the vehicle sub-categories. In addition, vehicle travel typically varies over time (e.g. because of variations of fuel prices and changes in average individual wealth) and, within a given timeframe, across vehicle age classes.

Information on vehicle travel can be obtained from specific surveys looking at individual vehicle use, as well as periodical odometer readings. For freight transport by specialized companies, as well as for public transport of passengers (on taxis, buses, metros, and trains), information on the average travel per vehicle should also be available for the fleet operators. The average travel per vehicle can also be deduced from origin-destination surveys, even though the time span of the survey may require extrapolations.

At the macroscopic level, travel per vehicle can be deduced from the information published on the total transport activity (expressed in vehicle km) and the data on the vehicle stock (examples of sources of data on both of these parameters have been listed earlier in this section). On the other hand, detailed information on the average annual travel of vehicles is not readily available. This is partly due to the lack of detailed data collection efforts, and partly due to the fact that the data collected by primary sources are further elaborated before being published. Sometimes, numerical information on average vehicle travel by class is disseminated in specific studies, also providing analytical information on the subject. Such studies are likely to be available in countries where vehicle use monitoring procedures are well established, and much less likely to exist elsewhere (unless they are associated with a very specific initiative).

A few examples of sources of information that may report data on the light duty vehicle usage rates as a function of the vehicle age are the following:

- statistical reports, like the one published by the ORNL for the United States (ORNL, 2011); and
- specific analyses looking at transport activity or other issues, such as fuel consumption and CO_2 emissions from specific vehicle categories, such as the one performed in France on light duty vehicles (Léglise, 2011), building on the data collected for a vehicle usage survey that was recently updated (CGDD, 2012).

In the EU, Eurostat also provides some information for road vehicles (passenger and freight), on vehicle travel by type and age of vehicle (Eurostat, 2012a), and the review of past trends concerning vehicle characteristics. Pelkmans et al. (2003) also reports data on light duty vehicle usage rates over time relative to the late 1990s.

Little or no information exists focusing on the evolution of average travel patterns with vehicle age for second hand road vehicles traded across borders (Melhart et al., 2011). Nevertheless, it is conceivable that the usage rates of such vehicles are similar to those of vehicles sold in the same country belonging to the same sub-category and having the same age.

Data on the average vehicle travel (eventually coupled with figures on the volumes of fuel consumed) are also used in combination with other economic variables (e.g. fuel prices and personal income) in scientific literature that attempts to evaluate the elasticities of vehicle travel with respect to the cost of driving (because of variations of fuel prices) and/or personal income (i.e. the degree at which vehicle travel reacts at changes in the cost of driving and/or personal income), or even cross-elasticities for rail demand related to road freight price variation.

Reviews of studies that undertook this sort of analysis for road vehicles (eventually extended to other parameters, like vehicle ownership) include work from Goodwin et al. (2002), Graham and Glaister (2002), Small and Van Dender (2007), US CBO (2008), Litman (2011) and Christidis and Leduc (2009). The latter also includes a review of studies looking at cross-elasticities for rail demand related to road freight price variation.

The difficulties in characterising the availability of data on the average vehicle travel can have an impact on the quality of the transport activity statistics that are published, since the average vehicle travel is one of the main parameters needed for their evaluation. This is also one of the reasons why information on transport activity tends to be less frequently available than data concerning other parameters, such as the new vehicle registrations and the magnitude of the vehicle stock.

The limited availability of statistics describing travel patterns for different vehicles also results in an increased need to rely on simplified descriptions of them. Such descriptions typically build on the characterisation of the average vehicle loads in different circumstances, leveraging on in those cases where the collection of information on load patterns is well established.

Average vehicle load

Vehicle loads are also not uniform for transport services (passenger or freight), modes (road, rail, etc.) and vehicle types. The wide variety of vehicle characteristics, economic drivers, goods types and passenger needs is such that understanding vehicle loads is a task that requires a significant amount of information. A proper characterisation is therefore difficult to achieve, unless detailed systems for the collection of information are in place.

Loads (and the way to measure them) may be grouped in a few main sets, selecting them on the basis of the characteristics of transport services, modes, and vehicle categories:

- individual passenger transport vehicles (cars, two wheelers) typically transporting a limited number of people, averaging between one and two in OECD countries;
- collective public transport vehicles for the movement of passengers (buses, tramways, trains), whose load is generally expressed on the basis of their transport capacity and the average occupancy rate. Load factors on these vehicles are subject

to larger variations (e.g. across the day and the travel pattern) than those of individual transport vehicles;

- road freight vehicles (LCVs, trucks), whose loads are typically expressed considering the share of laden travel (excluding empty runnings) and the average load transported on laden trips. In addition, load factors require the knowledge of the available transport capacity;
- freight rail vehicles, where loads and load factors can be evaluated on the basis of information on loaded and empty wagons for conventional and intermodal traffic, as well as their the net consignment weight, the gross-tonnage and the tare of wagons; and
- inland waterways vessels, for which it is necessary to gather information on loaded and empty journeys (vessel movements);

Oil pipeline transport can also be characterized in terms of load by considering the capacity utilization rate.

The load of goods vehicles can also be characterised on the basis of the commodity transported, the service provider (on hire or own account), the nature of the transport (national, cross-trade, international, or cabotage), and the origin and destination of the carriage.

Average vehicle load data may be deduced from top-down statistics on passenger and freight activity (passenger-km and tonne-km) and vehicle activity data (vehicle km). Average load factors can be further deduced from information on the corresponding vehicle capacities. Examples of published data that can lead to this sort of estimation have been provided in previous sections that dealt with transport activity, transport vehicles and vehicle characteristics.

Vehicle usage surveys and reports from transport companies (providing either passenger or freight transport services) are the primary sources of these data. As in the case of vehicle travel, this information is further elaborated before being published. As a result, detailed information on vehicle load characteristics is more likely to be hidden behind aggregate indicators like passenger freight and vehicle activity (measured, respectively, in passenger-km, tonne-km, and vehicle km), rather than in the form of detailed data for the different vehicle categories. Such details, however, may still be included in specific studies that provide analytical explanations of the methodology used for the estimation of transport activity data.

Overall, data on the average vehicle loads are not widely available, especially outside the OECD area. This mirrors the data availability limitations and the variable quality concerning statistics on transport activity previously discussed. Such a situation also calls for the establishment of solid data collection procedures. In the short-term, it also increases the need and the value of the analyses looking at data and relationships capable of leading to their estimation, e.g. on the basis of macroeconomic and other data (on fuel prices, for instance), notwithstanding the inevitable uncertainties associated with any assessment carried out in the absence of a proper basis of statistical information.

The complexity of the information on vehicle loads, as well as the significant hurdles associated with the collection of detailed data, is also likely to require an adequate legal framework for an effective functioning. The EU and its legal acts on transport statistics provide a relevant example of an international effort undertaken in this respect. In this framework, Eurostat is also publishing and regularly updating a report looking at the methodologies used for surveys concerning data on road freight transport for EU Member States and Candidate Countries (Eurostat, 2011b).

Unfortunately, the systematic evaluation of data collection procedures is not a common practice at the international level, even if it would be especially relevant to assess the quality of the information contained in international databases.

Infrastructure

Eurostat, the ITF and the UNECE collect data on transport infrastructure through their joint questionnaires (UNECE, 2009a to UNECE, 2009d). The statistical information required in the questionnaires relates to different inland transport modes. It includes:

- length of road by type of road (motorways, state roads, provincial roads, communal roads, E-roads[11]);
- length of operated railway tracks by type of traction (non-electrified, electrified), number of truck (single, double or more), track gauge (standard, large, narrow) and nature of traffic (passenger only, freight only, passenger and freight). Those electrified are also split according to the type of current (50 Hz/25000 V, 16 2/3 Hz / 15000 V, other alternative current, DC3000 V, DC1500 V, other direct current);
- length of inland waterways by type of waterway (canal, river and lake) and navigability according to the carrying capacity of vessels; and
- investment and maintenance expenditure in transport infrastructure split by each mode of transport.

Regardless of the information required in the questionnaire, the data published in the corresponding databases are as follows:

- Eurostat publishes disaggregated data according to the criteria previously mentioned for all EU Member States (Eurostat, 2012a). The length of railway lines is also provided by maximum speed (dedicated high speed, upgraded high speed, conventional);
- the UNECE database (2012) provides relatively disaggregated data in case of road and rail transport (without splitting by type of traction), but there are no data available concerning inland waterways. Railway density expressed in total length of lines operated (km) per 1000 km^2 land area is also published; and
- the ITF (ITF, 2012a) publishes data regarding investment and maintenance in infrastructure, rather than statistics on the extension and the capacity.

[11] Numbering system for roads in Europe that was developed by UNECE.

The North American Transport Statistics Database (NATS, 2012) contains the following data for Canada, United States and Mexico:

- length of road by type of surface (paved, unpaved), type of road (major road system, local road) and number of lanes (less than four, four or more);
- length of railway by type of railway (rail, transit rail); and
- length of inland waterway.

More detailed data are available from the US BTS (US BTS, 2012), Transport Canada (Transport Canada, 2011) and the Mexican Annual Statistical Yearbook (INEGI, 2010).

The statistics on transport infrastructure collected by the majority of OECD countries also include details on specific sub-regions within each country. Most of them also publish disaggregated data by type of road and/or by type of road surface, while in the case of rail transport, the data published are more aggregated. In some cases, the length of cycle lanes and foot paths, as well as the number of solid crossing facilities, such as bridges and tunnels is also collected. Selected examples include:

- in Australia, the Bureau of Infrastructure, Transport and Regional Economics annually publishes Australian infrastructure statistics (BITRE, 2011), which contains data regarding the length of road by type of surface (e.g. bitumen, concrete, improved surface — such as gravel or crushed stone);
- the Central Bureau Statistics in Israel (CBS, 2011) publishes data on the length of roads and on area of road network by type of road (non-urban, urban, access). The overall length of paved roads and of operated railway tracks is also collected;
- the Ministry of Transport in New Zealand publishes key transport statistics (Government of New Zealand, 2011). In particular, statistics concerning the length of road by type of road (state-highway, urban, rural) and type of surface (total and sealed), as well as the length of rail track and cycle path, are provided;
- the Swiss Federal Statistical Office (SFSO, 2011) provides transport statistical data. Regarding transport infrastructure, data on the length of railway lines and on the length of road by type of road (state-highway, urban, rural) are published; and
- in Turkey, the national statistical office (TÜİK, 2012) publishes data on the length of road by type of road (motorway, state road, provincial road, village road) and type of surface (unpaved, graded and ungraded, bituminous surfacing, stone black, stone crushed and stabilized). The length of railway tracks is collected by type of traction (electrified, non-electrified) and maximum speed (high-speed train).

Some countries publish detailed information establishing more categories and subcategories according to other parameters such as the width and the functional system of the road. Selected examples include:

- the Japan Statistical Yearbook (Japan Statistics Bureau, 2012) provides abundant disaggregated data such as the length of road by width (> 19.5 m, 19.5 m ≥ width > 13 m, 13 m ≥ width > 5.5 m, 5.5 m ≥ width ≥ 3.5 m, < 3.5 m) and the overall length of roads (roads with side walks vs. roads with central zone). The total area of roads (roadside, roadway), as well as the number of facilities of solid crossing for pedestrian (bridges, under-passes, etc.) is also published; and

- the Bureau of Transportation Statistics of the United States of America (US BTS, 2012) updates continuously data that include the length of road by functional system (principal arterials, minor arterials, major collectors, minor collectors, etc.).

Looking at non-OECD countries, most public institutions provide information on infrastructure according to similar criteria. Apart from those mentioned in other sections, some new references are the followings:

- Ministerio do Transporte do Brasil (2011) provides in its annual report disaggregated statistical data for road and rail infrastructure. In particular, the length of railway tracks is published by infrastructure manager, type of traction (non-electrified, electrified) and track gauge (1.00 m, 1.10 m, 1.00/1.44 m, 1.00/1.60 m, 1.60 m);
- Georgia Department of Transportation (GDOT, 2012) publishes transport statistics. In particular, disaggregated data are available on the length of road by type of road (state routes, county roads, city streets), type of surface (unimproved, graded/drained, soil surface, stone/gravel, low-type bitumen, high-type bitumen, PC Concrete, brick or block) and functional system;
- the Ministry of Transport of Jordan (Government of Jordan, 2009) publishes an annual report on statistics that includes transport infrastructure data;
- the Central Administration Statistics of Lebanon (CASL, 2009) publishes the Statistical Yearbook that contains statistical data on transport. In particular, the length of road by type of road and the density of the road network are published;
- the National Bureau of Statistics of the Republic of Moldova (NBSRM, 2012) updates continuously transport statistical data, including those related to infrastructure; and
- the Statistical Office of Montenegro (MONSTAT, 2011) publishes a statistical yearbook that contains disaggregated data on road and rail infrastructure. The total number of rail stations is also available.

In Asia, limited information (railway density, road density and percentage of paved roads) is also published by the UN ESCAP (UN ESCAP, 2012). Similarly, data on the length of the road and railway networks are available in the statistical database of the UN ECLAC (UN ECLAC, 2012).

The International Bank for Reconstruction and Development (IBRD) and the World Bank gathered data on African infrastructure (including figures on road, rail, navigation and air transport) in the context of the Africa Infrastructure Country (AICD), a project designed to expand the world's knowledge of physical infrastructure in Africa. This work led to the publication of a comprehensive report on the status of African infrastructures (Foster and Briceño-Garmendia, 2010). This publication is also accompanied by a dataset containing a significant amount of information covering the transport sector (ADBG, 2012). In particular, data included in this dataset includes figures on the length and density of the road network, classified amongst different road characteristics.

For pipelines, the Organization of Petroleum Exporting Countries (the OPEC) publishes data on oil and gas pipelines in its member countries (OPEC, 2011a). Similarly, Eurostat provides data on pipeline length and capacity for European countries (Eurostat, 2012a). Similar information is available in other countries from institutions like national statistical offices, transport ministries, and national oil companies.

Within the private sector, the IRF, the UIC and the Union Internationale des Transports Publics/International Association of Public Transport (UITP) provide country-level data on transport infrastructure:

- the IRF database includes annual data such as the total road network by type of road (motorways, highways, secondary, other). The share of paved roads, as well as the density of the road network (expressed in km of road per km^2 land area) is also published for each country. These data are used by the World Bank's World Development Indicators database (World Bank, 2011a);
- the UIC dataset (UIC, 2011) includes detailed information for each country and its infrastructure managers. In particular, the length of operated rail lines is disaggregated by operational direction (running generally on the right, running generally on the left, no general running direction), track gauge (standard (1.435 m), broad gauge, narrow gauge), number of lines (single, double or more) and type of traction (electrified, non-electrified). In case of electrified lines, data are split according to the railway electrification system (supplied by catenary with alternating current, supplied by catenary with direct current, supplied by direct current contact rail). Furthermore, the overall track length (also taking into account tracks situated inside buildings, all cross-over switch lines counted from the switch, tracks branching off from main running tracks in stations, etc.) is also available. These data are also used by the World Bank's World Development Indicators database (World Bank, 2011a); and
- some publications by UITP (e.g. UITP, 2001) contain detailed information on public transport network. For instance, the number of routes, total mileage and distance between stops is published for some cities in case of bus, trolleybus and tramway.

Finally, it must be highlighted that the combination of data on transport infrastructure with the total number of vehicles in circulation allows the evaluation of basic indicators on traffic.

Drivers of transport demand

Travel habits and travel time

There is an increasing recognition by researchers that on average, people spend a consistent amount of time travelling.

According to Schäfer (2000), Tanner (1961) first suggested that on average, people spend the same (aggregated) amount of money and time (converted into monetary units) for travelling on motorized modes, regardless of whether they reside in an urban or a rural area. Later, Zahavi (1974 and 1981) proposed that urban travellers, i.e. residents who make at least one motorized trip a day (on a surveyed day), consistently spent – on average – the same amount of time (between 1 and 1.5 hours) of their daily time travelling.

More recently, Schäfer (2000) and Schäfer and Victor (2000) suggested that this conclusion can be generalized across a wide array of countries with varying incomes, as well as for motorized and non-motorized modes of travel, even if many variations are evident when examining the behaviour of small populations and individuals. Schäfer and Victor (2000) also underlined that the travel time budget per traveller is typically higher at lower incomes (lower incomes are associated with more constraints on the choice of living locations and transport modes), but also that the percentage of travellers compared to total population is lower in low-income societies, ultimately extending the idea of a quasi-constant average travel time across the whole population. Marchetti (1994), also suggested that the travel time budget has likely remain unchanged across centuries.

Table 5. Compendium of national and European travel and mobility surveys

Area	Title	Year	Reference
Belgium	MOBEL	1999	Cornelis, 1999
Canada	Travel Survey of Residents of Canada (TSRC)	2010	Statistics Canada, 2012e
European Union	Passenger Mobility in Europe	2007	De la Fuente Layos, 2007
European Union	Up-to date inventory of national surveys on passenger mobility	2011	Eurostat, 2011c
Finland	The National Survey 2004-2005	2005	Finnish Transport Agency, 2011
France	Mobilité régulière et locale; Enquête nationale transports et déplacements	2008	MEDD, 2011
Germany	The German Mobility Panel	2010	MOP, 2012
Ireland	Household Travel Survey	2010	CSO, 2012
Italy	Audimob	2011	ISFORT, 2012
Japan	Summary of the 4th Nationwide Person Trip Survey	2005	MLIT, 2007a
Japan	Person trip surveys carried out by municipalities	2007	MLIT, 2007b
Netherlands	The Dutch Travel Survey (OViN)	2010	DANS, 2012
New Zealand	New Zealand Household Travel Survey	2011	MOT NZ, 2012
Norway	2009 Norwegian Travel Survey Key results	2009	TOI, 2011
Singapore	Household Interview Surveys from 1997 to 2008 A decade of Changing Travel Behaviours	2008	Cheong and Toh, 2010
South Africa	The First South African National Household Travel Survey 2003	2003	DOT SA, 2005
Spain	Movilia 2006/2007	2007	SMPW, 2012
Sweden	RES 2005-2006 The National Travel Survey	2006	SICA, 2007

Switzerland	Microrecensement transports 2005	2005	SFSO, 2010
United Kingdom	National Travel Survey 2010	2010	DFT UK, 2011
United States of America	The 2009 NHTS	2009	NHTS, 2012

The instruments that are most likely to include information on the subject (travel time), but also containing data trips per capita, trip purpose and modal choice are likely to be travel and mobility surveys. Their geographical scope may vary, spanning from the urban level (for the analysis of local travel patterns) to the national level (for the identification of overarching trends), typically obtained from the aggregation of a set of information obtained at the local level.

A compendium of national travel and mobility surveys was recently published by the ITF (Violland, 2011). Additional data, focusing on previous decades, are included in Schäfer (2000), Schäfer and Victor (2000), as well as Schäfer et al. (2009).

Table 5 contains an updated list of national and European travel and mobility surveys, while other surveys, developed at the city level (mainly concerning Latina America) are included in Table 6.

Table 6. Mobility surveys in selected cities

Area	Title	Latest year	Reference
Argentina (metropolitan areas)	Informes de movilidad	2009	PTUBA, 2012
Australia (Melbourne)	30 years of travel in Melbourne: 1978/79 and 2007/08	2008	McGeoch, 2011
Chile (Santiago de Chile)	Encuesta Movilidad del Gran Santiago Año 2006	2006	SECTRA, 2012
Colombia (Bogotá)	Encuesta de Movilidad 2011	2011	SDM, 2012
Global (13 cities)	Urban travel behavior characteristics of 13 cities based on household interview survey data	2001	JICA, 2005
Latin American Cities	Observatorio de Movilidad Urbana para Ameríca Latina	2007	CAF, 2010

Data on travel time can also be obtained from Time-Use Surveys (TUS). These surveys are generally carried out by national statistical offices (usually undertaken once per 5 or 10 years, since they are intensive surveys and since the pattern of time use does not change very quickly over time). In the UNECE region 29 countries from have carried out a time use survey. The resulting data on travel time (with breakdown according to gender) are available in the UNECE Statistical Database (UNECE, 2012c). In Europe, more detailed time-use survey data for 14 countries are also available in the Eurostat database (Eurostat. 2012d).

Travel budget

Building on the observations of Zahavi (1982) and their own work, Schäfer et al. (2009) illustrate that households relying exclusively on non-motorized modes spend around 3-5% of their income on travel, while those owning at least one automobile dedicate close to 10% of their income to transport needs. Schäfer et al. also mention that the 10% tends to be reached at a motorization level of 300 vehicles per 1000 people, and that this share tends to remain stable at higher motorization levels. The same authors underline that travel money expenditures per household, similar to travel time per traveler, display regularities that make them valid across developed and developing countries, and make them applicable to entire countries at the aggregate level.

The considerations just mentioned result in a great deal of interest in the availability of information on the consumer (or household) expenditure for transportation. This information is typically included amongst the economic data published by national statistical offices and collected via household surveys. The level of detail of the information available varies across countries. In some cases, the availability of data is limited to aggregate categories. In India, the personal consumption expenditure related to transportation is further specified at the level of personal transport equipment, its operation, and the purchase of transport services (IMSPI, 2012). In Lebanon, the information on transport-related expenditures is disaggregated in only two sub-categories: road transportation and air travel (LR PCM EAM, 2010).

Some sources also publish additional figures, further detailing its structure. A few relevant examples are mentioned below:

- the US BTS (US BTS, 2012) publishes data on the total consumer expenditure, the share of transport and the amounts concerning transport sub-categories, differentiating amongst user-operated transportation (new cars and net purchases of used cars, new and used trucks and recreational vehicles, motor vehicle parts and accessories, repair and rental, petroleum fuels, parking fees and tolls, and insurance premiums, excluding the paid claims), purchased intercity transportation (on railroad, intercity bus, airline, and other means) and local transportation (mass transit and taxi). Data on personal consumption expenditure in transport for the United States are also published in ORNL (2011);
- the Eurostat database contains information on the structure of the consumption expenditure of private households, including the share of transport (Eurostat, 2012a). In particular, it contains statistics on the expenditure concerning the purchase of vehicles (motor cars, motor cycles, bicycles and animal drawn vehicles), the operation of personal transport equipment (spares parts and accessories, fuels and lubricants, maintenance and other services), the purchase of transport services

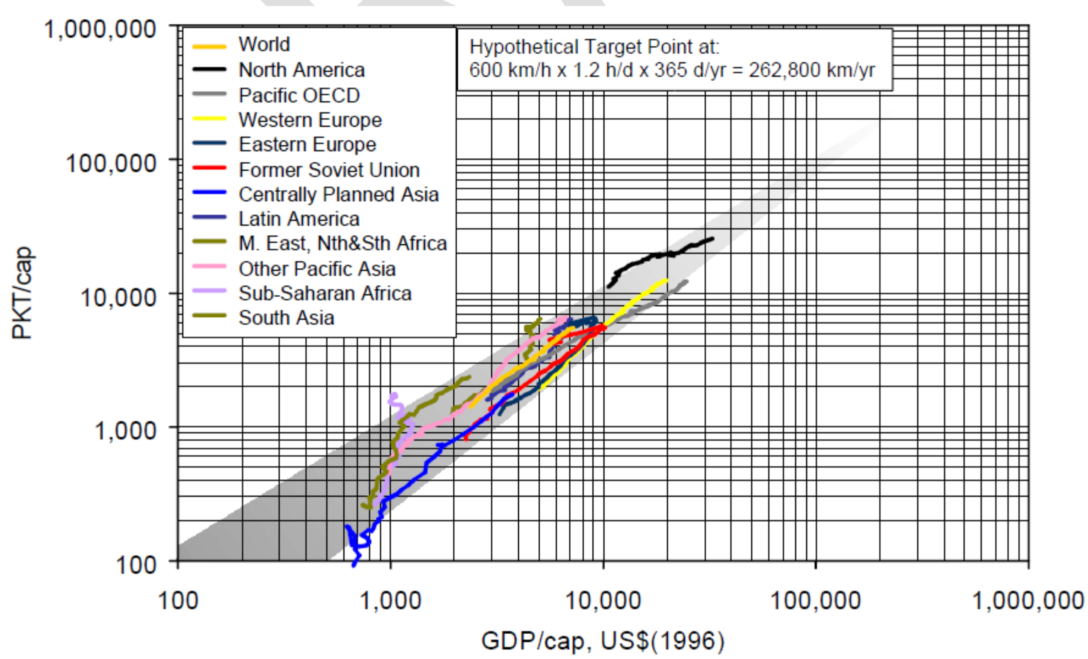
(by railway, road, air, sea and inland waterway, combined transport and other transport services);

- the Japan Statistical Yearbook (Japan Statistics Bureau, 2012) contains data on the annual expenditures of and quantities differentiation amongst the major household commodities and including, for transport, expenditures for public transportation (railway fares, railway season tickets for students and commuters, fares for buses, taxi and airplanes) and private transportation (automobiles, bicycles, gasoline, automotive maintenance and repair services, and automotive insurance premiums);
- Statistics Canada publishes data on personal expenditures for transportation, distinguishing amongst: new and used (net) motor vehicles, motor vehicle repairs and parts, motor fuels and lubricants, other auto related services, and purchased transportation services (Statistics Canada, 2012b); and
- the basic tables released by the national statistical office of Mexico on its household survey include data on the household expenditure for public transport (national and not), acquisition of personal transport vehicles, vehicle maintenance and fuel purchase (INEGI, 2012b).

In other countries (typically with lower incomes per capita), even aggregated data on household or personal consumption expenditures are generally not available, unless specific studies (e.g. looking at the distribution of household expenditure in specific areas and/or cities) have addressed the issue. An overview of the share of GDP dedicated to travel, expressed as a function of the motorization level and covering a range of developed and developing countries, is included in Schäfer et al. (2009).

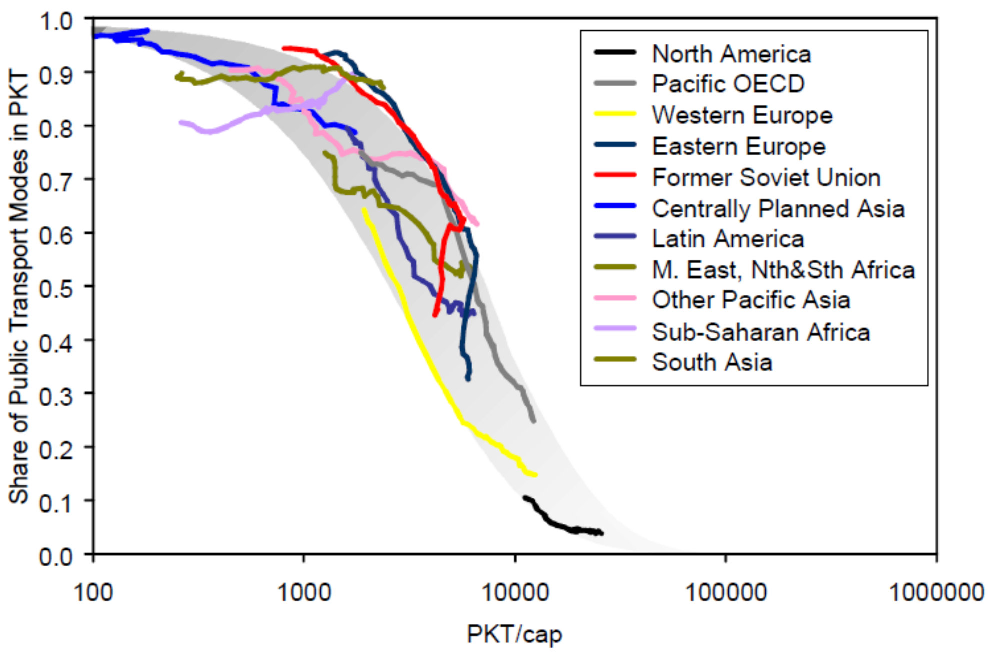
Socio-economic and geographical characteristics

Figure 6. Global mobility trends (1950-2000)



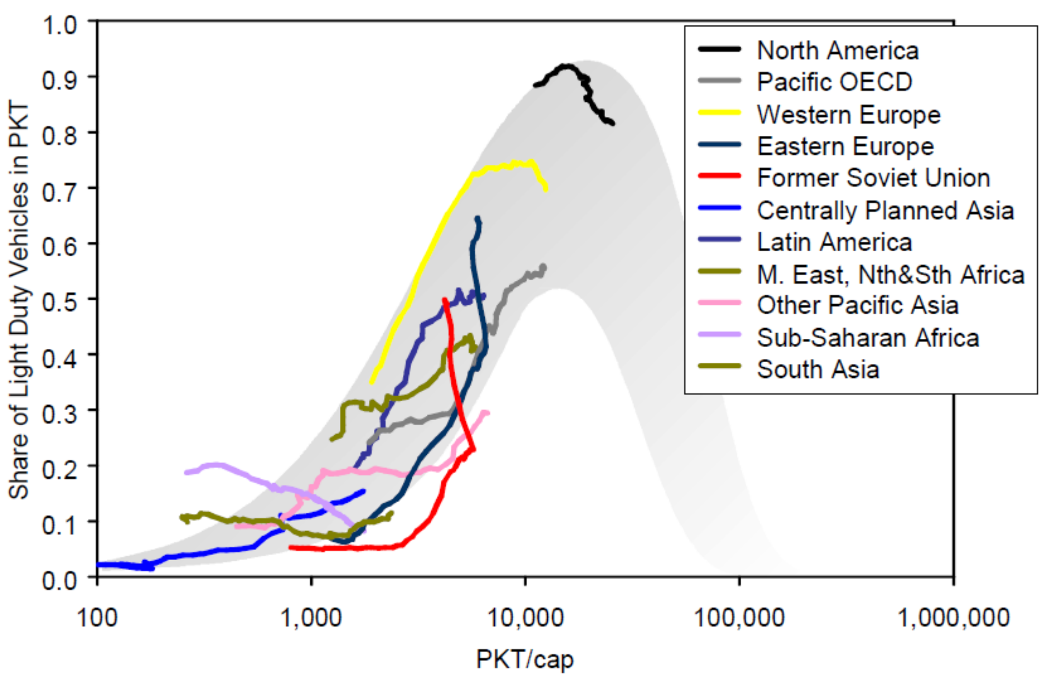
Source: Schäfer, 2005

Figure 7. Public transport share in total passenger transport activity (1950-2000)



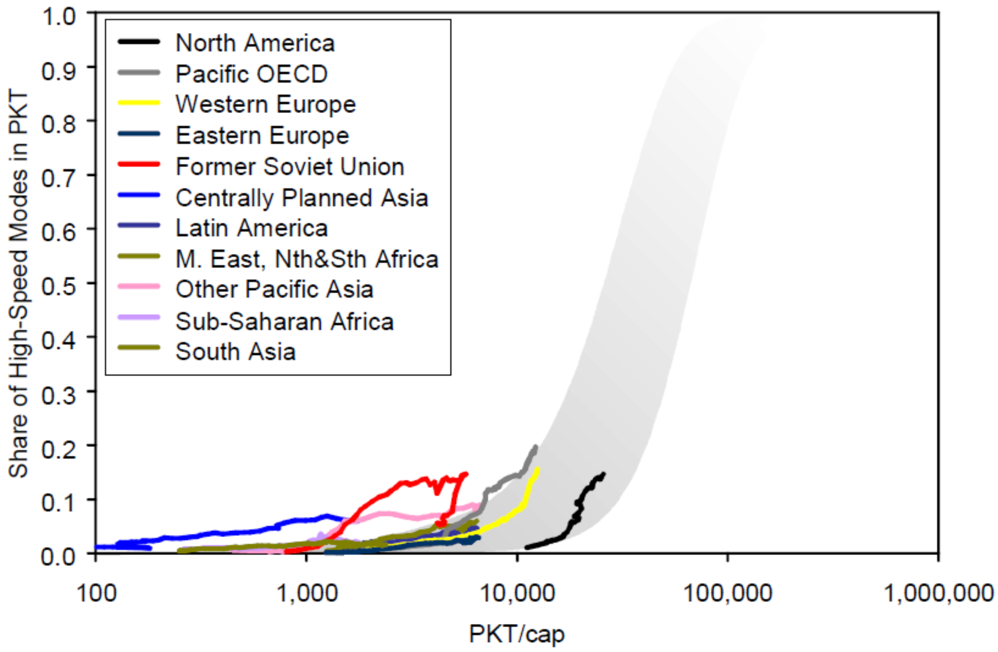
Source: Schäfer, 2005

Figure 8. Share of light duty vehicle travel in total transport activity (1950-2000)



Source: Schäfer, 2005

Figure 9. Share of air travel in total transport activity (1950-2000)



Source: Schäfer, 2005

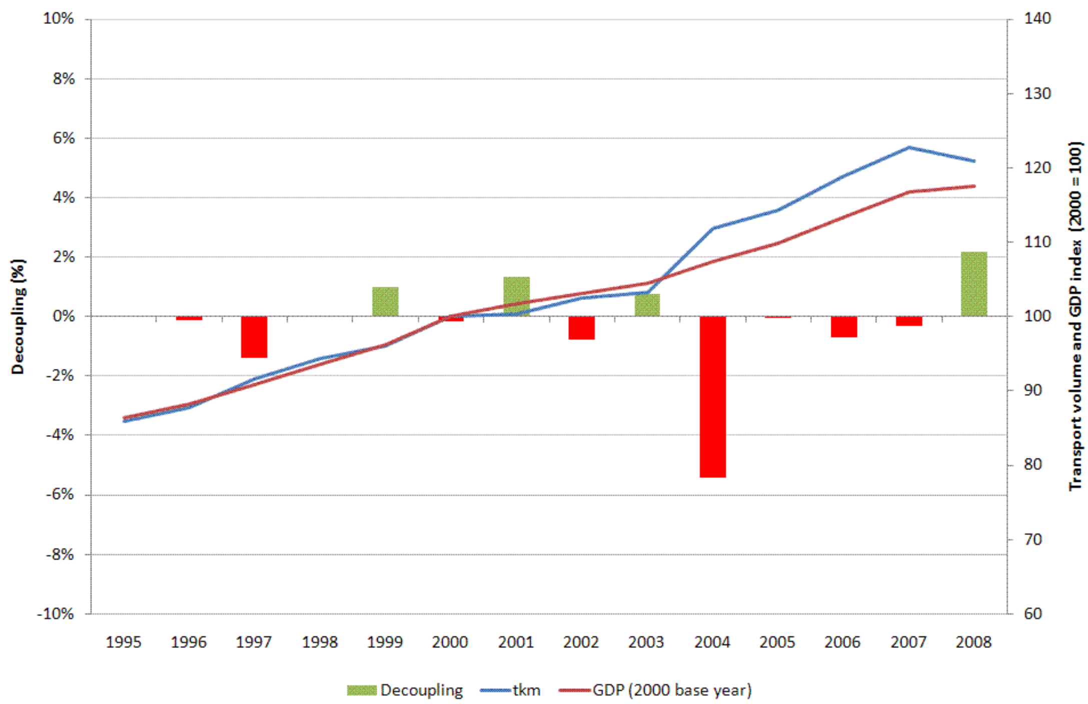
Schäfer (2005) showed that the combination of constant travel time budgets and partly growing transport-related budget shares link well with the worldwide trends observed in global mobility (passenger-km per capita) (Figure 6). Overall, these ideas also suggest that people tend to travel farther if they have access (either because of a growing income or other factors) to faster modes of travel (Figure 7, Figure 8 and Figure 9).

The same concepts also fit with the idea that increased mobility appears to trigger changes in lifestyles, such as living farther from work and more frequent and longer trips away from home (Schäfer, 2000; and Schäfer et al., 2009), even if this does not necessarily mean that people choose to travel on motorized vehicles, as long as other modes can provide similar speed and travel time (IEA, 2004).

In addition to the overarching link between the growth of population and GDP with transport activities, other analyses began to link different passenger vehicle saturation levels (typically observed in developing economies where average personal incomes exceeds 25 thousand USD per year) to differences due to demographic factors, urban population and population density (e.g. Dargay et al., 2007, Kenworthy and Laube, 1999; Kenworthy, 2006; and Newman and Kenworthy, 2006), since a higher proportion of urban population and greater population density tend encourage the availability and use of public transport services, and can reduce the distances traveled by individuals and for goods transportation. Further effects are likely to be associated with fuel prices.

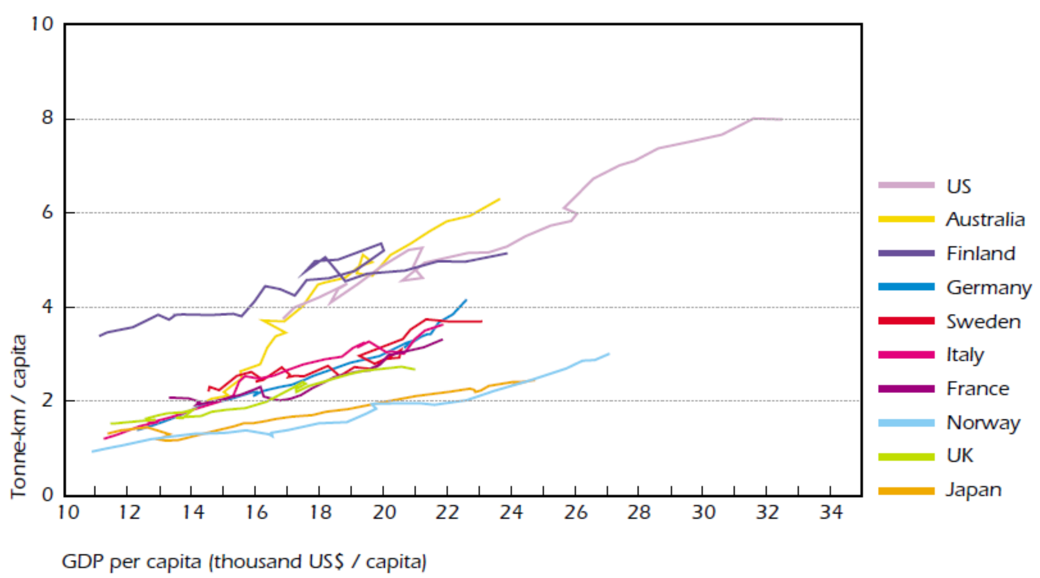
Statistics also show a close coupling between freight transport activity and economic growth (Figure 10 and Figure 11), further illustrating the importance of socio-economic parameters like population and GDP in the determination of transport activity trends, as well the crucial role of transport in the facilitation of economic development. In addition, even if Figure 10 and Figure 11 focus mainly on developed economies, this relationship is also evident in developing economies.

Figure 10. Trend in European freight transport demand and GDP[12]



Source: EEA, 2011c

Figure 11. Trucking activity (tonne-km) per capita as a function of GDP per capita (1973-2000)



Source: IEA (2004)

[12] The increase in freight activity in 2004 is due to a change in the methodology used to calculate the estimates for this year.

All these reasons justify the need to include socio-economic figures like population and GDP, as well as geographic characteristics such as urbanization rates, for the analysis of transport activity.

Since all national statistical offices collect data or estimates on socio-economic statistics like population and GDP, the overview presented here will focus only on international data sources. Similar considerations have been extended to include geographical characteristics.

Demographic data

At the international level, most organizations publish data on population and other background data. In most cases, they are also disaggregated by age classes and sex. Selected examples are:

- the UN Population Division (UNPD, 2010) publishes worldwide data disaggregated by country, sex and age classes. Apart from historical data, population projections until year 2100 are also available; and
- the United States Census Bureau provides an International Database (USCB, 2012) that contains historical aggregated data for several countries as well as populations projections until 2050. Moreover, links to national statistical offices around the world are published.

International data sources (including those previously mentioned) are also used by the Development Data group of World Bank to compile the population tables of the World Development Indicators database (World Bank, 2011a).

At the continental level, the Eurostat database, containing disaggregated national and regional data for the EU Member States (including population projections until year 2060), provides a high level of details (Eurostat, 2012a). The UNECE Statistical Database (UNECE, 2012a) also provides these data (as well as information on land area and GDP, discussed below) for all UNECE countries.

Land area

The most common geographic indicator (available from any national statistical office) is the total area, including the area of lakes and rivers. A second indicator that is frequently used (even if it is calculated according to different national criteria and not always available) is the land area, typically defined as the total area once inland water bodies are excluded.

As in the case of population, several organisations publish internationally comparable data on geographical characteristics. Selected examples include:

- Eurostat, which publishes national and regional data for each European country (Eurostat, 2012a) on total area and land area. Disaggregated data by land use (agriculture, forestry, hunting and fishing, heavy environmental impact, services and residential, no visible use) and land cover (artificial land, cropland, woodland, shrub land, grassland, bare land, water wetland) are also available; and
- The Food and Agriculture Organization of the United Nations (FAO, 2012), which provides country profiles that display total and land area.

In addition regional institutions, such as the Secretariat of the Pacific Community (SPD, 2012), also publish statistics on the land area of their member states.

Data on land areas are also published by a number of sources in the case of cities. These figures may be subject to different types of classifications, typically related to administrative boundaries, sometimes leading to the overlap of information concerning urban centres, urban areas, and metropolitan areas (frequently associated with the larger administrative regions around a city). A body of scientific literature also attempts to analyse issues like the dynamics of urban expansion, looking at a wide spectrum on city sizes and populations, sometimes using and satellite images (e.g. Angel et al., 2005).

Population densities and urbanisation rates

Population density is calculated by dividing the population by the land area, since it is defined as the number of population per unit of total land area of a country. Selected examples of international sources of information include:

- the UN Population Division (UNPD, 2010), which publishes worldwide data on population density and its projections until year 2100 according to population projections; and
- Eurostat, which provides national and regional data on population density for each European country (Eurostat, 2012a)[13].

The urbanisation parameter indicates the share of population inhabiting urban areas and along with urban land areas, it is used for urban density calculations. Nevertheless, since the definition of urban areas does not always follow a uniform criterion (it can be based, for instance, on land use characteristics or on density thresholds), cross-country information may not be directly comparable.

Selected examples providing information on the urbanisation rate are:

- the UN Population Division (UNPD, 2009), which publishes statistics on the share of urban population in each country. Moreover, this dataset includes figures on the number of urban agglomerations (by size classes) and the percentage that contributes to the overall urban population. The UN Population Division also publishes projections on the urbanisation rate until 2050, and its statistics are used in the World Bank's World Development Indicators database (World Bank, 2011a);
- Eurostat (Eurostat, 2012a) provides information on selected urban areas for each European country (Urban Audit, 2012). In particular, several indicators from the domain of demography, such as urban population and population density, are published by each urban area. Two main different levels are contemplated: city core (area corresponding to the general perception of the city), and larger urban zone (area including the surroundings of the city). In addition, some information on sub-city district indicators may also be available; and

[13] In this case, when land area is not available, the total area is used for the calculation.

- the Secretariat of the Pacific Community (SPD, 2012), which publishes urbanisation rates for each of its Pacific Island members.

Pieces of scientific literature mentioned earlier for the analysis of the dynamics of urban expansion (as well as other scientific literature) also focused on the evolution of population densities in urban areas. Similar information, also combined with economic and other transport-relevant figures, can also be extracted from studies carried out for companies working in different areas of urban developments (e.g. Siemens, 2012).

Gross Domestic Product

The System of National Accounts (UN SD, 2008) is the internationally agreed standard set of recommendations on how to compile measures of economic activity, including GDP. The updated version of the System of National Accounts was published jointly by the United Nations, the European Commission, OECD, the International Monetary Fund (IMF) and the World Bank Group. This is also the system that is typically used by international organizations that publish information on the subject. Selected examples of such organizations include:

- the OECD, which annually publishes the national accounts of OECD countries (OECD, 2011b and OECD, 2012), releases estimates calculated according to the three different approaches (income, output and expenditure) for each country. The GDP is available in different units: national currencies at current prices, national currencies at constant prices (national base year or OECD base year), USD at current prices and PPPs (Purchasing power Parities), and USD at constant prices and PPPs (OECD base year);
- the UNSD, which collects data on national accounts through a questionnaire (UNSD, 2011) and publishes a summary of the main national accounts aggregates, supplementing the information provided by countries with estimates (UNSD, 2012). The National Accounts Main Aggregates Database (UN, 2012c) also displays worldwide data on GDP at current prices and at constant 2005 prices in national currency and in USD, by applying the corresponding market exchange rates as reported by the IMF;
- Eurostat publishes data on GDP (Eurostat, 2012a) at national and regional levels for each European country. The data are recorded at current and constant prices and include the corresponding implicit price indices (deflators). They are expressed in ECU/Euro, in national currencies and in Purchasing Power Standards (an artificial common currency obtained by the use of PPPs);
- Twice a year the IMF publishes (IMF, 2012a) the World Economic Outlook, which contains detailed and abundant worldwide data on GDP. The statistics are also available in a database format (IMF, 2012b); and
- The World Bank's World Development Indicators database (World Bank, 2011a), contains worldwide data on GDP partly based on OECD and UNSD sources.

Economic data are also available at the local level, especially in developed cities, either from local administrations or national statistics including information for lower administrative levels. Other sources of data also include the studies carried out for companies working in different areas of urban developments, such as Siemens (2012).

Fuel costs, prices, subsidies and taxes

The price faced by final transport fuels users (the result of production costs, prices, subsidies and taxes) is also influencing the evolution of transport demand though effects spanning from urban forms, modal choices and vehicle characteristics.

Data on fuel costs, prices, subsidies and taxes are available from a wide range of sources. First, the IEA publishes on a quarterly basis data on fuel prices and taxes, including a differentiation between excise taxes and value added tax, for OECD countries and a selection of non-OECD countries (IEA, 2012a). The data are reported in national currencies and USD. In particular, these statistics (available for purchase) include:

- spot prices of crude oil, gasoline, automotive diesel, jet kerosene, marine bunker fuel, naphtha, light fuel oil and heavy fuel oil (since 1982);
- import costs and export prices of crude oil, main petroleum products, natural gas and coal in OECD countries (since 1980); and
- end-user prices and taxes (since 1978), including information on the share of excise taxes and value added tax (VAT) (whose refund is the main reason for the difference between household/non-commercial and non-household/commercial prices) for the following products and sectors: heavy fuel oil (industry, electricity generation), light fuel oil (industry, electricity generation, and household) automotive diesel (commercial use and non-commercial use), premium and regular gasoline, automotive LPG (commercial use and non-commercial use), natural gas (industry, electricity generation and households), steam coal (industry and electricity generation), cocking coal (industry), and electricity (industry and households).

A second relevant source of global data on the prices of gasoline and diesel fuel (as well as the entity of fuel taxes and subsides) is the International Fuel Prices report of the GIZ (formerly GTZ) (GIZ, 2012), a long-time effort to provide decision-makers with global data on fuel prices which, up until now, was updated every two years. The information published in this report is based on a survey conducted in mid-November of even years, leveraging the global network of regional GTZ offices, German embassies/consulates worldwide and the German Automobile Association (ADAC). It covers more than 170 countries. The GIZ data are also one of the sources used for the compilation of the World Bank's World Development Indicators (WDI) database (World Bank, 2011a).

Information on primary commodity prices is also available from the World Bank GEM Commodities database, a collection of monthly commodity prices and indices from 1960 to present, updated on the third working day of each month (World Bank, 2012). The International Monetary Fund provides similar information, updated on a weekly basis (IMF, 2012c). For transport, the most relevant commodity prices reported in these databases include oil (used for the production of petroleum products), other energy sources (coal, natural gas), cereals like maize and wheat (since they can be used for ethanol production), rapeseed oil, palm oil and other vegetable oils (used as a feedstock for biodiesel production), wood (potentially used for advanced biofuels), and sugar (related to the prices of its primary materials, i.e. sugar-bearing crops, also used for ethanol production).

The OPEC annually publishes a few data on the share of taxes in the price of a unit of oil sold to major consuming countries: Canada, France, Germany, Italy, Japan, the UK and the USA (OPEC, 2011a and OPEC, 2011b). It also publishes data on the spot prices of OPEC reference basket and other oils, as well as spot prices of the main petroleum products (gasoline, gasoil and fuel oil), and retail prices of petroleum products (gasoline, diesel oil, kerosene and fuel oil) in its member countries (OPEC, 2011a).

Fuel prices, as well as data on fuel taxation, are also available from institutional sources at the national level, even if some national statistical offices only publish price indexes (e.g. INE Chile, 2012 for Chile and INSC, 2011 for Cameroon). Some examples of national institution publishing detailed data include:

- for the United States, the statistics issued by the US BTS (US BTS, 2012) include information on the sales price of transportation fuel to end-users (road, rail and air modes), as well as average passenger fares on collective modes, together with a number of other statistics on consumer expenditures for transportation;
- for the European Union and its member states, annual industry prices of automotive diesel, unleaded gasoline (95 RON), residual fuel oil and electricity used to be published every year (EC, 2010), even if the prices reported on the Eurostat statistical database only concern gas and electricity (Eurostat, 2012a);
- in Japan, consumer prices of gasoline, LPG, kerosene and electricity (by province) are collected through price surveys and published annually on the Statistical Yearbook (Japan Statistics Bureau, 2012);
- in Canada, Statistics Canada publishes figures on the average retail prices (by urban center, and monthly) of gasoline and fuel oil (Statistics Canada, 2012c). Transport Canada annually releases figures on the retail price of regular unleaded gasoline and road diesel fuel in selected cities, as well as information on the components of the retail price of road fuels and on the price of other transportation fuels (transport Canada, 2011). A compendium of information on oil and gas prices, taxes and consumers was also published in 2006 (Finance Canada, 2006); and
- in Brazil, the ANP (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis/National Agency of Oil, Natural Gas and Biofuels), which annually publishes, in its statistical yearbook (ANP, 2012), information on the average spot price of crude oil (Brent and WTI): the average producer, importer and consumer price of gasoline, diesel fuel, LPG, jet kerosene, light fuel oil and heavy fuel oil, and the average consumer price of hydrous ethanol.

In South America, the UN ECLAC database also includes information on the price structure (refinery price, taxes, estimated gross margin and consumer price) of oil products such as gasoline (regular and premium), diesel oil, LPG, kerosene and fuel oil (UN ECLAC, 2012). Altomonte and Rogat (2004) analyzed in detail the policies of different countries with respect to fuel prices in South America. Campodonico (2009) also addressed the same subject, as well as Altomonte (2008). These two reports used information drawn from a wide range of national sources and can also be used as reference for the identification of data sources at the national level.

Fuel taxation data for African countries have also been collected and published in the context of the Africa Infrastructure Country Diagnostic (AICD) (ADBG, 2012). The data included in the dataset accompanying the report of Foster and Briceño-Garmendia (2010) on this topic include, in particular, information on fuel levies to fund road maintenance. Additional information on this subject is also available in Gwilliam et al. (2008).

Industrial groups and their associations also release additional data concerning the prices of primary materials they use. A relevant example, for sugar cane, is the UDOP (União dos Produtores de Bioenergia, Union of Bioenergy Producers) (UDOP, 2012).

Considerable information on the fiscal treatment of fuels is also available in analyses looking specifically at the importance of subsidies in the energy and transport sectors. The Global Subsidy Initiative (GSI) published some of the most interesting pieces of analysis in this area (e.g. Charles and Wooders, 2011, as well as other reports listed in GSI, 2012a and GSI, 2012b), at times working in collaboration with the IEA (e.g. for IEA, 2011b).

Further information on this topic is also available in the next Chapter.

Vehicle costs and vehicle taxation

Information on vehicle costs may be extracted from publicly available databases containing information on the values and volumes associated to the relevant sub-category of the consumer (or household) expenditure. In the case of Canadian road vehicles, for instance, Statistics Canada reports both the value of their purchase and the corresponding sales volume (Statistics Canada, 2012d), providing information that are sufficiently disaggregated to extract the unit cost of new road vehicles entering the market. Other sources of information on the average vehicle prices include ORNL (2011) for passenger cars sold in the United States. In European Union, an indication of the price of vehicles can be obtained from EC (2011d), a report aimed at the comparison of prices across the different EU member states.

Specific reports attempting to provide information that summarize vehicle prices, like ORNL (2011) and EC (2011d), focus mainly on light duty passenger vehicles. In the case of EC (2011d), the price data are only concerning a selection of models and motorizations, and they correspond to the prices as recommended by manufacturers, rather than those actually applied by distributors. EC (2011d) also does not provide price figures that are coupled with sales volumes. On the other hand, Eurostat (2012a) and EC (2011) provide data on the evolution of consumer prices for passenger transport, including indexes for motor cars, as well as motorcycles, bicycles and animal drawn vehicles (all in one category).

A complete picture on vehicle prices for different transport modes is not easy to obtain. One solution is the use of detailed data provided by the consultants already mentioned on the section concerning vehicle characteristics, since vehicle prices can be one of the parameters associated with the vehicle sales volumes in their databases. As in the case of other vehicle characteristics, such data are mainly available for the automotive market (road modes, and light duty vehicles in particular).

Another possibility is the estimation of vehicle prices from assessments analyzing vehicle costs on the basis of the vehicle technical characteristics, with special attention paid to differences due to the powertrain technology used. These analyses are available for different vehicle types within each mode, even if in most cases they have a continental (or national) coverage. Road vehicles (and, in particular, light duty passenger vehicles) also tend to be the subject of a larger number of studies. Selected examples of this sort of assessments for inland transport vehicles are included in A complete picture on vehicle prices for different transport modes is not easy to obtain. One solution is the use of detailed data provided by the consultants already mentioned on the section concerning vehicle characteristics, since vehicle prices can be one of the parameters associated with the vehicle sales volumes in their databases. As in the case of other vehicle characteristics, such data are mainly available for the automotive market (road modes, and light duty vehicles in particular).

(rail and inland waterways) and Table 8 (road).

Table 7. Assessments CO_2 emission reduction potential and costs on rail vehicles and inland waterways vessels

Mode	Vehicle type	Assessment	Reference
Rail	All vehicles	Technical options to reduce GHG for non-road transport modes	Halzedine et al., 2009
	Passenger	Rail passenger transport. Techno-economic analysis of energy and greenhouse gas reductions	Andersson et al., 2011a
	Freight	Rail freight transport. Techno-economic analysis of energy and greenhouse gas reductions	Andersson et al., 2011b
Inland waterways	All vehicles	Technical options to reduce GHG for non-road transport modes	Halzedine et al., 2009
		General cost structure and development	CCNR, 2012
		Technical options for maritime and inland shipping	Skinner, 2009

The use of the last approach has the advantage of also being suitable for expected vehicle costs in the future, but also the disadvantage of being an estimate. In order to avoid errors, it is important to calibrate them correctly, e.g. by using public information on the prices of representative vehicles that are released by the companies that manufacture them.

The characterization of vehicle prices also depends on the taxation regime concerning their purchase and use: this typically includes a combination of the value added tax, a registration tax, and an annual circulation tax.

An overview of motor vehicle taxation in 31 European countries, as well as other major world markets (Brazil, China, India, Japan, Korea, Russia and the United States) is regularly published by Assocation des Constructeurs Européens d’Automobiles, European Vehicle Manufacturers Association (ACEA) (ACEA, 2011a).

Table 8. Assessments CO_2 emission reduction potential and costs on vehicles (road modes)

Mode	Vehicles	Assessment	Reference
Road	All vehicles	Technical GHG reduction options for fossil fuel based road transport	Sharpe, 2010
		Transport, energy and CO_2. Moving towards sustainability	IEA, 2009a
	Light duty vehicles	Well-to-wheels analysis of future automotive fuels and powertrains in the European context. Vehicle retail price estimation	Edwards et al., 2011
		Techno-economic analysis of low-GHG emission passenger cars	Safarianova et al., 2011a
		A portfolio of power-trains for Europe: a fact-based analysis. The role of battery electric vehicles, plug-in hybrids and fuel cell electric vehicles	McKinsey, 2010
		Estimate of the technological costs of CO_2 emission reductions in passenger cars	Herbener et al., 2008
		Energy efficiency technologies for road vehicles	Kobajashi et al., 2009
		More sustainable transportation: the role of energy efficient vehicle technologies	Heywood, 2008
		Potential and costs for further CO_2 reduction beyond 2012 – development of indicative future cost curves	Smokers, 2008
		An overview of hybrid technologies	Jackson, 2007
		The King Review of low-carbon cars. Part I: the potential for CO_2 reduction	King, 2007
		Review and analysis of the reduction potential and costs of technological and other measures to reduce CO_2-emissions from passenger cars	Smokers et al., 2006
		Trends in vehicle and fuel technologies. Review of past trends	Pelkmans et al., 2003
	Heavy duty vehicles	Reduction and testing of greenhouse gas (GHG) emissions from heavy duty vehicles	Hill, Finnegan et al., 2011
		European Union greenhouse gas reduction potential for heavy-duty vehicles	TIAX, 2011b
		Techno-economic analysis of low-GHG emission light, medium and heavy duty vehicles	Safarianova et al., 2011b
		Technologies and approaches to reducing the fuel consumption of medium- and heavy-duty vehicles	NRC TRB, 2010
		Reducing heavy-duty long haul combination truck fuel consumption and CO_2 emissions	NESCCAF et al., 2009

An overview of fiscal and other economic measures intended to reduce CO_2 emissions from cars focusing on the European Union, was also undertaken by Bastard (2010), together with a qualitative analysis of the impact of these instruments in terms of market fragmentation and challenges for manufacturers.

Prior to this assessment, a quantitative analysis on the effects of fiscal measures aimed to reduce CO_2 emissions from new passenger cars in the EU was undertaken by COWI (2002). This study was paired with a study on vehicle taxation in the EU (TIS.PT, 2002)[14]. Other studies (e.g. ECMT, 2007) also cover this topic.

Further information on this topic (as well as fuel taxation), contextualized in a broader framework on transport polices, is also available in the next Chapter.

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[14] Both analyses were aimed at the preparation of the ground for a Communication (EC, 2005) that proposed a directive containing policies and options aimed at the improved functioning of the internal market (by removing existing tax obstacles to the transfer of passenger cars across EU countries) and at the establishment of an EU structure for passenger car taxes to attain environmental objectives, even if this text has not been converted into EU legislation, to date (EC, 2012b).

3. Policy measures aimed at the reduction of CO_2 emissions

The context

Table 9. Climate change: fundamental steps

Year	Event	Documentation
1979	First World Climate Conference (WCC)	
1988	Setup of the Intergovernmental Panel on Climate Change (IPCC)	
1990	IPCC's 1st assessment report	IPCC, 1990
	IPCC and second World Climate Conference calling for a global treaty on climate change	
	Beginning of the United Nations General Assembly negotiations on a framework convention	
1991	First meeting of the Intergovernmental Negotiating Committee (INC)	
	Establishment of the Global Environment Facility (GEF) as a pilot program in the World Bank	
1992	Adoption of the UNFCCC text by the INC	UNFCCC, 1992
	Rio Earth Summit	
	UNFCCC opened for signature along with its sister Rio Conventions: UN Convention on Biological Diversity (UNCBD) and the Convention to Combat Desertification (UNCCD)	
1994	Entry into force of UNFCCC	
	Restructuring of the GEF, entrusted to become the financial mechanism for both the UNFCCC and the UNCBD	
1995	IPCC Second Assessment Report	IPCC, 1995
	First Conference of the Parties (COP1), in Berlin	
1996	Setup of the UNFCCC Secretariat	
1997	COP3: adoption of the Kyoto Protocol	UNFCCC, 1998
1998	COP4: Buenos Aires Action Plan	
2001	IPCC's Third Assessment Report	IPCC, 2001
	COP6 Part II: adoption of the Bonn Agreements	
	COP7: adoption of the Marrakesh Accords	
2005	Entry into force of the Kyoto Protocol	
	COP11: first Meeting of the Parties to the Kyoto Protocol (MOP1), in Montreal	
	COP11: launch of negotiations on next phase of Kyoto Protocol	
	COP11: Nairobi Work Programme on Adaptation	
2007	IPCC's Fourth Assessment Report	IPCC, 2007
	COP13: Bali Road Map and Bali Action Plan	UNFCCC, 2007
2009	COP15: Copenhagen Accord	UNFCCC, 2009
2010	COP16: Cancun Agreements	UNFCCC, 2010
2011	COP17: Durban Platform for Enhanced Action	UNFCCC, 2011a

The reduction of CO_2 emissions shall be framed in a context that takes into account the emergence of increased awareness on the climate change phenomenon, the build-up of institutional instruments designed to address it (in the UN framework) and the improved understanding of its scientific foundation (resulting in the IPCC Assessment Reports). The key overarching steps contributing to the definition of this context are summarized in Table 9.

The United Nations Framework Convention on Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC), which entered into force in March 1994, sets the overall framework for intergovernmental efforts to tackle the challenges posed by climate change. It now has universal membership (all 195 countries ratified it).

The Kyoto Protocol (2008-2012)

The Kyoto Protocol is an international agreement linked to the UNFCC, which was adopted in December 1997 and entered into force in February 2005. It recognizes the larger responsibility of developed countries for the growing levels of GHG concentration in the atmosphere, and, under the principle of "common but differentiated responsibilities", sets binding targets for 37 industrialised countries and the European Union for reducing GHG emissions, committing them (as a group) to curb domestic emissions by about 5 per cent relative to 1990 in the "first commitment period" (2008-2012) (IEA, 2011a).

The Kyoto Protocol also creates three cooperative mechanisms by which industrialised countries can transfer emission allowances among themselves and earn emission credits from emissions reduction projects in other countries:

- the Clean Development Mechanism (CDM);
- the Joint Implementation (JI); and
- emission trading.

The Marrakesh Accords further defined the principles, nature and scope of all three cooperative mechanisms (specifying that that their use of the mechanisms is "supplemental to domestic action", even if they did not impose any concrete limits on the extent to which the mechanisms may be used). They also charted in detail the reporting and review framework introduced by the Kyoto Protocol. In order to understand whether its targets are met, the Kyoto Protocol requires the transparent and verifiable reporting of the GHG emissions and removals (also subject to a review by experts) through the submission of annual emission inventories and national reports by the Parties that committed themselves to the binding targets. Following the decisions of the Marrakesh Accords[15], countries are also required to have a national system in place to estimate GHG emissions and removals, along with a national registry to account for, record and monitor transactions related to the

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[15] The Marrakesh Accords (in 2001) followed the Bonn Agreements (in 2001). Both contributed to settle some the issues concerning operational details of the Kyoto Protocol that were defined by the Buenos Aires Action Plan (in 1998). These steps were all instrumental for the following adoption of the Protocol. The Marrakesh Accords also include a decision concerning the establishment of a fund for the financing of adaptation projects.

cooperative mechanisms. The UNFCCC Secretariat also keeps an international transaction log to verify transactions are consistent with the rules of the Protocol. In addition, a compliance system ensures that Parties are meeting their commitments.

Despite its extensive coverage (193 Parties), not all major emitters are included in reduction commitments: the United States, for instance, remains outside of its jurisdiction and the Minister of the environment of Canada recently announced that Canada will formally withdraw from it (BBC, 2011).

Currently, the Kyoto Protocol requires action on less than one-third of global CO_2 emissions, as measured in 2008 (IEA, 2011a).

Post-2012 climate change policy

The beginning of the negotiations on the post-2012 climate change policy follows the 2005 entry into force of the Kyoto Protocol (COP11), with the establishment, in Montreal (COP11) of an Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP), focusing on the design of post-2012 commitments for Parties that committed themselves to GHG emission targets under the Protocol.

Bali Road Map and Bali Action Plan

The Bali Road Map, adopted in 2007 (COP13), specifically includes the Bali Action Plan. This does not contain binding commitments to reduce GHG emissions, but it is a first move toward a broadened scope for the post-2012 negotiations, since it launched a comprehensive process aimed at the adoption of an international climate policy agreement two years later in Copenhagen[16]. The Bali Action Plan also introduced measurable, reportable and verifiable Nationally Appropriate Mitigation Actions (NAMAs), placing them in the broader context of sustainable development and enlarging the scope of commitments that can be taken under the Convention to all Parties, including developing countries (and not only countries that committed to targets under the Kyoto Protocol). The Action Plan also included the decision to enhance the action on the provision of financial resources and investments on mitigation, adaptation and technological cooperation (from developed countries and to developing countries); something that is now central to the establishment of a post-2012 framework for climate action[17].

Copenhagen Accord

In Copenhagen (2009, COP 15), there was no agreement on further climate action under either of the two negotiating tracks (AWG-LCA for the Convention or AWG-KP at the Kyoto Protocol level), even if the mandate to work under both these tracks was extended in order

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[16] The Bali Action Plan also led to the establishment of another Ad-Hoc Working Group, looking at Long-Term Cooperative Action (AWG-LCA). This group was expected to work in parallel with the AWG-KP while also being able to move beyond the scope and limitations of the latter, since the AWG-KP lacked a mandate to encourage participation from Parties that do not commit to any target under the Kyoto Protocol or did not ratify it.

[17] In addition, the Bali Road Map includes the decisions to take enhanced actions on adaptation, technology development and on the provision of financial resources, as well as measures against deforestation.

to deliver results at the next COP (Cancún). The outcome of COP15 was the Copenhagen Accord, a deal negotiated between 30 Heads of States and Governments, whose countries are responsible for more than 80 per cent of the global GHG emissions.

This accord enabled countries that committed to Kyoto targets to announce further pledges strengthening the emissions reductions initiated by the Kyoto Protocol (but also commitments concerning financing), as well as developing country Parties to proceed with the definition of NAMAs. In addition, it stated the intention to establish the Green Climate Fund for the provision of financial resources, intended to be the operating entity of the financial mechanism of the UNFCCC.

The accord also clarified that NAMAs encompass projects, programmes, policies and other activities implemented at national, regional, or local levels.

Cancún Agreement

The Cancún Agreement included substantive decisions that helped renew faith in the UNFCCC process for the achievement of a legally binding framework for climate action for the period after 2012.

In Cancún, the key elements of the Copenhagen Accord were formally adopted into the UN process. This included:

- the first official endorsement in a UN document of the target to limit a global temperature increase to less than 2 °C above pre-industrial levels (with reference to a 1.5 °C in the long-term);
- the endorsement of the voluntary commitments for 2020 from Parties bound by targets under the Kyoto Protocol, as well as the endorsement of the NAMAs concept for all other Parties;
- the actual decision to establish the Copenhagen Green Climate Fund for the provision of financial resources;
- the sketching of a framework for monitoring and reviewing mitigation actions and commitments comprised of the decision to require quadrennial submissions of national communications (including inventories) and biennial updates of inventories to all Parties, as well as other requirements in terms of GHG emission measurement, reporting and verification; and
- provisions for the establishment of a registry to record NAMAs seeking international support to facilitate the matching of finance, technology and capacity-building support for them.

The Cancún Agreement also took note of quantified economy-wide emission reduction targets to be implemented by Parties that committed to GHG emission mitigation actions under the Kyoto Protocol (submitted following the Copenhagen Accord), as well as NAMAs already communicated, and recognized the commitment to a goal of jointly mobilizing USD 100 billion per year by 2020 to address the needs of developing countries.

Finally, it includes a number of decisions on adaptation[18] and, in the area of technology transfer, on the establishment of a Technology Executive Committee and a Climate Technology Centre and Network for the promotion and facilitation of technology development and transfer (to be made operational in 2012).

Durban Platform for Enhanced Action

The main outcome of COP17, held in Durban in 2011, was the "launch of a process to develop a protocol, another legal instrument or an agreed outcome with legal force under the Convention applicable to all Parties", including those that are not currently bound under the Kyoto Protocol under new Ad-hoc Working Group on the Durban Platform for Enhanced Action (AWG-DPEA). This Working Group has been mandated to start work in 2012 and deliver an outcome as soon as possible, and no later than 2015, building on the Fifth IPCC Assessment Report. This instrument shall come into effect and be implemented from 2020.

Another important outcome was the implementation of the Green Climate Fund, to support projects, programmes, policies and other activities in developing countries that are consistent with national climate strategies. The Fund shall promote a shift toward low-emission development pathways in the context of sustainable development. It shall receive financial inputs from developed country Parties and other public, private and alternative sources, but its financing in the long term, as well as the share of the annual commitment of USD 100 billion (included in the Cancún Agreement) that could actually flow through the Fund (Allen et al., 2012).

In addition, the Durban Conference delivered a number of decisions in the framework established by the Copenhagen Accord and their formal adoption in Cancún. It included some progress on the information to be included in the registry that will record NAMAs seeking international support, and it encouraged developing countries to define low-emission development strategies (LEDs), with the implication that NAMAs will be framed within these. Guidelines for biennial reporting and their international consultation and analysis for developing country Parties were also developed.

Current situation

The agreement envisaged by the Durban Platform for Enhanced Action is not expected to enter into force sooner than 2020. The first commitment period of the Kyoto Protocol will expire in 2012.

For countries that committed to binding targets under the Kyotp Protocol, the AWG-KP decided that the second commitment period shall begin in 2013 and end either on at the end of 2017 or 2020. At the moment, the emission reduction targets to be implemented beyond 2012 are those that emerge from the voluntary commitments for 2020 taken in the framework of the Copenhagen Accord and the Cancún Agreement. A compilation of these economy-wide emission reduction targets to be implemented by countries, bound by their

[18] The establishment of the Cancun Adaptation Framework with the objective of enhancing action on adaptation (including technical assistance and financial support), the establishment of an Adaptation Committee under the Convention, and the start a process to enable least developed country Parties to formulate and implement national adaptation plans.

commitments under the Kyoto Protocol, was issued by the UNFCCC secretariat in 2011 (UNFCCC, 2011b).

In addition, the decisions of the AWG-KP have the goal to ensure that GHG emissions by Parties that committed to targets under the Kyoto Protocol are reduced by at least 25 to 40 per cent below 1990 levels by 2020 (UNFCCC, 2011c). These ranges (both in terms of timelines and GHG emission reduction), as well as the Canadian decision to withdraw from the Kyoto Protocol (BBC, 2011) leave a question mark over the actual impact of international climate change mitigation actions for this period.

For countries that did not commit to binding targets under the Kyotp Protocol, NAMAs are increasingly seen as the framework under which can mitigate their GHG emissions and to receive international support for their efforts. They are also expected to be the main vehicle for mitigation action in developing countries under a future climate agreement. A compilation of information on nationally appropriate mitigation actions to be implemented by Parties that are not bound by Kyoto targets was issued by the UNFCCC secretariat in 2011 (UNFCCC, 2011d).

IEA calculations suggested that emission reduction pledges for 2020 fall short of what is needed to limit the long-term concentration of GHGs in the atmosphere to 450 parts per million of CO_2-equivalent, in line with a 2 °C average temperature increase (IEA, 2010b).

CO_2 emission mitigation polices in transport

Countries that committed to GHG emission reduction targets in the framework of the Kyoto Protocol, as well as other developed and developing economies, established national strategies and implemented a number of polices to curb GHG emissions.

A number of these policies are relevant for the transport sector and, in particular, for inland transportation. A selection of strategies and targets that were recently implemented in developed countries is included in the following section.

Policy instruments

Demand for transport services is economically rational when the willingness of individuals and businesses to pay for trips/freight movements exceeds the social (private plus external) marginal costs of each trip (ECMT, 2007). Measures aiming at the regulation of economic activities (including transport) should assure that this is the case.

This also suggests that the ideal instruments to regulate economic activities are those capable of:

- "internalize" externalities (eliminating the divergence between marginal private cost and the marginal social cost);
- allow the lowest cost options to be exploited first; and
- limit this process to the point where marginal social costs actually equal marginal social benefits.

Experience has shown that a wide range of considerations should be taken into account when considering the potential effectiveness of policy. These considerations range from the need to coordinate between all levels of governance, the involvement and participation of stakeholders, as well as the availability of coherent political support and firm commitments (ADB, 2009a). To gguarantee that policy measures can attain these results, policies need to:

- openly identify the objective (be rational);
- clearly illustrate how to achieve the relevant objective (be transparent);
- lead to costs increases that do not exceed the increase of benefits, in order to guarantee the best use of resources (be efficient);
- avoid imposing different marginal costs to different people and businesses, i.e. avoid discriminatory advantages and disadvantages, and provide solutions if they do occur (be fair);
- deliver results without unnecessary costs or excessive procedural costs for users (e.g. because procedural costs exceed the difference in marginal cost imposed to users) (be cost-effective);
- address the negative impacts of the choices of some users on the utility of other users, particularly if this takes place without adequate compensation (avoid negative externalities); and
- assure the availability of necessary resources for implementation (be economically sustainable).

In the case of CO_2 emission abatement policies, cost-effectiveness has been evaluated as the fundamental determinant for the policy selection (ECMT, 2007). This is also the case when the contribution of the transport sector has to be evaluated in comparison with CO_2 emission mitigation efforts concerning other sectors of the economy.

In transport, most analysts agree that CO_2 emission mitigation should be comprehensive and integrated across different modes.

Some researchers also argue that, even if CO_2 emission abatement opportunities in the transport sector can be derived effectively through a wide set of policy options, carbon and fuel taxes are the ideal measures for addressing CO_2 emissions, since they are estimated to have the highest impact of a wide range of CO_2 emission mitiagtion measures (ECMT, 2007).

Other authors note that a complex task such as the development of a low-carbon transport strategy is unlikely to be feasible using a single policy intervention, especially when polices do not only tackle the CO_2 emission abatement, but also other problems like local pollution, congestion and noise. This is why they suggest that an effective strategy should include the adoption of a package of instruments, often comprising a range of different types of policies reinforcing the impact (and offsetting the disadvantages) of others (ADB, 2009a).

The instruments available to get to this objective typically include economic measures, regulatory approaches and participatory initiatives.

Economic measures

Economic measures, and in particular, the use of price signals to manage demand for transport, have a profound influence on the way traffic and infrastructure develop and play a fundamental role in conditioning the impact and effectiveness of almost all government policies toward transport (ECMT, 2007). They typically include taxes, subsidies, the exemptions from levies and other financial incentives, or in some cases the combination of these instruments.

In the case of GHG emissions, the carbon tax (i.e. a tax on each unit of GHG emissions), ideally set to a level that assures the balance between increasing marginal social costs and benefits, is probably the best example of a policy capable of attaining all the objectives required for a CO_2 emission abatement policy.

Alternatively, the same efficiency and fairness can be achieved by cap-and-trade market-based mechanisms (technically equivalent to a carbon tax, but governed by a fixed target rather than a fixed cost).

While the first approach (carbon tax) assures less uncertainty in terms of costs (but larger uncertainties with respect to the objective to attain in terms of emission reduction), the second possibility allows for better control of the targets to be reached (in terms of emissions), but offers less certainty in terms of costs. In addition, market-based mechanisms tend to be characterised by a higher level of political acceptability because of the weaker perception by the public of their effect on the price of goods and services.

In case of road usage, the best way to address all the requirements mentioned earlier (including the possibility to internalize externalities) is likely to require a pricing scheme capable of taking into account the need to recover infrastructure costs and at the same time the negative externalities of traffic (i.e. the incremental loss of time imposed by users of congested infrastructures on other uses).

The main disadvantages of this solution are its complexity for users; the distance from measures currently implemented to recover infrastructure costs and to deal with traffic; and the need to develop and deploy from scratch a substantial set of specific instruments for its enforcement.

In some occasions, the complexity of market-based instruments led to the adoption of solutions that attempt to narrow the gap between individual self-interest and the social optimum using the combination of some generic assumptions with economic instruments. Looking at transport polices for GHG emission mitigation, the main examples in this respect are feebates (a combination of taxes and subsidies) and differentiated taxation on vehicles, since deterministic vehicle characteristics are combined with the estimated average vehicle usage over the course of a given period of time (e.g. one year in case of annual vehicle circulation taxes).

Other economic instruments specifically target the promotion of research for the development of advanced technologies, as well as the support of their deployment. A sound justification for these measures is given by the opportunities offered by the deployment and scale-up of new technologies. This is due to economies of scale and the technology learning process, both leading to cost reductions with increasing sales volumes (see for instance Wene, 2000).

Regulatory polices

Command and control (or regulatory) policies can be easier to implement than economic instruments, but they are not immune from inefficiencies such as the obligation to face different marginal costs for different users. They are best suited for a number of specific situations: emergencies, interventions targeting specific fields and cases when the optimum is very close to a condition that can be easily and precisely defined (e.g. zero emissions of a given pollutant, when even a small release of this pollutant would lead to high social and environmental losses).

Some examples of command and control polices include mandatory fuel quality specifications (such as those needed to assure the adequate functioning of instruments capable of reducing pollutant emissions, or those concerning the carbon content of fuels), standards limiting pollution levels (e.g. for noxious pollutants released by the uncontrolled combustion of fuels), the regulation of access to road transport infrastructure, setting speed limits to guarantee the safe usage of infrastructures, decisions on land-use planning, as well as fuel efficiency standards for light duty and heavy duty road vehicles.

Participatory instruments

A third category of measures encompasses instruments that are concerned with the direct involvement of consumers and businesses. These measures typically include awareness-raising campaigns, instruments capable to improve consumer information (e.g. labeling schemes or the dissemination of best practices) and the negotiation of voluntary agreements between the industry and regulators.

They can be combined with economic instruments (e.g. reducing the cost of training programs through fiscal incentives, or using taxation in combination with labeling) and regulatory approaches (e.g. the progressive phase-out of obsolete and underperforming options, combined with labeling and awareness-raising initiatives).

Classification of transport policies

Policy options having an impact on the mitigation of CO_2 emissions in transportation have been classified following the extended ASIF framework (where emissions are determined on the basis of Activity, Structure, energy Intensity and Fuel characteristics) (ECMT, 2007). In this case, they were associated with four different targets:

- the total transport activity or the total movement of goods and people within an economy (Activity);
- the market share of each mode of transport (modal split, or Structure);
- the energy required to move one passenger-kilometre or one tonne kilometre (energy Intensity or fuel efficiency); and
- the carbon intensity of alternative fuels (Fuel characteristics).

Merging the last two bullet points into one, transport policy options have also been grouped according to three fundamental strategies, well represented by the Avoid-Shift-Improve keywords (ADB, 2009a):

- avoiding or reducing the need for travel, managing the total travel demand (Avoid);
- shifting travel to more sustainable transport modes (Shift); and
- improving the sustainability of vehicles, fuels and infrastructures concerning all modes, leveraging technologies capable to reduce or eliminate the emissions of GHG and noxious pollutants (across their entire life cycle of products), as well as noise (Improve).

Table 10 and Table 11 contain a list of the main economic instruments and regulatory policies that are frequently used in transport, broadly classified according to this framework (even if the interpretation of some of these instruments may actually cover more than one field). The measures listed include:

- instruments, such as levies on fuels and levies on road usage, which typically characterize the transport sector, even if they do not exclusively target the CO_2 emission mitigation;
- policies that are specifically targeting CO_2 emission mitigation (like the carbon tax and regulatory measures on the carbon content of fuels); and
- measures that aim to achieve other goals (such as increased energy diversification in transport, or the countercyclical support of economic development), but also have an impact in terms of CO_2 emission mitigation.

Table 10. Economic measures related to CO_2 emission abatement in transport

	Economic measure
Avoid/Shift	Levies on road usage Levies on fuels (excise taxes, mineral oil taxes, energy levies) Levies (access, congestion, parking) aimed to discourage the use of private vehicles (traffic management)
Shift	Subsidies, incentives, exemptions to promote public transport Subsidies, incentives, exemptions to promote energy-efficient freight transport modes
Improve	Levies on fuels based on carbon content (carbon tax, emission trading) Differentiated acquisition levies (passenger light duty road vehicles) Differentiated annual circulation levies (passenger light duty road vehicles) Differentiated annual circulation levies (heavy duty and commercial road vehicles) Instruments (subsidies, incentives, exemptions from levies) promoting the commercial deployment of fuel efficient vehicles (e.g. electric and hybrids) Instruments promoting the commercial deployment of vehicles using alternative fuels (mainly natural gas) Instruments promoting biofuels Instruments promoting natural gas use in transport Instruments linked to vehicle scrappage schemes (for fleet renewal) Levies linked to the import of old used vehicles or parts (deterrent)

Table 11. Regulatory polices related to CO_2 emission abatement in transport

	Regulatory policy
Avoid/Shift	Urban passenger transport and land-use planning (communities, non-motorized transport, public bicycle schemes, urban density, mixed-use, public transport network integration and enhancement) Traffic management measures like travel restrictions (access, parking, low pollutant emission zones) for specific vehicle categories and/or specific times Freight transport planning (freight networks, hubs and logistical centers)
Shift	Improvement/restructuring of the regulatory framework on urban public transport
Improve	Fuel economy standards for light duty road vehicles Fuel economy standards for heavy duty road vehicles Mandates on biofuels Regulatory measures on the carbon content of fuels Regulatory framework for fuel efficient vehicles (e.g. electric and hybrids) Mandates on fuel efficient vehicles Mandates on natural gas vehicles Improved periodical technical control of vehicles (including enforcement) Import bans and restrictions for old used vehicles

In addition to this, infrastructural measures focusing specifically on the development of the transport network, as well as participatory instruments, can also lead to CO_2 emission mitigation.

In the case of infrastructural measures, this is especially the case for initiatives targeting the development of the most efficient transport modes (e.g. promoting modal shift in urban areas to public transport, improving the public transport characteristics making it a more attractive mobility option, or developing non-motorized modes like walking and cycling), initiatives related to long-distance passenger transport (such as the establishment of high speed rail links between large cities) and the development of intermodal freight transport. Other initiatives, such as the improvement of road networks, are more likely to result in GHG emissions and energy use increases, rather than savings. In addition, they find their justification mainly in the areas of increased safety and improved mobility and accessibility, at least in developing countries.

Looking at participatory instruments, GHG emission mitigation can be fostered through awareness raising campaigns addressing the environmental characteristics of transport vehicles (possibly resulting in avoided travel and shifts to more efficient modes, or incentivizing eco-driving trainings), labeling schemes on energy consumption and CO_2 emissions (since they provide better consumer information), and voluntary agreements between governments and the manufacturers of vehicles, equipments and components.

Application of CO_2 emission mitigation policies in transport

This section links the most significant transport policies that are having an impact on CO_2 emission mitigation with countries that are enforcing them (or did so in the past decade), also distinguishing amongst measures that target primarily fuels and vehicles,as opposed to measures that are addressing the transport system as a whole.

In addition, it builds on announcements and analytical assessments to summarize some of the expected policy developments, mainly focusing on the next decade.

Finally, it includes discussions on the usage patterns of regulatory policy instruments across countries that are now facing different types of challenges, attempting to identify whether there is a tendency to adopt similar solutions and, if so, what are the preferred options corresponding to selected representative cases[19].

Policies on transport fuels

According to the GIZ (GTZ, 2009 and GIZ, 2012), between two thirds and three quarters of the countries in the world impose levies on road transport fuels, while in the remaining fraction (mainly composed of oil producing and exporting countries), fuel prices are currently below the international minimum benchmark for a non-subsidized road transport policy.

Typically, countries imposing levies on fuels do so using instrument like excise taxes, mineral oil taxes, other energy-related levies and the VAT. In most cases, these instruments target road as well as other inland transport modes, even if there are a number of cases when fuels are subject to exemptions if they are used for public transport or specific transport modes (e.g. because of their better efficiency), like rail and inland navigation (Table 12).

Despite certain shortcomings, fuel taxes are also used in several developed and developing countries to charge road users: the financing of the roads and highways infrastructure via fuel taxes is the primary pricing policy instrument worldwide (GTZ, 2009), even if other charges (namely annual circulation levies for heavy duty and commercial road vehicles, often differentiated on the basis of the vehicle weight) are also collected for this purpose. On a global average, some 80% to 90% of all transport sector revenues are raised via fuel taxes (GTZ, 2009).

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[19] This section partly builds on the information collected by the UNECE through a questionnaire developed by the UNECE Transport Division (jointly with the other Regional Commissions of ECA, ECLAC, ESCAP and ESCWA), circulated to all member countries of the UN, as well as a number of international and non-governmental organizations and resulting in the provision of information by roughly 40 institutions. Specific desk research, targeting a number of literature sources (as indicated) was also performed to complement this information.

Table 12. Economic measures aiming to manage travel demand and shift transport towards more efficient modes

Economic measure	Countries	Sources
Subsidies, incentives, exemptions to promote public transport	Canada (tax credit for public transport passes), EU (passenger transport services frequently subject to lower VAT), France (partial refund on the excise tax levied on diesel fuel for public transport), Germany (reduced fuel tax for public transport), Hungary (refund of excise tax on diesel fuel in rail), Finland (tax exemption for electricity in rail, reduced VAT for public transport, tax relief for employer-subsidized tickets), Italy (income tax allowance for public transport; 60% reduction in the excise tax on petroleum products used for public transport, and 70% reduction on the excise tax on diesel fuel in rail), Mexico (financing scheme for cities), Spain (tax exemption on employer-paid public transport), Sweden, Turkey (mass transit companies exempt from tax if public administrations manage or own them), United States (tax credits for commuter trip reduction at the State level)	EEA, 2007 OECD, 2011c OECD-EEA, 2012 UNECE questionnaire
Subsidies, incentives, exemptions to promote energy-efficient freight transport modes	Hungary (refund of excise tax on diesel fuel in rail), Finland (excise tax exemption for electricity used in rail and vehicle tax refund for lorries transported by rail), Germany (fuel-tax exemption for internal waterway transportation), Italy (70% reduction in the excise tax on diesel used in rail; fuel tax exemption for shipping, including inland waterways), Spain (aviation, navigation, and railway transport exempt from the fuel tax normally levied on sales of petroleum products), Switzerland (compensation of freight rail transportation), United States (State level: exemption from the state excise tax levied on sales of both diesel and gasoline for commercial watercraft and railroad locomotives in West Virginia)	OECD, 2011c OECD-EEA, 2012

Fuels used in international transport represent an important exception in the context of fuel taxation, since they are generally exempt from it. An international agreement signed in December 1944 exempts fuels used for international aviation from any kind of levy[20] (even if this is not the case for domestic flights[21]), while a number of other arrangements also exempt fuel used in international transport by rail and water (OECD, 2011c). Nevertheless, since 2012 (EC, 2008), all airlines operating domestic and international flights involving an airport located in the EU are obliged to comply with the EU Emission Trading Scheme (ETS) (EC, 2003a), a market-based instrument implemented in 2005 to limit GHG emissions arising from the most energy-intensive sectors of the economy (representing around half of all European GHG emissions).

Market-based measures like the European ETS, as well as carbon taxes, are amongst economic policies concerning transport fuels that aim specifically at the mitigation of CO_2 emissions. This is also the case of regulatory measures like the adoption of specific requirements on the carbon content of fuels. Table 13 couples all the measures primarily aimed at CO_2 emission mitigation in transport with countries where they are being enforced, clearly illustrating that these sorts of instruments are mainly used in developed countries, and often in the framework of the commitments they signed under the Kyoto protocol.

Table 13. Countries adopting measures that aim primarily at the mitigation of CO_2 emissions in transport

Policies	Countries	Sources
Levies on fuels based on carbon content (carbon tax, emission trading schemes)	Albania (carbon tax component on fuels), European Union (emission trading scheme), Finland (fuel tax based on energy content, carbon content and local/particle emissions), Iceland, Ireland (carbon tax of 15 €/t on fuels), Luxembourg (fuel tax used to mitigate climate change), New Zealand (emission trading including the transport sector), Norway and Sweden (carbon tax component on fuels)	EC, 2003a EC, 2008 OECD-EEA, 2012 UNECE questionnaire
Regulatory measures on the carbon content of fuels	California (low carbon fuel standards), Canada (Ontario and British Columbia, similar to California), European Union (fuel quality directive), United States (renewable fuel standard)	Baral, 2009 EC, 2009c ICCT, 2010 US EPA, 2012b

[20] This was mainly aimed at the prevention of distortions of aviation markets among countries (such as double taxation of fuel) and at avoiding inefficient tax-avoidance behavior (such as airlines scheduling routes ad refueling stops in a way allowing to reduce tax payments).

[21] Several OECD countries, including the United States, the Canadian province of Alberta, Japan and Norway now apply taxes on fuel used for domestic flights. In the European Union, a fuel tax can be levied on domestic flights within Member States (EC, 2003b).

Table 14 and Table 15 provide information on countries that adopted economic and regulatory measures concerning transport fuels that have important impacts, even if they do not aim only at CO_2 emissions mitigation.

The instruments listed in Table 14 and Table 15 deliberately exclude inefficient subsidies for petroleum fuels, since there is little in them that could be beneficial for the reduction of CO_2 emissions (Koplow and Kretzmann, 2010)[22]. On the other hand, they include lower excise duties for specific fuels, financial support for refuelling stations and the exemption from some levies for fuel production units[23], as well as biofuel blending mandates, even if a number of these measures have been the subject of strong criticism in recent years[24].

Table 14. Countries enforcing biofuel mandates

Regulatory policy	Countries	Sources
Mandates on biofuels	Argentina, Australia (state level), Bolivia, Brazil, Canada, Chile, China (ethanol, province level), Colombia, Costa Rica, European Union (renewable energy directive), India (ethanol), Indonesia, Jamaica (ethanol), Japan, Kenya (ethanol, local level), Malaysia (biodiesel), Mexico (ethanol, local level), Norway, Nigeria (ethanol), Paraguay, Peru, Philippines, Taiwan, Thailand (biodiesel), Uruguay, United Kingdom (renewable transport fuel obligation), United States (renewable fuel standard), Venezuela (ethanol), Zambia	Baral, 2009 EC, 2009b IEA, 2011d UNFCCC, 2012 US EPA, 2012b

The geographical distribution emerging from the country lists included in Table 14 and Table 15 shows that biofuels and natural gas have been supported in an area that is significantly more diverse than the one characterizing policies specifically targeting the reduction of CO_2 emissions. This area includes three main categories of countries:

[22] In the field of CO_2 emission mitigation, the phase out of inefficient fossil fuel subsidies is something that could lead to substantial benefits: the IEA and the OECD estimated that, if existing subsidies were to be removed, global greenhouse-gas (GHG) emissions would be 10% lower, by 2050, than in a business-as-usual scenario (IEA et al., 2010).

[23] It is important to mention that the exemption from some levies for fuel production units is often common practice (at least in OECD countries) also for conventional fuels, e.g. when industries engaged in the upgrading or transformation of energy from one form to another – including oil refineries – are exempted from excise taxes on energy (OECD, 2011c).

[24] In the case of biofuel and natural gas subsidies, the main reasons for the critiques have been the high societal costs in comparison with the environmental benefits delivered (see, in particular, GSI, 2012b for biofuels, as well as OECD, 2011c and Koplow and Krezmann, 2010 for natural gas). In the case of biofuel mandates, most of the criticism is has been focusing on the risks associated with indirect land use change: see Searchinger et al., 2008 and Fargione et al., 2008, Gallagher, 2008, CEPA, 2009, Al-Riffai, 2010, Croezen et al., 2010, Edwards et al., 2010 and Laborde, 2011.

- developed countries attempting to develop CO_2 emission mitigation policies (namely in Europe and in North America);
- developed and developing countries seeking to foster energy diversification in transport (spanning from large energy consumer in the OECD to developing countries in Latin America, Central and East Asia, especially in the case of natural gas);
- developing countries looking for solutions that would reduce local pollution (e.g. India and East Asian countries promoting fuel substitution to natural gas for some vehicle categories, such as three wheelers); and
- developing countries particularly endowed with the (sometimes stranded) primary resources required for the production of alternative fuels (e.g. Latin American countries with tropical climates for biofuels, Iran and the Russian Federation for natural gas).

Table 15. Economic measures on transport fuels related to CO_2 emission mitigation

Economic measure	Countries	Sources
Instruments (subsidies, incentives, exemptions from levies) promoting biofuels	Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Czech Republic, Denmark, Estonia, France, Hungary, Germany, Indonesia, Ireland, Italy, Latvia, Lithuania, New Zealand, Poland, Romania (ethanol), Slovakia, Slovenia, South Africa (biodiesel), Spain, Sweden, Switzerland, Turkey, United Kingdom, United States	IEA, 2009b IEA, 2011d GSI, 2012b OECD-EEA, 2012 UNECE questionnaire UNFCCC, 2012 US DOE EERE , 2011
Instruments promoting natural gas use in transport	Argentina, Armenia, Bangladesh, Belarus, Belgium, Brazil, Bolivia, Bosnia and Herzegovina, Canada, Chile, China, Colombia, Croatia, Czech Republic, Egypt, Estonia, Finland, France, Hungary, Germany, Greece, Iceland, India, Indonesia, Iran (natural gas, beyond the strong subsides for petroleum products), Italy, Japan, Korea, Kyrgyzstan, Latvia, Lithuania, Luxembourg, Malaysia, Mexico, Moldova, Netherlands, Norway, Pakistan, Philippines, Poland, Portugal, Russian Federation, Serbia, Singapore, Slovakia, Slovenia, Spain, Sweden, Switzerland, Tajikistan, Thailand, Trinidad and Tobago, Turkey, Ukraine, United Kingdom, United States, Uzbekistan	IANGV, 2009 IEA, 2010c NGA Europe, 2011 NGV Global, 2012 OECD, 2011c OECD-EEA, 2012 UNFCCC, 2012 US DOE EERE, 2011

This characterization is also fully consistent with the idea that the enforcement of policies promoting alternative fuels is associated with a wider set of drivers, not only limited to climate change mitigation.

Interest in the development of biofuels has been expressed by a number of countries that are not included in Table 14 and Table 15, such as Armenia, Bangladesh, Chad, the Dominican Republic, Ethiopia, Ghana, Jordan, Madagascar, Namibia, Niger, Tajikistan, and Uruguay (UNFCCC, 2012). Algeria, the Dominican Republic, Gabon, Ghana, Jamaica, Kazakhstan, FYR of Macedonia, Togo, the United Arab Emirates and Vietnam (public transport only) expressed similar interest for natural gas (UNFCCC, 2012).

On the other hand, the strong criticism targeting biofuel mandates and subsidies supporting biofuels and fossil fuels (including natural gas) compelled a number of countries to progressively replace or phase out some of these instruments. This is especially relevant in the case of biofuels, where mandates have been coupled with regulatory measures that focus on the carbon content of fuels in the EU, the United States and some Canadian provinces (Table 13), also including attempts to deal with the issue of land-use change. Subsides that do not specifically promote innovative biofuel production technologies are also being phased out in Germany (GSI, 2012b).

Policies on transport vehicles

A number of measures aimed at CO_2 mitigation specifically target transport vehicles. This is the case for economic instruments, such as differentiated acquisition and circulation levies for passenger light duty road vehicles that are specifically conceived on the basis of the fuel consumption and CO_2 emission characteristics of vehicles (Table 16 and Table 17) [25], regulatory measures such as fuel economy standards for light duty and heavy duty road vehicles, as shown in Table 18, and even participatory instruments, such as energy labeling for transport vehicles and their components (for instance, tyres), often used in conjunction with other policy solutions.

Differentiated levies based on parameters like fuel consumption, CO_2 emissions, vehicle weight and the engine volume have been typically characterizing policy action in countries where CO_2 emission mitigation is one of the priorities of transport policy development, e.g. because of a commitment to reduce GHG emissions under the Kyoto protocol.

Similar considerations can be extended to the use of fuel economy standards and economic instruments aimed to support fuel-efficient vehicles ().

In addition, countries (or groups of countries) that have already introduced labeling schemes designed to improve consumer information include Brazil, Canada, Chile, China, the European Union, India, Israel (voluntary), Japan, Mexico (selected vehicles), South Africa, Singapore, Turkey, and the United States (OECD-EEA, 2012; UNFCCC, 2012 and UNEP, 2012).

In order to enlarge the scope of countries enforcing legislation on fuel economy and to promote further research and discussion, as well as concrete actions to improve fuel economy worldwide, the FIA Foundation, the IEA, the ITF and UNEP launched the Global Fuel Economy Initiative in 2009. In addition to the cooperation with governments in developing policies to encourage fuel economy improvement for vehicles produced or sold

[25] In some circumstances, differentiated taxation is also taking into account other health- and environment-related parameters, such as the emissions of noxious gaseous pollutants.

in their countries, the initiative also aims to support regional awareness initiatives that provide consumers and decision makers with the information they need to make informed choices (GFEI, 2012a).

Table 16. Economic measures related to the acquisition of light duty road vehicles

Economic measure	Countries	Sources
Differentiated acquisition levies (passenger light duty road vehicles)	Australia (cars: weight), Austria (cars: CO_2), Belgium (cars: engine power, CO_2), Bosnia and Herzegovina (cars and motorcycles: engine volume), Brazil (cars: engine volume and fuel used), Bulgaria (cars: engine power), Canada (cars: fuel consumption; heavy cars; cars: engine volume in Quebec), China (cars: engine volume), Cyprus (cars: CO_2), Denmark (cars: CO_2), Estonia (cars: engine volume and age; motorcycles: age), Finland (cars: CO_2), France (cars: CO_2), Iceland (engine volume, two classes only), Ireland (cars: CO_2; motorcycles undifferentiated), Israel (cars: by emission group and "green grade"), Italy (cars: engine power), Korea (engine volume), Luxembourg (cars: engine volume), Netherlands (cars: CO_2 and weight), Norway (cars: weight, pollutants and CO_2), New Zealand (motorcycles: engine volume; cars: engine power, weight and CO_2), Philippines (import tariffs based on engine volume), Portugal (cars: engine volume, two classes, and CO_2), Romania (engine volume), Singapore ("Green Vehicles"), Switzerland (only for vehicles above 1.6 t), Unites States (gas guzzler tax, based on fuel consumption, limited to least performing vehicles)	ACEA, 2011a ACEA, 2011b ANFAVEA, 2011 ECMT, 2007 UNECE questionnaire UNFCCC, 2012 UNEP, 2008 UNEP, 2012

Table 17. Economic measures related to the acquisition of light duty road vehicles

Economic measure	Countries	Sources
Differentiated acquisition levies (passenger light duty road vehicles)	Australia (cars: weight), Austria (cars: CO_2), Belgium (cars: engine power, CO_2), Bosnia and Herzegovina (cars and motorcycles: engine volume), Brazil (cars: engine volume and fuel used), Bulgaria (cars: engine power), Canada (cars: fuel consumption; heavy cars; cars: engine volume in Quebec), China (cars: engine volume), Cyprus (cars: CO_2), Denmark (cars: CO_2), Estonia (cars: engine volume and age; motorcycles: age), Finland (cars: CO_2), France (cars: CO_2), Iceland (engine volume, two classes only), Ireland (cars: CO_2; motorcycles undifferentiated), Israel (cars: by emission group and "green grade"), Italy (cars: engine power), Korea (engine volume), Luxembourg (cars: engine volume), Netherlands (cars: CO_2 and weight), Norway (cars: weight, pollutants and CO_2), New Zealand (motorcycles: engine volume; cars: engine power, weight and CO_2), Philippines (import tariffs based on engine volume), Portugal (cars: engine volume, two classes, and CO_2), Romania (engine volume), Singapore ("Green Vehicles"), Switzerland (only for vehicles above 1.6 t), Unites States (gas guzzler tax, based on fuel consumption, limited to least performing vehicles)	ACEA, 2011a ACEA, 2011b ANFAVEA, 2011 ECMT, 2007 UNECE questionnaire UNFCCC, 2012 UNEP, 2008 UNEP, 2012

Currently the adoption of fuel economy standards for cars is being considered by Israel, FYR of Macedonia, Mexico, Montenegro, South Africa, and Switzerland (UNECE questionnaire, UNFCCC, 2012), while the United Arab Emirates is considering the introduction of differentiated levies for the acquisition of passenger light duty road vehicles (UNFCCC, 2012). The Chilean Government also plans to introduce a law on differentiated taxation for clean vehicles in 2012 (GFEI, 2011), and the Caucasus Environmental NGO Network (CENN) has begun developing the Caucasus Fuel Economy Initiative (GFEI, 2012b).

Table 18. Economic measures related to the usage of light duty road vehicles

Economic measure	Countries	Sources
Differentiated annual circulation levies (passenger light duty road vehicles)	Austria (cars: engine power), Azerbaijan (cars: engine volume), Belgium (cars: road tax on engine power, motorcycles undifferentiated), Bulgaria (cars: engine power, motorcycles undifferentiated), Croatia (cars and motorcycles: road tax on engine volume, vehicle tax on engine power and age), Czech Republic (cars: fuel consumption and age), Denmark (cars: fuel consumption and age), Finland (cars: CO_2), France (company cars: CO_2), Germany (cars: CO_2), Greece (cars: engine volume), Iceland (by weight), Ireland (cars: engine capacity), Israel (all vehicles by age), Italy (cars and motorcycles: regional, by pollution class and engine power), Hungary (all vehicles by age), Japan (cars: partly based on vehicle weight), Latvia (cars: weight; motorcycles undifferentiated), Luxembourg (cars: CO_2), Montenegro (cars and motorcycles: engine volume), Netherlands (cars: CO_2 and weight; motorcycles undifferentiated), New Zealand (motorcycles: engine volume; cars undifferentiated), Portugal (motorcycles and cars: engine volume and age), Romania (engine volume, two classes only), Serbia (motorcycle and cars: engine volume), Slovenia (motorcycles: engine volume; cars: CO_2), South Africa (cars: penalty beyond CO_2 threshold), Spain (motorcycles: engine volume; cars: engine power), Sweden (cars: weight and CO_2; motorcycles undifferentiated), Switzerland (local level, different criteria - some CO_2-based for cars), Turkey (cars and motorcycles: engine volume, age), United Kingdom (cars: CO_2; motorcycles: engine volume), United States (cars: weight-based tax in some States)	ACEA, 2011a ECMT, 2007 JAMA, 2011 OECD-EEA, 2012 UNECE questionnaire

Table 19. Regulatory policies on fuel economy standards

Regulatory policy	Countries	Sources
Fuel economy standards for light duty road vehicles	Australia, Canada, China, European Union, Japan, Korea, United States	ICCT, 2011e UNECE questionnaire
Fuel economy standards for heavy duty road vehicles	Canada, Japan, United States	ICCT, 2012 US EPA, 2012a

Road usage charges are collected in a wide range of countries (sometimes through fuel levies) and in the case of heavy duty and commercial road vehicles they can be complemented by differentiated levies (when this is the case, these levies are mainly conceived on the basis of vehicle weight classes). Their imposition favors more efficient transport modes like rail and waterways. This is also the case of fiscal instruments aiming to internalize the external costs of freight transport on road modes (sometimes based on electronic systems, as in the case of Austria, the Czech Republic and Germany).

On the other hand, road freight vehicles (as well as inland transport vehicles used for non-road modes) have not been the object of extensive regulatory actions to improve their performance in terms of CO_2 emissions. This is likely due to the importance of fuel costs for decision- making in freight transport and logistics, something that has been assumed as a sufficient incentive for better fuel efficiency in freight vehicles. Recent analyses, however, show there is a significant potential for improvement in fostering the adoption of fuel efficiency standards for road freight vehicles (e.g. NRC TRB, 2010). To date, only three countries passed legislation regulating the fuel economy of new heavy duty vehicles entering their markets: Canada, Japan and the United States (Table 19). Nevertheless, similar policies are currently under consideration or under development only in China and the European Union (ICCT, 2011e, UNECE questionnaire).

Table 20 illustrates that several economic instruments are being used to promote the commercial deployment of fuel efficient vehicles (e.g. electric[26] and hybrids) or vehicles using alternative fuels (mainly natural gas). These policies, also requiring the availability of a regulatory framework for the type approval of fuel efficient vehicles (e.g. electric and

[26] In the case of electric vehicles, the efficacy of this approach has been questioned by some authors. Perkins (2011) notes that the risks associated with subsidies induce rather negative attitudes towards them in most economists, and quotes a recent analysis of the costs of providing support to consumers for the purchase of electric cars (taking into account the difference in maintenance costs, the costs due to local pollution and CO2 emissions, as well as the vehicle costs, performance and subsidies available in France: EUR 5000 per vehicle), highlighting the conclusion that, when compared with cars powered by conventional internal combustion engines, the present electric car is still far from securing lower costs for both individuals and society. Even considering the large uncertainties for several of the parameters used in a sensitivity analysis, Perkins reports that only when several of the parameters scrutinized are favorably changed for electric vehicles, the difference in costs is reduced significantly. This means that it is necessary to achieve very significant cost and efficiency improvements in order to achieve successful results. Should technology improve more rapidly than envisaged, the benefits potentially delivered could be very large, but the risk is to follow a path that may require massive subsidies to achieve them.

hybrids), are primarily used in developed countries, similar to other economic and regulatory instruments discussed earlier.

Table 20. Economic measures for fuel efficient vehicles and vehicles using alternative fuels

Economic measure	Countries	Sources
Instruments (subsidies, incentives, exemptions from levies) promoting the commercial deployment of fuel efficient vehicles (e.g. electric and hybrids)	Austria (electric and hybrid), Belgium (electric and hybrid), Bhutan, Chile (hybrid), China, Colombia (electric), Czech Republic (electric and hybrid), Denmark (electric), France (CO_2 based, electric and hybrid), Germany (electric), Greece (electric and hybrids), Iceland (electric), Ireland (electric and hybrid), Israel (electric and hybrid), Italy (electric), Japan (fuel efficiency based), Luxembourg (CO_2 based), Netherlands (electric and hybrid), New Zealand (electric), Portugal (electric and hybrids), Romania (electric and hybrid), Spain (electric, hybrid), Sweden (CO_2 based, electric and hybrid), United Kingdom (electric and hybrid), United States (electric and hybrid)	ACEA, 2011a ACEA, 2011b IEA, 2011e JAMA, 2009 JAMA, 2011 OECD-EEA, 2012 Perkins, 2011 UNECE questionnaire UNFCCC, 2012
Instruments promoting the commercial deployment of vehicles using alternative fuels (natural gas, unless indicated otherwise)	Bolivia, Brazil (ethanol), Canada, Colombia, Czech Republic, France, Germany, Iceland, Iran, Israel, Italy, Korea (buses), Japan, Malaysia, Pakistan, Peru, Singapore, Spain, United States	ACEA, 2011a ACEA, 2011b ANFAVEA, 2011 IANGV, 2009 IEA, 2010c GSI, 2012b NGV Global, 2012 OECD-EEA, 2012 UNECE questionnaire UNFCCC, 2012

Unlike in the case of alternative fuels and low-carbon energy carriers, regulatory instruments such as mandates are only marginally used for vehicles. Some of the most relevant examples are:

- the California LEV (Low-Emission Vehicle) program, which has historically focused on gaseous pollutants and includes an obligation under which at least 11 per cent of the passenger cars and lightest light-duty trucks sold in California in 2009 must nominally be Zero Emission Vehicles (ZEVs) (CARB, 2009). The program is now being revised in order to incubate technologies like plug-in hybrids and pure ZEVs for large scale market penetration to also address GHG emissions (CARB, 2012); and
- the requirement to use buses powered by natural gas in New Delhi (India) (IANGV, 2010).

Supportive instruments like subsidies, incentives, and exemptions from levies for efficient vehicles and vehicles fuelled by alternative fuels also have an industrial policy connotation, since they are frequently coupled with the presence of important vehicle and component manufacturing facilities in countries adopting them.

Another area of policy intervention with an industrial policy connotation is well-represented by economic incentives aimed at the renewal of the vehicle fleet (Table 22) and regulatory instruments, such as import bans and restrictions for older used vehicles (Table 21).

Table 21. Import bans and restrictions for old used vehicles

Regulatory policy	Countries	Sources
Import bans and restrictions for old used vehicles	Algeria (3 years), Argentina, Bangladesh (3 years), Barbados (4 years), Bermuda (6 months), Bhutan, Bolivia (5 years), Bosnia and Herzegovina (7 years for passenger, 10 years for commercial), Brazil, Brunei Darussalam (5 years), Chile (except special vehicles like ambulances, fire-fighting vehicles, etc., and free trade zones), China, Colombia, Czech Republic (8 years), Cuba (4 years), Ecuador, Egypt (3 years), Honduras (7 years), Hungary (4 years for passenger, 8 years for commercial), India (3 years), Indonesia (ban for passenger, 10 years for commercial), Jordan (5 years), Kuwait (5 years), Lebanon (8 years), Mexico (NAFTA only, at least 10 years old vehicles), FYR of Macedonia (6 years), Moldova (7 years fro passenger, 10 years for commercial), Myanmar, Nicaragua (10 years), Pakistan (2 years), Palestine (3 years), Paraguay (10 years), Peru (5 years for passenger, 8 years for commercial), Poland (10 years for passenger, 3 years for commercial), Qatar (5 years), Serbia (3 years for passenger), Singapore (3 years), South Africa, Sri Lanka (3 years for passenger, 5 years for commercial), Suriname (5 years), Syria (2 years), Thailand, Tunisia (3 years), Turkey (3 years), Uruguay, Venezuela, Vietnam (passenger), Yemen (5 years)	UNECE questionnaire UNEP, 2008a UNEP, 2008b UNEP, 2011a UNEP, 2011b UNFCCC, 2012 US DOC, 2008

Table 22. Economic measures aimed at the renewal of the vehicle fleet

Economic measure	Countries	Sources
Instruments linked to vehicle scrappage schemes (for fleet renewal)	Australia, Austria, Belgium, Chile (commercial vehicles), Cyprus, Czech Republic, France, Germany, Hungary, Italy, Japan, Luxembourg, Mexico, Netherlands, Poland, Portugal, Russia, Turkey, Slovakia, Spain, United Kingdom, United States	IEA, 2009b TNO, 2011 SMMT, 2009 UNECE questionnaire UNFCCC, 2012 UNEP, 2012
Levies linked to the import of old used vehicles or parts (deterrent)	Albania, Australia, Brazil (tariff on used parts, used vehicle import forbidden), Bulgaria, Côte d'Ivoire (more than 10 years old vehicles), Lithuania, Peru, Philippines	OECD-EEA, 2012 UNEP, 2008 UNFCCC, 2012 US DOC, 2008

In the case of vehicle scrappage schemes, Perkins (2011) reports that costs per ton of CO_2 mitigated for most schemes introduced in the 1980s and 1990s have been found to be very high, also underlying that targeted subsidies focusing on removing only the oldest vehicles from circulation typically led to better results. This means that all vehicle scrappage schemes do not have a clear impact on CO_2 emissions (as well as other health- and environment-related emissions). In addition, it suggests that their scale-up to provide significant stimulus to the car industry is likely to destroy their cost-effectiveness in terms of environmental benefits (Perkins, 2011).

In terms of import bans, Davis and Kahn (2010) analyzed the consequences of the fall of trade restrictions between Mexico and the United States in 2005. They found that traded vehicles are dirtier than the stock of vehicles in the United States and cleaner than the stock in Mexico, leading to lower average vehicle emissions per km in both countries when a vehicle is traded from the United States to Mexico. However, that trade also led to an increase in total emissions because the scheme resulted in a faster motorization increase in Mexico. This ultimately suggests that import bans on used vehicles may have an overall beneficial effect in terms of GHG and pollutant emission containment (because of a lower growth of vehicle ownership, likely to be linked to higher vehicle prices), and that policies concerning trade in used durables require the adoption of detailed impact assessments.

Managing travel demand and shifting transport towards more efficient modes

Polices aimed toward the management of travel demand and shifting transport towards more efficient modes comprise a very wide range of instruments.

For urban passenger transport, they include congestion charges, traffic guidance systems, solutions related to Intelligent Transport Systems (ITS), travel and access restrictions for specific vehicle categories, parking policies (including charges and restrictions), the integration of transport in spatial and land-use planning (e.g., to promote transit-oriented urban development), infrastructure measures for the development of transport networks (e.g. for public transport, including ITS), solutions improving the urban environment to make non-motorized modes of transport such as walking and cycling more attractive, as well as the improvement or restructuring of the urban public transport regulatory framework.

An urban transport initiative that has been particularly relevant and effective in improving public transport services in several cities and megacities (including many cases in non-OECD countries) is the development of Bus Rapid Transit, an high-quality bus-based transit systems combining that deliver fast, comfortable and cost-effective urban mobility combining stations, vehicles, services, segregated right-of way infrastructure and ITS elements. Like light rail and underground urban and suburban railway links (but with lower investment required), this system requires infrastructural investments, coordination with land-use planning for urban development and the establishment of a new regulatory framework. Where implemented, it has frequently replaced an unregulated set of minibuses and other collective transport vehicles, alleviating congestion and improving urban mobility.

Looking at long-distance transport, policies that are relevant for CO_2 emission mitigation are made up of infrastructural measures, such as investments in high-speed rail. Such measures are most effective when traffic is sufficiently dense and where rail journey times can be brought close to three hours. In some cases, the environmental benefits created by the development of high speed rail links are unlikely to be significant enough to justify their development. On the other hand, provided that high load factors can be achieved and the infrastructure can be accommodated without excessive environmental damage, there are no strong arguments against their development either (Perkins, 2011).

A list of countries applying economic measures aimed at managing passenger travel demand to promote public transport and generally shifting passenger transport demand toward more efficient modes was previously shown in Table 12. Table 23 partly complements this list, focusing on regulatory approaches rather than economic instruments.

In addition to the set of policies and countries mentioned in these tables, a wide range of other measures (often requiring decisions to be made at the local level) also target traffic management. These measures are widely adopted in OECD countries, as well as some rapidly developing countries. The most prominent amongst these measures are congestion charges, whose implementation took place in Italy (Milan), Singapore, Sweden (Stockholm), and the United Kingdom (London) (OECD-EEA, 2012 and UNFCCC, 2012) and are now also being considered in China (Beijing, Nangjing and Shanghai) and India (New Delhi) (Burke, 2011).

According to national communications to the UNFCCC and other literature sources, several countries expressed interest or are expected to develop policies aimed at managing travel demand through transport and land-use planning, the development and improvement of the public transport network, and some of the other measures that were previously mentioned. An extensive, although not comprehensive list of interested countries showing widespread interest for these polices in different global areas (possibly also due to the nature of these polices, typically enforced at the local level, even if national coordination is possible) is proposed in Table 24. Within this group, more focus is given to public transport network development, improvement and integration, although integrated transport and land-use planning measures are also increasingly considered.

Table 23. Regulatory polices aiming to manage travel demand and shift transport towards more efficient modes

Regulatory policy	Countries	Sources
Urban passenger transport and land-use planning (communities, non-motorized transport, public bicycle schemes, urban density, mixed-use, public transport network integration and enhancement)	Australia, Austria, Bangladesh (Dhaka), Belgium, Bosnia and Herzegovina, Brazil, Bulgaria, Canada, Chile (Santiago), China, Chinese Taipei (Taipei), Colombia, Croatia, Czech Republic, Ecuador, Estonia, France, Finland, Germany, Greece, Guatemala (Guatemala), Hungary, India, Indonesia, Iran (Tehran), Ireland, Israel, Italy, Japan, Korea (Seoul), Latvia, Luxembourg, Mexico, Montenegro, Netherlands, Norway, Nigeria (Lagos), New Zealand (Auckland), Poland, Portugal, Romania, Russian Federation, Serbia, Singapore, Slovakia, Spain, South Africa, Sweden, Switzerland, Thailand (Bangkok), Turkey (Istanbul), United Arab Emirates, United Kingdom, United States, Venezuela	ERRAC, 2004 EMBARQ, 2012 Hidalgo et al., 2010 UNFCCC, 2012 Wright, 2005 Wright and Fjellstrom, 2005 Wright and Hook, 2007 UNFCCC, 2012
Travel restrictions (access, parking, low pollutant emission zones) for specific vehicle categories and/or specific times	China (Shanghai), European Union (several cities in Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovenia, Spain, Sweden, United Kingdom), Iceland (Reykjavik), Israel (Tel Aviv), Norway	UNEP, 2010b ISIS and PWC, 2010 UNFCCC, 2012
Improvement or restructuring of the urban public transport regulatory framework	Australia, Bangladesh (Dhaka), Brazil, Canada, Chile (Santiago), China, Chinese Taipei (Taipei), Colombia, Ecuador, France, Guatemala (Guatemala city), India (several cities), Indonesia, Iran (Tehran), Italy, Japan, Korea (Seoul), Mexico, Netherlands, Nigeria (Lagos), New Zealand (Auckland), Spain, South Africa (Johannesburg), Thailand (Bangkok), Turkey (Istanbul), United Kingdom, United States, Venezuela	EMBARQ, 2012 Hidalgo et al., 2010 UNFCCC, 2012 Wright, 2005 Wright and Fjellstrom, 2005 Wright and Hook, 2007

Table 24. Countries interested in polices aiming to manage travel demand and shift transport towards more efficient modes

Target	Countries	Sources
Interest in • Public transport network development, improvement and integration • Transport and land-use planning (e.g. transit-oriented developments promoting urban density, mixed-use, non-motorized transport)	Algeria, Angola, Antigua and Barbuda, Argentina, Armenia, Australia, Austria, Bangladesh, Belgium, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Burundi, Canada, Cape Verde, Central African Republic, Chile, China, Chinese Taipei, Colombia, Congo, Congo Democratic Republic, Costa Rica, Croatia, Czech republic, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Ethiopia, Finland, France, Gabon, Georgia, Germany, Ghana, Greece, Guatemala, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kyrgyzstan, Kenya, Korea, Latvia, Lebanon, Luxembourg, Madagascar, Mauritania, Mauritius, Mexico, Mongolia, Montenegro, Morocco, Netherlands, New Zealand, Nigeria, Norway, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russian Federation, Samoa, Senegal, Serbia, Sierra Leone, Singapore, Slovakia, South Africa, Spain, Sweden, Switzerland, Tajikistan, Tanzania, Thailand, Togo, Tunisia, Turkey, Uganda, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela	Binsted, 2011 EMBARQ, 2012 ERRAC, 2004 Hidalgo et al., 2010 UNFCCC, 2012 Wright and Fjellstrom, 2005 Wright and Hook, 2007

In freight transport and logistics, polices aimed at the management of travel demand and more efficient transport modes encompass transport planning strategies, which has led to the development of freight networks that are already quite advanced in the most developed countries. This includes multimodal hubs and logistical centers, infrastructure measures linked to them and aimed at the development of network capacity for the most efficient modes, the application of new information technology (including the solution stemming from ITS), the restructuring and liberalization of freight transport and logistics and the abolition of common carrier obligations and tariff controls on rail freight operations. However, similar progress in developing countries is not as pronounced (IEA, 2009a).

One of the possibilities considered amongst infrastructure measures for freight transport that deserves a special mention is the development of dry ports, a concept where the majority of freight is transported by rail between a seaport and inland intermodal terminal. In Asia, where dry ports are seen as instruments capable of integrating regional transport networks, such dry ports have already been developed. Examples can be found in India, Thailand and China (UNESCAP, 2010).

An overview of national communications to the UNFCCC for non-Annex I countries (i.e. countries not bound by Kyoto targets) show that systemic measures concerning freight are less frequently included amongst the instruments that may contribute to CO_2 emission mitigation. Similar measures targeting passenger transport are much more widely communicated. To date, the only countries that have explicitly mentioned an interest in the development of less energy- and carbon-intensive freight transport (including logistics) in their national communications are Brazil, Egypt, Madagascar, Mongolia, Thailand, Tunisia, and Turkmenistan (UNFCCC, 2012). The development of alternative modes of transport is another key factor for the reduction of CO_2 emissions in select Annex I countries, such as France (UNFCCC, 2011b).

4. Assessing inland transport CO_2 emissions and evaluating CO_2 mitigation policy impacts in transport with models

In developed countries, the availability of statistics and modelling tools allows to establish baseline outlooks and alternative policy scenarios for the estimation of the impacts of mitigation interventions. Estimating the policy impact in terms of social costs and benefits is an essential requirement in the policy development process, since it provides a fundamental justification for the opportunity of a legislative intervention in the field under scrutiny, assuring that society would be better off after the policy implementation. In many cases (like, for instance, for the policy proposal process in the European Union), this is even a legal requirement.

In developing countries and in the UNFCCC climate policy framework, the requirement to establish consistent baselines and estimating the policy impact in terms of social costs and benefits is currently best characterized by the measuring, reporting and verifying requirements that are associated with international funding schemes.

To date, these requirements have been a significant barrier to the development of internationally funded climate policies in the transport sector. This is clearly demonstrated by the fact that, in developing countries, the transport sector that was only marginally touched by CDM projects (as discussed by Dalkmann et al., 2009 and, later, in Allen et al., 2012[27]).

The difficulties to leverage international funds that were encountered in transport suggest that countries should invest more in data collection exercises allowing them to create better inventories and in analytical tools to be able to quantitatively assess the macroeconomic and policy-related implications affecting the transportation sector.

Increasing the quality of the statistical and analytical tools available can also allow countries to access climate finance and bilateral funding opportunities for a greater number of mitigation projects in the transport sector (Allen et al, 2012): in the post-2012 climate policy framework, ensuring that transport interventions can fulfil the measuring, reporting and verifying requirements is something that also appears to be very relevant for NAMAs that seek international funding. This is particularly important in transport, where NAMAs are seen as an opportunity to move beyond the CDM (Dalkmann et al., 2010 and GIZ, 2011).

The following section clarifies the reasons for the need of a better measuring, reporting and verifying scheme for the transport sector. In particular, it highlights how transport activity, energy use and CO_2 emissions can be estimated on the basis of the statistical information mentioned in Chapter 2, as well as how to evaluate future emissions on the basis of demographic information, macroeconomic variables, and policies (after their transformation in numerical inputs). These considerations also include a brief introduction of selected efforts that have already been undertaken for analysis and the projection of future transport activity and CO_2 emissions levels, with or without policy interventions.

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[27] A brief analysis highlighting the differences between CDM projects and NAMAs has been issued by the GIZ (Diaz-Bone, 2011).

Estimation and projection of transport activity, energy use and CO_2 emissions

Two main groups of models can be taken into account when looking at transport activity, energy use and CO_2 emissions:

- the first (briefly discussed in the following section) focuses on the assessment of historical emissions of CO_2 (and, often, other gases);
- the second (addressed later) targets specifically their projections in a future timeframe.

When the objective is the assessment of quantitatively assess the macroeconomic and policy-related implications affecting the transportation sector, this second group is clearly the most relevant. Nevertheless, the first group remains interesting because the calculations and methodologies used for the estimation of historical emissions are also used in models that attempt to estimate fuel consumption, GHG and other pollutant emission projections.

Assessing historical emissions

In transport, historical information on activity (typically expressed in passenger-km and tonne-km, eventually separating average loads from vehicle km) and energy use (typically expressed in energy units, like Joules or litres of gasoline equivalent) are available from statistical assessments, as shown in Chapter 2. On the other hand, CO_2 emissions (as well as the emissions of other GHGs and pollutants) cannot be directly measured and require an estimation method.

The historical assessment of CO_2 emissions is frequently coupled with the estimation of historical emissions of the two other main GHG (i.e. N_2O and CH_4), as well as regulated pollutants (i.e. CO, VOC, NO_X and Particulate Matter), SO_2, NH_3, heavy metals and persistent organic pollutants.

A few countries use specific models like ARTEMIS, COPERT, HBEFA, LIPASTO, TREMOD and MOVES for the estimation of CO_2, other GHG and regulated pollutant in transport, while other countries have developed own approaches, typically based on spreadsheets and database applications.

In most cases, assessment of GHG emissions is performed relying on IPCC guidelines (IPCC, 2006). The EMEP/EEA air pollutant emission inventory guidebook (EEA, 2009) is frequently used for non-GHG emissions.

Artemis, COPERT, HBEFA, MOVES and TREMOD are further described and discussed below.

ARTEMIS

General information

ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) has been developed in the framework of a large research project funded by the European Commission. The ARTEMIS consortium included 36 organizations involved in research on transport emissions from 15 countries.

The ARTEMIS tools were designed for three main applications: (i) emission inventories, (ii) scenario calculation for assessing the impacts of alternative measures, (iii) inputs for air quality models for assessing local and temporal impacts on the environment. The model was designed to enable calculation at various levels of aggregation down to the street level.

The software and relevant documentation can be found in ARTEMIS, 2004.

Applicability

ARTEMIS is a harmonized emission model for road, rail, air and ship transport to provide consistent emission estimates at the national, international and regional level. The road model has many similarities with the COPERT and HBEFA models covering the same vehicle classes and the same GHG and air pollutants. Also, the input emission factor data relies for all three models to a large extent on the emission factor database compiled within the ARTEMIS and COST-346 projects. However, the model has not been further updated since its initial development and hence only vehicle technologies up to Euro 4 are included.

So far, the model has only been fully implemented for compiling national air emission inventories in four countries (Austria, Germany, Sweden and Switzerland). Application of the model to other countries is not possible without the involvement of the ARTEMIS modelling team.

Data requirements and availability

Similarly to HBEFA, all necessary input data on the vehicle fleet in operation are included in the database of the model. This includes the number of vehicles, travelling speeds for urban, rural and highway conditions, annual mileage values and shares, distributed per fuel and sub-category down to technology level.

COPERT

General information

COPERT 4 is a software tool used worldwide to calculate air pollutant and greenhouse gas emissions from road transport. The development of COPERT is coordinated by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre for Air Pollution and Climate Change Mitigation. The European Commission's Joint Research Centre manages the scientific development of the model. COPERT has been developed for official road transport emission inventory preparation in EEA member countries. However, it is applicable to all relevant research, scientific and academic applications.

The COPERT 4 methodology is part of the EMEP/EEA air pollutant emission inventory guidebook (EEA, 2009) for the calculation of air pollutant emissions and is consistent with the 2006 IPCC Guidelines (IPCC, 2006) for the calculation of greenhouse gas emissions. The use of a software tool to calculate road transport emissions allows for a transparent and standardized, hence consistent and comparable data collecting and emissions reporting procedure, in accordance with the requirements of international conventions and protocols and EU legislation.

The software and relevant documentation are freely available on the web (EMISIA, 2009).

Applicability

COPERT calculates tailpipe (tank to wheel) emissions of GHG and most air pollutants from road transport, as well as evaporative and other emissions (e.g. due to tyre wear), but no other transport modes are covered. It also covers all important vehicle classes, including passenger cars, light commercial vehicles, heavy duty trucks, buses and coaches, mopeds and motorcycles, differentiated by fuel, engine capacity and weight classes.

COPERT was developed to fulfil the reporting obligations under international conventions and protocols of the European countries. Hence, apart from the EU Member States it can be readily used by those countries following the pollutant emission standards that were first defined and enforced in the EU context, such as Argentina, Australia, China, India, Indonesia, Philippines, Russia, Singapore, South Africa, Thailand, Turkey and Vietnam.

Data requirements and availability

Very detailed data on the vehicle fleet in operation are required as input to the model. This includes information on the number of vehicles, travelling speeds for urban, rural and highway conditions, annual mileage values and shares, distributed per fuel and sub-category down to technology level. In addition to these, ambient temperatures and fuel specifications should also be provided, as these are relevant for the estimation of cold start extra emissions (even if this is mainly relevant for emissions other than CO_2).

The input data are consistent with the Eurostat classification. As a result, the model is well suited for EU Member States reporting detailed statistical information (this is not always the case, since the data are not always available in full detail). The model may also be used in few countries outside Europe with a well-developed data collection scheme (such as Australia, Canada, USA). Nevertheless, a few estimations are likely to be required in non-EU countries, unless the data collection is carried out in a way that is consistent with the Eurostat classification (e.g. on vehicle classes). For other countries (in particular African ones), data availability is rather poor and the collection of the necessary data would be a very difficult task. Provided that some basic vehicle population (e.g. the total number of passenger cars) and activity (e.g. total fuel consumption) data can be made available, missing data could be approximated based on expert judgment (e.g. using data from a country with similar characteristics to distribute vehicles in different classes).

HBEFA

General information

The Handbook of Emission Factors for Road Transport (HBEFA) was originally developed on behalf of the Environmental Protection Agencies of Germany, Switzerland and Austria. Other countries (Sweden, Norway, and France) as well as the JRC (the Joint Research Centre of the European Commission) are also supporting HBEFA.

The software and relevant documentation can be found in HBEFA, 2010.

Applicability

HBEFA calculates emissions of GHG and most air pollutants from road transport, but it does not cover other transport modes. It takes into account all important vehicle classes, including passenger cars, light commercial vehicles, heavy duty trucks, buses and coaches, mopeds and motorcycles, differentiated by fuel, engine capacity and weight classes for a variety of traffic situations.

HBEFA contains a database with all country-specific vehicle fleet data necessary for running the model. However, it is not possible for the user to apply the model for running a different country than those already included in the database. Adding new information, i.e. more countries, could be realized only by the HBEFA modelling team.

Data requirements and availability

All necessary input data on the vehicle fleet in operation are included in the database of the model for the countries mentioned above. This includes population, travelling speeds for urban, rural and highway conditions, annual mileage values and shares, distributed per fuel and sub-category down to technology level.

MOVES

General information

The MOtor Vehicle Emission Simulator, developed by the US Environmental Protection Agency's (EPA) Office of Transportation and Air Quality, is a new modelling system that estimates emissions for mobile sources in road transport. It is mainly used for emission inventory preparation in state implementation plan and for regional emissions analysis for conformity purposes. MOVES has replaced EPA's previous emissions model for on-road mobile sources, MOBILE6.2.

The software and relevant documentation can be found in US EPA, 2012c.

Applicability

MOVES currently estimates emissions from cars, trucks and motorcycles, covering a broad range of pollutants, as well as GHG emissions (the capability to model non-highway mobile sources is expected to be added in future releases). It derives its emissions estimates from second-by-second vehicle performance characteristics for various driving modes (e.g. cruise and acceleration). It incorporates large amounts of in-use data from a wide variety of sources, such as data from vehicle inspection and maintenance programs, remote sensing device testing, certification testing, portable emission measurement systems (US EPA, 2012c).

MOVES has a database-centred design and calculates emissions due to combustion, evaporation, and other processes (brake wear, tire wear, well-to-pump, vehicle manufacture and disposal). It characterises vehicle activity, for specific classes of vehicles and a number of subcategories (e.g. weight class, fuel type, engine technology, emission standard), into "bins" for Vehicle Specific Power (VSP), accounting for speed, acceleration, grade and road load. Any driving pattern can then be modelled based on distribution of time spent in each bin (Rogers, 2011).

MOVES has been conceived for the United States, for which it also includes a default database of meteorology, vehicle fleet, vehicle activity, fuel, and emission control program data.

Data requirements and availability

MOVES is designed to allow users to analyse motor vehicle emissions at multiple scales, using different levels of input data. The main input data required by the user includes vehicle population and vehicle miles travelled (VMT), i.e. the equivalent of annual mileage, per vehicle type. For more detailed calculations, e.g. on a higher spatial resolution, age distribution, average speed distribution, road type distribution, fuel formulation or supply and inspection and maintenance programs are also required (US EPA, 2012c).

TREMOD

General information

TREMOD (Transport Emission Model) has been developed in the framework of the R&D project carried out on behalf of the German Federal Environmental Agency since January 1993. The scope of the project was the analysis of motorized transport in Germany, i.e. its mileage, energy use and emissions. Part of the project was the development and updating of corresponding calculation software.

In the road transport sector, TREMOD is harmonized with the Handbook Emission Factors for Road Transport (HBEFA).

The software and relevant documentation (only available in German) can be found in IFEU, 2010.

Applicability

TREMOD analyses all means of passenger transportation (cars, two-wheelers, buses, trains, aircrafts) and all means of freight transportation (lorries, light-duty commercial vehicles and trailers, trains, inland navigation vessels, aircraft) for Germany. The model is not available to the public, mainly due to its complexity. However a number of German institutions are using it.

The model can calculate tank to wheel and life cycle energy use and emissions (i.e. emissions directly emitted by the vehicle, as well as indirect emissions, i.e. emissions from the upstream energy generation and supply chain) of the main GHG and air pollutants.

Data requirements and availability

Since the model uses the HBEFA for calculating road transport emissions, all necessary input data on the vehicle fleet in operation are included in the database of the model. This includes the number of vehicles, travelling speeds for urban, rural and highway conditions, annual mileage values and shares, distributed per fuel and sub-category down to technology level. For the non-road modes activity data, mileage and emission factors are required as input to the model.

Projections and the assessment of policy impacts

Models focusing on the assessment of future emissions are often explicitly conceived to understand and estimate the impacts of policy measures. They combine the features of models assessing historical trends (eventually simplifying them or focusing only on specific emissions, like CO_2) with features related to socio-economic aspects, leveraging on macroeconomic data and a number of other inputs allowing the characterization of policies like those considered in Chapter 3.

Transportation forecasting focuses on the estimation of the number of vehicles or people that will use a specific transportation facility in the future. The classical approach used for this purpose involves four main steps:

- the trip/freight transport generation, depending on the activity of different locations (e.g. based on land-use characteristics and the distribution of the population);
- the trip/freight transport distribution, matching origins and destinations (e.g. taking into account that the attraction between two locations declines with increasing distance, time, and cost);
- the modal split, where modal choice is characterized (e.g. with models conceived to address the discrete choice amongst available options and their characteristics with respect to time and cost);
- the route assignment, i.e. the allocation of trips on a given mode to a specific network portion (e.g. assuming that transportation takes place in a context where everyone chooses the best combination possible taking into account travel time and travel cost).

In sectoral models looking specifically at transportation, some of these aspects may be addressed in a simpler manner, linking macroscopic socio-economic aspects like macroeconomic, geographic and demographic variables (like GDP, population, population density, and urbanization rate) to specific characteristics of the transport sector (e.g. vehicle ownership, average mileage, share of the total travel on public transport). This is the case for "ASIF" approaches, based on the decomposition of into transport Activity, energy Intensity and Structural components of the Fuel use. The ASIF approach is also coupled with decomposition analysis, a proven approach that helps identifying the main factors behind changes in energy consumption widely used in the field of energy efficiency indicators.

In addition, most of the models need to take into account changes in the price of fuels and other primary and secondary materials, since they have an impact of the transport cost.

The policy characterization needed in this type of models typically requires the provision of information on vehicle and fuel prices, parameters related to technological characteristics of vehicles (such as data on vehicle performance, especially in terms of energy consumption, coupled with costs) and fuels (e.g. information on their well-to-tank emissions, as well as data on their costs), and instruments allowing the definition of the taxation in place.

Scenarios are typical instruments used to assess/quantify the impact of various measures taken, and they are frequently adopted in the analyses focusing on policy impacts, since scenarios are essential for the evaluation of costs and benefits of a policy option with respect to a situation without policy intervention ("business as usual") and/or with respect to other policy solutions.

The following section describes and discusses the general characteristics, the scope and the applicability of a wide selection of some of the most representative modelling tools that belong to this second category, as well as the data they require (and their availability).

Amongst the models selected for this overview, some focus specifically on transport and look more closely to vehicle characteristics (MOMO, PRIMES-TREMOVE, and TREMOVE). A few have a primary focus on the network utilisation (TRANS-TOOLS). A number of models do not only look at transport, but they include a module aiming specifically at the analysis of the transport sector (EFFECT, NEMS and POLES). Finally, some focus on local dimensions (TEEMP), others look at the national level (e.g. NEMS), others consider global macro-regions (ASTRA, PRIMES-TREMOVE, TRANS-TOOLS, TREMOVE). Finally, a few target global projections, typically on the basis of national and macro-regional information (MOMO and POLES), and one is primarily a modelling environment including simple accounting features that can be applied at different levels of aggregation (LEAP).

ASTRA

General information

ASTRA (ASsessment of TRAnsport Strategies) is an integrated model, developed in a system dynamics environment, covering macroeconomic, transport and environmental issues. It has been implemented as classical 4-stage model, but it considers endogenous reactions on all stages and does not require fixed trip generation and distribution (origin-destination matrix) inputs.

It has been developed since 1997 by IWW Karlsruhe and TRT Trasporti e Territorio. Since 2005, the model has been improved and maintained in the course of various projects by Fraunhofer ISI and TRT (AsTra-model, 2012).

It consists of nine integrated modules (AsTra-model, 2012 and Krail and Schade, 2010):

- a population module (POP), addressed on the basis of statistical information, as well as inputs on fertility and death rates;
- a macro-economic module (MAC), which consists of five elements: supply side, demand side, an input-output model based on 25 economic sectors, employment model and government model. It generates several outputs used by other modules, including the gross domestic product (GDP) at the country level;
- a regional economic module (REM) focuses mainly on trip generation (detailed by origin and destination and expressed in daily passengers and tonnes lifted) and the spatial distribution of freight and passenger transport, taking into account different distance categories for each of the regions characterizing the module, as well as drivers like employment, car ownership, and economic trade flows (converted into physical flows of goods by means of value-to-volume ratios);
- a foreign trade module (FOT), looking at intra-EU trade (in detail) and at flows between the EU and different regions in the rest of the World, estimating trade volumes on the basis of GDP growth and other factors (like changes in labour productivity and, in intra-EU trade, the cost of passenger and freight transport) and following the differentiation into 25 economic sectors also used the MAC module, to which the FOT module feeds information on trade flows;

- an infrastructure module (INF), containing information on the network capacity (for different modes), dealing with infrastructure-related investments and using speed-flow curves for the evaluation of travel speeds and travel time;
- a transport module (TRA), performing the modal allocation (between five passenger and three freight modes), calculating transport activity shares (expressed in vkm, after taking into account load factors) and total transport costs on the basis of information on trips by origin and destination from the REM module, travel times from the INF module, information on fuel prices, fuel taxes, and transport charges, as well as data on the structure of the vehicle fleets;
- an environmental module, using transport activity data by mode, distance class and traffic situation (from the TRA module), as well as data in the vehicle fleet characteristics, to estimate transport emissions and fuel consumption, but also fuel expenditures and tax revenues (fed back to the MAC module) and the number of accidents (based on accident rates);
- a vehicle flee module (VFT) taking care of the structure of the road vehicle fleet and the vehicle characteristics with respect to fuel consumption and emissions (up to 8 emission standards). It evaluates specifically vehicle purchase, technological choice – using a discrete choice approach to decide on the chosen engine technology and car size (depending on the parameters of the vehicles and the socio-economic drivers), and vehicle stock for passenger cars, buses, light duty and heavy duty freight vehicles;
- a welfare measurement module (WEM) calculating macroeconomic, environmental and social indicators.

ASTRA has also been linked with other energy models (POLES, TREMOVE and TRANS-TOOLS) in the framework of the iTREN-2030 European research project.

Additional information it are available in AsTra-model (2012) (e.g. Rothengatter et al., 2000a and Krail and Schade, 2010), as well as other research papers (e.g. Krail, 2008).

Applicability

ASTRA has been specifically developed for the assessment of impacts related to transport policies. It has been used for the analysis of transport-related polices in the fields of CO_2 emission mitigation, high oil prices, employment, and renewable energy (AsTra-model, 2012).

The initial version of ASTRA included 5 regions (4 within the EU 15 and one for the rest of the world) and six functional zones (from metropolitan centres to low density regions) and 12 economic sectors. The model was later extended to cover first to 15 countries for the EU and 25 economic sectors[28], and then 29 countries (i.e. the EU 27 plus Norway and Switzerland) as

[28] Agriculture (including forestry and fishery products), fuel and power products, non-metallic mineral products, chemical products, rubber and plastic products, fuel and power products, ferrous and non-ferrous ores and metals, metal products except machinery, agricultural and industrial machinery, transport equipment, office and data processing machines, electrical goods, optical goods from office

well as 9 regions for the representation of EU trading partners across the World (Oceania, China, East Asia, India, Japan, Latin America, North America, Turkey and the rest of the World). In addition, two specific models, looking at Italy and Germany, have been derived from ASTRA (AsTra-model, 2012).

The modes covered by ASTRA include (Rothengatter et al., 2000a):

- slow modes, car, bus, train and air for passenger transport;
- road (light duty and heavy duty trucks), rail and inland waterways (aggregated into a single mode because they offer similar transport characteristics and compete on the same products and on the same distances and because inland waterway transport is limited to specific geographical areas) and shipping for freight (air freight and pipeline transport are excluded).

Passenger sectors are analysed on the basis of 5 distance bands: local (< 3.2 km), very-short (3.2 tp 8 km), short (8 to 40 km), medium (40 to 160 km) and long (> 160 km). The trip purposes considered are business & commuting and personal. In addition, tourism flows are modelled for long distance movements. Freight sectors are considered on the basis of short distribution (0 to 50 km), medium-short distance (50 to 150 km), medium-long distance (150 to 700 km) and long distance (> 700 km) (Rothengatter et al., 2000a).

Local, very short and short sectors refer to the local road network, while medium to long categories refer to the interregional network (Rothengatter et al., 2000a).

The technological options for road vehicles included in ASTRA comprise conventional gasoline and diesel vehicles, as well as six alternatives: compressed natural gas (CNG), liquefied petroleum gas (LPG), hybrids, bioethanol (E85), battery electric and hydrogen fuel cells (Krail and Schade, 2010). For rail, diesel and electric trains are considered.

Data requirements and availability

Even if ASTRA does not need a fixed origin-destination matrix, it is a complex model requiring several exogenous inputs with a significant level of detail.

Some of these inputs include input-output tables (describing the sale and purchase relationships between producers and consumers within an economy) at the country level. At the regional level, inputs are needed on demographic data (population in the base year, birth and death rates, life expectancy), information on the labour force over time, the spatial representation of regions with respect to their settlement characteristics, trip rates per person (which are relatively stable over time), car ownership rates, the initial distribution of GDP by industrial sector and the growth rates in different industrial sectors. Value-to-volume ratios are needed for the conversion of monetary flows into physical volumes. Other inputs include fuel prices, accident rates (as well as other parameters related to safety),

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and data processing, other manufacturing products, textiles and clothing (including leather and footwear), paper and printing products, wooden goods out of other manufacturing products, food (also beverages) and Tobacco, building and construction, recovery and repair services (also wholesale and retail), inland transport services, maritime and air transport services, auxiliary transport services, communication services, lodging and catering services, services of credit and insurance institutions, other market services, non-market Services (Rothengatter et al., 2000b).

vehicle occupancy and load factors (defined by freight category, type of network and functional zone), vehicle characteristics in terms of fuel consumption and emissions, vehicle stocks in the base year, and vehicle mileage.

A number of other data are also necessary for the calibration of its equations and other relationships (e.g. speed-flow diagrams) (calibrating parameters).

The model is not freely available for download.

EFFECT

General information

The Energy Forecasting Framework and Emissions Consensus Tool (EFFECT) was first developed by the World Bank's Energy Sector Management Assistance Program (ESMAP) to assess the impact of policy choices on GHG emissions levels in the context of an activity aimed to support consensus building and planning in key sectors of the Indian economy.

The model is based on the "ASIF" structure, where information on Activity (passenger travel), Structure (travel by mode, load factors), and energy Intensity allows the estimation of Fuel consumption and corresponding CO_2 emissions. It is now defined as an accounting framework to design low carbon scenarios, calculate total investment costs and GHG emission levels (Audinet et al., 2011).

EFFECT is implemented in Excel and Visual Basic. It uses micro-level data that reflect individual and household behaviour to examine the ownership and the use of energy-consuming devices and consider efficiency scenarios from an engineering point of view. A summary of results with aggregated data is provided as an output.

The structure of the model is based on a general module and several sub-modules that cover the sectors of greatest growth in GHG emissions: transport, power, agriculture, households, non-residential and industry.

The transport module focuses only on on-road transport and is structured around vehicle ownership. From the baseline vehicle population projected from historical sales data, the model can forecast the number of vehicles in use and evaluate their fuel consumption and resulting emissions under a number of vehicle fuel efficiency and usage considerations (Rogers, 2011).

Applicability

The transport module has being used at the country-level (e.g. India, Brazil, and Poland) as well as at city-level (e.g. Bangkok, Beijing, Chengdu, Guangzhou, Hanoi, Ho Chi Minh City, Jakarta, Manila, and Ulaanbaatar) (Audinet et al., 2011 and CAI, 2011).

Effect estimates emissions from on-road transport. The flow of calculations is split according to three different vehicle categories: cars and motorcycles, other on-road passenger transport (light duty vans, multi-use vehicles, buses and coaches) and on road freight transport (light duty pickups and trucks, multi-use vehicles, heavy duty rigid trucks and tractor-trailer combinations).

Emission estimations are generally distinguished in three sources: emissions produced during thermally stabilized engine operation (hot emissions), emissions occurring during engine start from ambient temperature (cold-start and warming-up effects) and NMVOC emissions due to fuel evaporation. The effects estimated by the model include greenhouse gases as well as air pollutants. In particular, CO_2 (with and without a biofuel portion), CO, VOC, NO_X and PM emissions are provided as an output for each vehicle type, sub-type and every year in the modelling period.

Data requirements and availability

The model is freely downloadable from WB website, after registration. E-learning courses are also available presenting an overview for policy makers as well as specific information for each sectoral module (World Bank, 2011b).

The general module requires overarching inputs, while disaggregated sectoral data are required for the specific modules. In transport, the data required include population, urbanization rate and GDP at a more aggregated level, as well as disaggregated data, by location (urban or rural) and for several fractions (centiles) of all households, on their number, size, and expenditure.

Other inputs needed include total passenger-km travelled, freight-tons transported, the light and heavy duty vehicle ownership, average mileage, average load, mortality rate, sales on new vehicles by technology combined with the technological characteristics of new vehicle entering the market (CAI, 2011).

Since the EFFECT model uses the Excel-based COPERT 4 calculation module to generate its emission factors, it also requires input parameters on local operating conditions (ambient temperature), biofuels, road speed, load and grade, and maintenance-related parameters. Locally measured road-test results also allow calibrating the emissions factors used by the model to convert transport activity into vehicle emissions and fuel consumption.

GAINS

General information

The Greenhouse gas – Air Pollution Interactions and Synergies (GAINS) model was developed at the International Institute for Applied Systems Analysis (IIASA) as an extension of the earlier RAINS (Regional Air Pollution Information and Simulation) model.

GAINS estimates emissions for six air pollutants (SO_2, NO_X, PM, NH_3 and volatile organic compounds) and for the six greenhouse gases included in the Kyoto protocol. The estimates are calculated on the basis of activity data (to be provided as an exogenous input) and associated emission factors (Ahman, 2008, Ahman et al., 2008, and E4MACS, 2012a).

GAINS also assesses health- and environment-related impacts of the emissions of pollutants and GHGs, focusing in particular on the impacts on human health due to fine particulate matter, health and environmental impacts due to ground-level ozone, the acidification of terrestrial and aquatic ecosystems and excess nitrogen deposition of soils due to air pollution, and global warming effects (Ahman, 2008, Ahman et al., 2008, and E4MACS, 2012a).

Using assumptions on emission mitigation potentials and costs for different options, GAINS takes into account three groups of measures to reduce emissions (Ahman, 2008, Ahman et al., 2008, and E4MACS, 2012a):

- behavioral changes that act on the drivers of pollutant and greenhouse gas emissions, including autonomous modifications of life styles as well as changes fostered by regulatory and economic policies;
- structural interventions, such as energy efficiency and the switch to more sustainable fuel options, that supply the same level of service to the consumer but with less polluting activities;
- technical solutions that have been developed to capture emissions at their sources before they enter the atmosphere (e.g. catalytic converters in the case of pollutants, or carbon capture and storage technologies for greenhouse gas emissions).

In transport, fuel consumption and CO_2 emissions in the baseline are calculated on the basis of input on the evolution of the vehicle stock, the average travel per vehicle and a penetration profile for new technologies, adjusting these parameters in order to reproduce a reference development for the fuel consumption in projected years.

Alternative scenarios are determined by either a higher penetration of new technologies, a higher efficiency of the same technology, or both (Borken-Kleefeld et al., 2009).

In transport, changes in behavior are not considered. Parameters like modal split, load factors, vehicle sizes etc. are not modified in different scenarios (Borken-Kleefeld et al., 2009). The actual technology penetration is evaluated by an optimization routine on the basis of the characterization of different technologies with respect to cost and fuel savings, inputs on the impact on the fuel price of a carbon tax, and assumptions on the discount rate applied for the vehicle technology selection, all else being equal (Borken-Kleefeld et al., 2009).

Applicability

GAINS addresses emissions from power generation, transport, industry, residential and the commercial sector, as well as a number of sub-sectors (namely for industry).

In transport, GAINS focuses exclusively on road, taking into account six road vehicle categories: light duty passenger cars, light duty trucks, medium and heavy duty trucks, medium and heavy duty buses, two- and four-stroke two-wheelers. These vehicles can be powered by improved internal combustion engines, hybrid electric and plug-in hybrid powertrains (focused light duty vehicles and urban buses, but not for medium and heavy duty trucks), full electric systems (excluding medium and heavy duty trucks) and fuel cell drivetrains (Borken-Kleefeld et al., 2009).

The fuel options considered for these technologies include gasoline, diesel, LPG, and natural gas, biofuels, hydrogen (in fuel cell vehicles) and electricity (either through electric traction – e.g. in trolley buses – or stored in a battery that is charged from the electricity grid). Biofuels are not differentiated by feedstock and production pathways, but they are divided in two groups, considering either conservative savings potential of 35% reduction in GHG emissions per energy unit (compared to the fossil fuel substituted) for first generation technologies, and 80% for second generation. Their potential in projected years is derived from IEA publications (Borken-Kleefeld et al., 2009).

The GAINS model allows either to estimate the costs and environmental effects associated with specific solutions, or, in the optimization mode, to identify the optimal combination of emission control solutions that fit with user-supplied targets on air quality and/or greenhouse gas emissions.

To take into account regional differences in emission control costs and atmospheric dispersion characteristics, the following macro-regional model implementations were carried out and are currently available:

- Europe: GAINS enables a full assessment of the interactions and synergies between air pollution control and greenhouse gas mitigation. In order to assist key policy negotiations, the model has been used for under the UNECE Convention on Long-range Transboundary Air Pollution (e.g. the Second Sulfur Protocol in 1994 and the Gothenburg Multi-pollutant/multi-effect Protocol in 1999). In the framework of the European Union, it was used for the Acidification Strategy in 1995, the National Emission Ceilings Directive in 1999, the Clean Air for Europe (CAFE) programme in 2004, the revision of the National Emission Ceilings Directive in 2007, and the Climate and Energy Package in 2008 (IIASA, 2012a);
- Asia: the same methodology as for Europe was implemented for China and India, and facilitates the development of air pollution control strategies also capable to minimize emissions of greenhouse gases (IIASA, 2012b);
- Annex I: implementation to compare GHG mitigation potentials and costs across Annex I Countries of the Kyoto Protocol (IIASA, 2012c);
- World: a version that complements detailed information that is contained in the implementations for Europe, Asia and the Annex I countries by data for the rest of the other countries of the world, in order to develop global projections of air pollution emissions until 2030 (IIASA, 2012d).

Data requirements and availability

GAINS requires a large amount of information, spanning from technical data for the characterization of technology options to inputs required to characterize the activity projections necessary to perform its estimations.

Once the user specifies the targets to be achieved and the emission targets, the model runs using its own data sources. A selection of input sources used by different GAINS modules is listed below:

- GAINS-Europe uses energy balances and agricultural statistics from EUROSTAT and National emission inventories from EMEP and from national sources. Moreover, it runs using the inputs from other models such as PRIMES, CAPRI, TREMOVE and the CCE IMPACT database (IIASA, 2012a).
- GAINS-Annex I builds upon information provided in the national submissions to UNFCCC of GHG inventories for the year 2005, exogenous projections that specify

the levels of activities in each economic sector and country in the target year 2020 (e.g. the IEA World Energy Outlook), and an inventory of several hundred mitigation measures to control emissions of CO_2, CH_4, N_2O and F-gases (Cofala et al., 2009).

- GAINS-World uses the activity projections of the energy scenarios developed for the Special Report on Emissions Scenarios (SRES) of the IPCC as input.

The implementations of the GAINS model as well as its related documentation are freely available on-line (IIASA, 2012e). The GAINS-World version is available only in the research mode and it is accessible upon request.

GMM

General information

The Global Multi-Regional MARKAL (GMM) model is a technologically detailed, cost-minimization and bottom-up model developed and maintained by the Energy Economics Group at Paul Scherrer Institute (PSI). GMM includes several end-use demand sectors (industrial, residential, commercial, and transportation, plus modules dealing with non-commercial biomass use and non-energy feedstocks). It determines the least cost combination of end-use technologies and fuel supply options, given certain constraints (such as regional mandates for the improvement of personal car efficiency and for the use of different type of biofuels) and given a demand profile that has to be defined exogenously (Barreto and Kypreos, 2006).

GMM has been used in the context of a number of research projects sponsored by the European Commission (ACROPOLIS, CASCADE-MINTS, SAPIENTIA) and the Swiss National Centre of Competence on Research on Climate Change (NCCR-Climate- Phase I) for the assessment of the impact of flexible climate mitigation policies (ETSAP, 2005). The World Energy Council has also used the model to quantify global transport scenarios to 2050 and to compare them in terms of fuel demands, number of cars in circulation, and CO_2 emissions from the transport sector (WEC, 2011).

The model includes technology learning, considering the improvements in cost/performance of technologies according to the market experience (cumulative production or capacity) as well as the effects of R&D and D&D activities (represented through a knowledge stock function). In particular, learning is considered for a list of key components that characterize the different end-use technologies under consideration in the model. For instance, the investment costs of hybrid cars are calculated on the basis of those pertaining to the battery (analyzed with learning), the rest of the drive-train system and the Balance of System (assumed to be non-learning).

The model is focused on CO_2 emissions, but marginal abatement curves for non-CO_2 greenhouse gases (CH_4 and N_2O) are also embraced for some sectors. GMM also features a representation of the atmospheric concentration of CO_2, CH_4 and N_2O.

The transport sector sub-module provides several outputs such as the total fuel demand, technology shares and CO_2 emissions in three sub-sectors: personal car transport (LDV) (also calculated separately), other surface transport (such as trucks, buses, trains, and ships), and aviation.

Applicability

The transport sector sub-module of GMM encompasses 15 world regions, including the US, Canada, Mexico, Brazil, China, India, Russia, Africa, the former Soviet Union (excluding Russia), OECD Europe, eastern Europe, OECD Pacific, other Latin America and the Caribbean (excluding Brazil and Mexico), other Asia (excluding India and China), and the Middle East. For each region, specific assumptions are applied to technology characteristics, energy demand profiles in transport, and other parameters.

Several technologies are considered for the analysis of personal car transport: they include vehicles powered by conventional internal combustion engines, as well as flex-fuel, hybrid-electric, battery electric, hydrogen fuel-cell, and plug-in hybrid electric vehicles. The most relevant key components, such as batteries, mobile auto-thermal reformers, and mobile fuel cells, are linked to the corresponding technologies. The fuelling options consider fossil fuels (gasoline, diesel, natural gas, and methanol derived from coal), different biofuels (assumed to have a small well-to-tank carbon content) that can be blended into the aforementioned fuels, and alternative fuels, comprising electricity and hydrogen, that have different dynamics in each region for their carbon content (well-to-tank).

In aviation, current technology options are represented along with a more advanced technology that has a better efficiency, but also higher costs operations and maintenance (excluding fuel costs). Fuelling options include conventional kerosene, and synthetic biomass- and coal-to-liquids fuels. Other surface transport is characterized by fuelling options and associated energy-efficiency factors.

Data requirements and availability

The input parameters used as exogenous variables by the transport model are (WEC, 2011):

- general (e.g. annual GDP growth rate, time horizon, and population);
- related to light duty vehicles (e.g. mileage, transport demand, motorization rate, efficiency, investment coast, efficiency targets);
- targeting aviation (e.g. transport demand, blend of biodiesel in aviation fuel, aggregated efficiency, aggregated cost);
- focusing on other surface transports (e.g. demand, share of fuelling options, aggregated efficiency, aggregated cost);
- characterizing fuels (e.g. share of fuels, CO_2-emission of fuels, CO_2-taxes, biofuel targets, production costs).

The transport sub-module is calibrated to technology activity and capacity statistics for the year 2005. The calibration includes current demands for each subsector, currently available fuelling options, and technology and fuel shares, as well as estimates on current costs of fuels and of technologies. The statistics for calibrating were taken from various sources such as the full GMM energy model, IEA, Oak Ridge National Laboratory's Transportation Energy Data book, the Annual Energy Outlook from the US Department of Energy, hybrid-car sale statistics from car manufacturers, and statistics from the international Gas Union, the International Road Federation, and the International Council on Clean Transportation. The model uses additional statistics for recent years in cases where reliable data are available (WEC, 2011).

The GMM model is not publicly accessible.

LEAP

General information

The Long-range Energy Alternatives Planning system (LEAP) is a scenario-based energy-environment modelling tool that was developed by the US branch of the Stockholm Environment Institute (SEI).

LEAP allows tracking energy consumption, production and resource extraction in all sectors of an economy. It can be used to account for greenhouse gas (GHG) emission sources and sinks both for the energy and non-energy sector, as well as emissions of local and regional air pollutants. The model only contains built in basic accounting relationships (i.e. conventional and non-controversial energy, emissions and cost-benefit accounting calculations), but it allows for additional modelling (i.e. spreadsheet-like expressions that can be used to specify time-varying data, as well as more sophisticated multi-variable models) to be added by the users. Since many aspects of LEAP are optional, its initial data requirements are relatively low (Heaps, 2012). On the other hand, the model does not provide advanced modelling features, unless users build them up.

Following the structure of an energy balance, LEAP contains modules focusing specifically on the demand, transformation and resources. Demand analysis can be addressed with three main methodologies: the activity level analysis (energy consumption is calculated as the product of an activity level and the energy intensity), the stock analysis (energy consumption is calculated by analysing the current and projected future stocks of energy-using devices, and the annual energy intensity of each device) and the transport analysis. In the transport analysis, energy consumption is calculated as the product of the number of vehicles, the annual average mileage and the fuel economy of the vehicles. LEAP uses the inputs entered by the user (i.e. exogenous inputs or information resulting from additional modelling) to calculate the stock average values for fuel economy, mileage and environmental loadings across all vintages and hence, ultimately, the overall level of energy consumption and environmental loadings. Emission factors can be based on travel (e.g. for air pollutants) or on energy consumption (e.g. for CO_2 and other greenhouse gases). Moreover, the emission factors can become dynamic by means of a degradation factor entered as a lifecycle profile. The outputs of the analysis are provided as transport results (stock average on-road fuel economy and vehicle mileage) and environmental results (for any effect for which environmental loadings have been specified) (Heaps, 2012).

LEAP includes 40 different effects to account for pollutants and other direct environmental impacts leading to external costs, it uses this information to perform a cost-benefit analysis, and it also allows for the addition of new pollutants. Similarly, LEAP provides the combined global warming potential (GWP) , based on the most up-to-date GWP factors recommended by the IPCC, for CO_2, CH_4, N_2O and the most common non-energy sector gases with high GWP (SF_6, CFCs, HCFCs and HFCs).

The latest version of LEAP also includes optimization capabilities (to calculate automatically least cost capacity expansion and dispatch of supply-side transformation modules), as well as new capabilities for modelling seasonal and time-of-day variations in demand and supply (Heaps, 2012).

Applicability

LEAP is used by government agencies, academics, non-governmental organizations, consulting companies, and energy utilities, at scales ranging from cities and states to national, regional and global applications (Heaps, 2012). It is also used for the preparation of a number of national communications to the UNFCCC (UNFCCC, 2012).

Data requirements and availability

The main variables used in the calculations of the transport analysis that must be introduced by the user of the model are the following:

- base year stock of vehicles, specifying a lifecycle profile describing the age distribution of vehicles within that stock;
- sales in the base year as well as future sales of vehicle to be introduced in scenarios;
- fleet roll over, in order to take into account that Government and business fleet vehicles became private fleets after a number of years;
- mileage of newly purchased vehicles of a given vehicle type (optionally with a degradation profile as vehicles age);
- mileage correction factor, in order to adjust the mileage value calculated for the total vehicle stock;
- fuel economy of newly purchased vehicles of a given vehicle type (optionally with a degradation profile as vehicle ages);
- fuel economy correction factor, in order to convert from rated to on-road fuel economies.

LEAP also contains a database containing technical characteristics, costs and environmental impacts of about a thousand of energy technologies (including existing technologies, current best practices and next generation devices), building on the information published in reports by dozens of institutions including the IPCC, the U.S. Department of Energy, and the IEA (Heaps, 2012).

The model is downloadable from the web, upon registration and at different pricing conditions for different users (SEI, 2011). Registering requires the acceptance of a license agreement.

In order to facilitate a starting point for analysts, SEI developed a series of national level starter data sets for use in LEAP (COMMEND, 2012).

MOMO

General information

The mobility Model (MoMo) developed by IEA is a global transport spreadsheet model, based on the ASIF framework, that supports projections and policy analysis. It allows the analysis of fuel consumption and the emissions of GHG and other pollutants, at the global scale, on the basis of transport activity, modal split, energy intensity and emission-related characteristics. It was first developed by the IEA as the backbone of the Sustainable Mobility Project (SMP) of the World Business Council for Sustainable Development (WBCSD), underpinning the Mobility 2030 publication (WBCSD, 2004).

MOMO also incorporates two other modules targeting safety and the analysis of materials demand and upstream emissions due to vehicle manufacturing.

It is suitable for simple "what-if" analysis to understand changing trends given the variation of one or more variables, as well as analysis based on inputs relative to economic growth, population growth and the variation of fuel prices. The model uses vehicle stock, average travel, and fuel consumption factors to calculate energy use. The results are then checked and calibrated against IEA energy use statistics to ensure that the identity is solved correctly for each region.

A more detailed description is available in IEA documents (such as Trigg, 2011), and on the IEA website (IEA, 2012c).

Table 25. MOMO: coverage of fuel pathways

Liquid petroleum fuels
Gasoline
Diesel (high- and low-sulphur)
Biofuels
Ethanol
Grain, sugar cane, advanced technologies (lignocellulosic)
Biodiesel
Conventional (transesterification of fatty acid methyl esters), advanced (e.g. BTL)
Synthetic fuels
GTL and CTL
Compressed Natural Gas (CNG) and biogas
Liquelfied Petroleum Gases (LPG)
Electricity
Separately for EVs and PHEVs; by generation mix, by region
Hydrogen
From natural gas, with and without CO_2 sequestration
From electricity, point of use electrolysis, with and without CO_2 sequestration
From biomass gasification
Advanced low-GHG hydrogen production

Source: Trigg, 2011

Applicability

MOMO covers a wide range of fuel pathways (Table 25), as well as several transport modes and vehicles (Table 26). It contains several technology-oriented details, including information on fuel economy potentials and cost estimates, as well as alternative fuel characteristics (like well-to-tank, tank-to-wheel emissions), with cost tracking and aggregation capabilities.

In MOMO, technological costs are also linked to cumulative production volumes through learning curves. Estimates on the market shares of different technologies hare heavily dependent on exogenous inputs.

MOMO allows making projections of transport activity, energy use, emissions of GHG (both well-to-tank and tank-to-wheel) and air pollutants, and to evaluate the associated vehicle and fuel costs until 2050.

MOMO produces results for 22 countries and regions (including some aggregates), covering the entire world.

Table 26. MOMO: coverage of transport modes and vehicles

2-3 wheelers		
Light duty vehicles		
	Spark ignition (SI) ICEs	
	Compression ignition (CI) ICEs	
	SI hybrid ICEs (including plug-ins)	
	CI hybrid ICEs (including plug-ins)	
	Hydrogen ICE hybrids (including plug-ins)	
	Fuel cell vehicles	
	Electric vehicles	
Heavy and duty vehicles		
	Passenger	
		Minibuses
		Buses
	Freight	
		Medium freight trucks
		Heavy freight trucks
Rail		
	Passenger	
	Freight	
Air		
Water transport		
	National	
	International	

Source: Trigg, 2011

Data requirements and availability

The model is not downloadable from the web for the general public and is currently only accessible for IEA partners (more information on the possibility to access the model is available in IEA, 2012c).

The input parameters required by MOMO have been collected on a country by country basis, and were included in a database coupled with the model. Such information includes official IEA data (such as fuel consumption estimates), statistics published by national statistical offices and other published information collected from various sources.

MOMO also requires inputs for the definition of economic growth, population growth and the variation of fuel prices, as well as assumptions on vehicle ownership, vehicle loads, fuel and vehicle technology characteristics and costs, sales on new vehicles by technology and total transport activity patterns in non-road modes.

Economic and demographic parameters are taken from published outlooks (e.g. on economic and demographic figures). Other data include information gathered from scientific literature, expert judgements based on analytical considerations (e.g. for the technological characterisation of vehicles and fuels) and assumptions (e.g. for the policy definition).

Being developed in a set of Excel files, MOMO requires significant storage space and memory. For the same reason, operations like the increased disaggregation of its regional scope are time-consuming activities.

NEMS

General information

The National Energy Modeling System (NEMS) was designed and implemented by the Energy Information Administration of the U.S. Department of Energy (US EIA). The US EIA is also updating and maintaining it.

NEMS is used to model of the United States energy markets projecting energy, economic, environmental, and security impacts on the United States of alternative energy policies and of different assumptions about energy markets (Chien, 2005).

The model is structured in modules representing four end-use demand sectors (including residential, commercial, industrial, and transportation), four energy supply areas (oil and gas, natural gas transmission and distribution, coal, and renewable fuels), two energy conversion processes (electricity and petroleum refineries), the energy-economic interactions through a macroeconomic component and a module accounting for the interaction between US and global energy production and consumption (e.g. through effecs on the oil price). These modules are interconnected by means of an integrating module (US EIA, 2010a).

Transportation is considered in one of the end-use demand modules: the Transportation Demand Module. This component is intended to generate projections of transportation energy demand, while incorporating endogenously technological innovation, macroeconomic feedback, infrastructural constraints, and vehicle choice in making the projections (US EIA, 2010b).

The NEMS Transportation Demand Module projects consumption of fuels in the transportation sector, vehicle sales, stocks and characteristics by size class (including the fuel efficiency of vehicle by technology type and information on alternative-fuel vehicle sales and stock by technology type), as well as vehicle travel. It receives from other modules inputs on energy prices, macroeconomic data like GDP, disposable personal income and industrial output, total vehicle sales, international trade and natural gas pipeline consumption (US EIA, 2010a).

The calculations characterizing the Transportation Demand Module are split mainly in four sub-modules, looking specifically at Light-Duty Vehicles (LDV), Aviation, Freight Transport (truck, rail, waterborne) and other transport (Miscellaneous: transit, recreational boats, aviation gasoline). Their specific tasks are further highlighted below (using information from US EIA, 2010b):

- the LDV sub-module uses econometric models to forecast passenger travel demand and new vehicle market share and uses engineering and expert judgment for estimating fuel economy. In particular, it provides estimates of new LDV fuel economy, the market shares of alternate fuel vehicles, sales of vehicles to business fleets and households. It generates estimates on the travel demand, fuel efficiency, and energy consumption, using stock models, both for business fleets and personal vehicles;
- the Air Travel sub-module estimates the demand for jet fuel and aviation gasoline using econometrics to forecast passenger travel demand and a stock model to determine the size and characteristics of the aircraft fleet, leveraging on inputs such as jet fuel prices, population, per capita Gross Domestic Product (GDP), world GDP, disposable personal income, and merchandise export;
- the Freight Transport sub-module uses information on fuel prices, trade, and industrial output to estimate travel demand and energy consumption for truck, rail, and marine freight transport;
- the Miscellaneous energy demand sub-module estimates projected passenger travel and energy demand from military, mass transit (including bus and rail), recreational boating, and lubricants.

The model is not freely available for download.

Applicability

The NEMS model is strongly focused on the United States and has been used to prepare the US EIA Annual Energy Outlook since the 1994 edition (US EIA, 2011). Within the United States, it operates at a Census region and Census division level (more aggregated than the State level). State-level results require extrapolations and interpolations, and no local- or county-level forecasts are possible (Chien, 2005).

Its current projection horizon extends to the year 2035 (US EIA, 2010a).

The transportation model can evaluate a range of policy issues, including fuel taxes and subsidies; fuel economy performance by market class and, in particular, the Corporate Average Fuel Economy (CAFE) standards; vehicle pricing policies by market class; demand for vehicle performance within market classes; fleet vehicle sales by technology type; alternative-fuel vehicle sales share; the California Low Emission Vehicle program; reduction in vehicle travel; and various other policies related to transportation energy use and greenhouse gas emissions (US EIA, 2010b). Policies designed to shift ridership from one mode to another are currently not measurable nor easy to implement (Chien, 2005).

Outputs are given as fuel consumption, vehicles miles travelled, fuel economies, and emissions (SO_X, NO_X, HC, CO and CO_2) by mode and vehicle type.

Data requirements and accessibility

NEMS requires inputs on macroeconomic and financial factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, cost and performance characteristics of energy technologies, and demographics (Chien, 2005).

Even though a large number of detailed data are required as input to run NEMS, data from many of the data sources used to develop the model reside at the federal agencies that created and currently maintain the model (or at other institutions) and are integrated in the input file of the model. Examples of data sources include ORNL (2011), US BTS (2012a) and US BTS (2012b).

The size of the entire NEMS model is very large and detailed, requiring substantial storage and computing resources. The model operates in Compaq Visual FORTRAN and requires the EViews software, as well as OML, a linear programming software, for the supply models (Chien, 2005).

POLES

General information

The POLES (Prospective Outlook for the Long term Energy System) model is a global sectoral simulation model for the development of energy scenarios until 2050, first developed by the French CNRS (Centre National de la Recherche Scientifique) and now by the UPMF University (Université Pierre Mendès France), Enerdata and the EC JRC IPTS (European Commission - Joint Research Centre - Institute for Prospective Technological Studies) (Kitou, 2006).

It is a global sectoral model for the world energy system, developed as a hierarchical structure of interconnected sub-models at the international, regional and national level (Russ et al., 2009). Its dynamics of the model are based on a recursive (year by year) simulation process of energy demand and supply with lagged adjustments to prices and a feedback loop through international energy price. Using exogenous inputs in overarching economic and demographic assumptions, it allows (E4MACS, 2012b):

- producing detailed long-term world energy outlooks with demand, supply and price projections, also incorporating learning curves to account for the effects of experience and training on new technologies;
- the estimation of CO_2 emission marginal abatement cost curves for each country and sector; and
- technology improvement scenarios, with exogenous or endogenous technological change, and analyses of the value of technological progress in the context of CO_2 abatement policies.

For road transport, the total vehicle stock is modelled in POLES before vehicle technologies through income elasticities and saturation levels, and transport modes are addressed in different ways. Road transport is decomposed in three parts: private transport, public transport (rail and bus) and goods transport (light trucks and heavy trucks). For passenger cars and trucks, mobility can be satisfied by the following technologies: conventional internal combustion engines (ICE) (using oil or biofuels), ICE-electric hybrid vehicles (oil, biofuels, electricity), electric vehicles (electricity), hydrogen fuel cell vehicles (hydrogen); and thermal hydrogen vehicles, burning hydrogen in a conventional ICE. Rail transport activity (assumed to increase constantly with GDP) can be satisfied by coal, oil and electricity, while oil-based fuels and biofuels can be used for aviation (EC JRC IPTS, 2010). As in other sectors, the technological selection in transport is based on least cost options and takes into account technology learning effects through learning curves.

A brief description of the model is available in Russ et al. (2007 and 2009), while a more extensive explanation is available in EC JRC IPTS (2010). Other information is given in Kitou (2006) and in EC JRC IPTS (2008a).

Applicability

In the current geographic disaggregation of the model, the world is divided into 47 countries or regions, with a detailed national model for each Member State of the European Union, four industrialised countries (USA, Canada, Japan and Russia) and five major emerging economies (Mexico, Brazil, India, South Korea and China). The other countries/regions of the world are dealt with in a simplified but consistent demand model (Russ et al., 2009).

POLES is suitable for the analysis of technical progress, with the possibility to simulate "technological breakthrough" scenarios. In addition, it can be used to analyse the impact of measures like those stemming from international agreements on the limitation of greenhouse gases.

Data requirements and availability

The main input data include: macroeconomic and demographic data; information derived from the energy balances of international databases (e.g. the IEA database); techno-economic data (such as energy prices, equipment rates, costs of energy technologies etc.) needed to defined learning curves for each technology; and data on the availability of energy resources (EC JRC IPTS, 2008a).

The model is not freely available for download.

PRIMES and PRIMES-TREMOVE

General information

PRIMES is detailed agent based and price driven model of the energy system in Europe, conceived for energy outlooks, scenario construction and impact assessment of policies, maintained by the Economics-Energy-Environment Modelling Laboratory (E^3MLab) of the National Technical University of Athens. It is used primarily for the European Commission, but also for industry associations and other research projects.

PRIMES formulates separate objective functions for different agents and simulates in detail the formation of energy prices (E^3MLab, 2011a). It is organised in a modular system with individual sub-models for energy supply (oil products, natural gas, coal, biomass, and others), energy demand (residential, commercial, transport, and industrial sectors), and energy conversion (e.g. electricity production and refining).

Since it only looks at a portion of the economy, it can be characterised as a partial equilibrium model, requiring exogenous inputs on macroeconomic and demographic parameters, fossil fuel prices. Other inputs include infrastructure-related characteristics, information capable to characterise policies, technical and economic variables used for the definition of learning curves for technologies, products characteristics subject to consumer choices and saturation effects, the supply cost-curves for potential of resources, new technologies and the use of new sites for energy plants and the perceived costs of technologies (E^3MLab, 2011a).

The model generates projections of energy balances (including supply, demand and energy conversion), investment costs, energy prices and CO_2 emissions (from energy combustion and industrial processes) per country, as well as the trade flows of electricity and gas and transport activity data for different modes and vehicle classes (E^3MLab, 2011a).

A detailed transport sector module (PRIMES-TREMOVE) is included in PRIMES and can also be optionally used for transport policy analysis and energy-emissions outlook as a stand-alone model (E^3MLab, 2011a). It is this module that projects the evolution of demand for passengers and freight transport by mode and vehicles, using total transport activity as an input. The projection is based on economic, utility and technology choices of transportation consumers (E^3MLab, 2011a).

PRIMES-TREMOVE consists of two main modules:

- the first focuses on the transport demand allocation to the various modes (also distinguishing between passenger transport by individual, businesses, and freight transport). The capital cost of the vehicles, their annual maintenance, insurance and registration costs, the fuel costs, taxes and subsidies (and the effects of other public policies), as well as the congestion (affecting time, whose value differs between individuals and businesses) influence the choice of transportation modes and means;
- the second takes care of the technology choice and equipment operation. For road transport, the technology choice is based on a nested logit utility function, and the vehicle fleet is represented using a stock model. A similar discrete choice methodology is formulated for the vehicle fleet, distinguishing between metro, tram, urban and non-urban trains. The technology choice model is less detailed for inland navigation and air transport (E^3MLab, 2011a).

Consumption of transport fuels is endogenously calculated by the model. For road transport, fuel consumption and emissions of non-CO_2 and a wide range of pollutants are calculated on following the COPERT methodology (the vehicle speed required for it are obtained from the endogenous estimates of travel time and mileage). For non-road transport modes, i.e. rail, inland navigation and air transport, average mileage and specific fuel consumption factors are used for calculating fuel consumption and CO_2 emissions (E^3MLab, 2011a).

The model documentation can be found in E^3MLab (2012) and other literature sources quoted in this section.

Applicability

PRIMES covers all transport modes (road, rail, inland navigation and air), several fuels and powertrain options (Table 27), for the EU27, candidate MS and neighbouring countries such as Norway, Switzerland, Turkey, South East Europe, with a 2050 time horizon by five-year periods (Capros, 2010).

According to E^3MLab, PRIMES can support strategic analysis on the security of energy supply, environmental concerns including climate change mitigation, the impact assessment of energy and environmental policies like pricing policy, taxation, emission trading, policies for the promotion of technologies (e.g. on renewable energy), regulatory standards influencing technology availability and choice, polices aimed to foster energy efficiency on the demand-side, alternative fuels, as well as other policy issues regarding electricity generation, gas distribution and new energy forms (E^3MLab, 2011a and 2011b).

PRIMES-TREMOVE can handle various policies and energy and environment related topics, including economic measures (e.g. charges, subsidies and taxes), regulatory measures (e.g. mandates, standards), measures aimed to favour the diffusion of new technologies, the development of new transport fuels (e.g. bio-fuels, hydrogen), and climate change policies (e.g. carbon tax, emission trading) (E^3MLab, 2011a and 2011b).

Data requirements and availability

Inputs to the PRIMES Model include macroeconomic statistics like GDP and the economic activity by energy end-use sector, demographic data, fossil fuel prices, tax rates and subsidy policies, interest rates, risk premiums, environmental policies and constraints, information on the gas and electricity network infrastructure, data describing the technical and economic characteristics of future energy technologies (including learning parameters), energy consumption habits and comfort parameters, supply curves for primary energy sources (including renewable energy sources), the availability of potential of sites for new plants, and the energy efficiency potential and cost (E^3MLab, 2011a).

PRIMES-TREMOVE requires the same input data as in TREMOVE are required for calculating emissions. This means that it requires additional inputs for historical data on vehicle stock for road and rail transport (taken from the TREMOVE database), vehicle costs (describing the technical and economic characteristics of future energy technologies), load factors and average vehicle travel. They are taken from the TREMOVE and SAPIENTIA databases, as well as statistics from the Eurostat database and other publications (E^3MLab, 2011a).

PRIMES and PRIMES-TREMOVE are not freely available for download.

Table 27. Correspondence of transport modes, vehicle technologies and fuels in PRIMES-TREMOVE[29]

			Buses	2W	Car	LCVs	HCVs	Rail	Water	Air
Liquid fuels	Gasoline blend	ICE		X	X	X			X	
	Ethanol	ICE			X					
	Diesel blend	ICE	X		X	X	X	X	X	
	DME	ICE	X		X	X	X	X	X	
	B100	ICE	X		X	X	X	X	X	
	Fuel oil blend	ICE							X	
	Jet fuel	Turbines								X
Gaseous fuels	Natural gas - hydrogen blend	ICE	X		X	X	X		X	
	Natural gas - biogas blend	ICE	X		X	X	X		X	
	Biogas	ICE	X		X	X	X		X	
	LPG	ICE	X		X	X	X			
Hydrogen		Fuel cell	X		X	X	X			
Electricty		Battery electric	X	X	X	X	X			
		Plug-in Hybrid ICE-electric			X	X				
		pn-grid						X		

Source: E^3MLab, 2011b

TEEMP

General information

The Transport Emissions Evaluation Models for Projects (TEEMP) is a tool that gathers several models (developed in Microsoft Excel) to estimate the Clean Air Initiative for Asian Cities (CAI-Asia), together with Institute for Transportation and Development Policy (ITDP), the Asian development bank (ADB), Cambridge Systematics and UNEP-GEF (CAI-Asia, 2012). It was initially intended to evaluate the emissions impacts of ADB's transport project, but

[29] 2W: two-wheelers; LCVs: light commercial road vehicles, HCVs: heavy commercial road vehicles (trucks); and ICE: internal combustion engines.

later on was modified and extended for projects funded by the Global Environment Facility (GEF) (Hook et al., 2010).

The tool quantifies the direct emissions in a baseline (business-as-usual) scenario excluding the project and in another scenario that includes the project development. The estimation is based on of ASIF (Activity, Structure, Intensity, Fuel) parameters like vehicle fuel efficiency, greenhouse gas intensity of the fuel used, amount of transport activity, mode of transport chosen, and amount of capacity/occupancy used. When relevant, emissions due to construction (e.g. for new roads or improvements on the current infrastructure) and operations (e.g. electricity consumption from Mass Rapid Transit operations) are also considered in the analysis.

The tool address measures of different nature, with a focus on infrastructure projects and instruments favouring model shifts. The projects targeted include (Gota, and Mejia, 2010 and Replogle, 2011):

- bike sharing;
- bikeways;
- pedestrian facility improvement;
- Bus Rapid Transit (BRT);
- Light Rail Transit (LRT)/Mass Rapid Transit (MRT);
- road projects – expressways, rural roads and urban roads;
- railways;
- city sketch analysis and other strategies, such as commuter strategies, pricing strategies, eco-driving, pay-as-you-drive insurance schemes.

Most of the specific models included in the TEEMP framework offer the possibility to perform either a sketch analysis (based on default values obtained from other similar projects) or a detailed analysis (requiring specific information), depending on the level of detail of the data introduced.

TEEMP provides several indicators in terms of CO_2, NO_X and PM emissions as outputs.

Applicability

Being focused on specific projects, TEEMP models are applicable at the local (project) level. It facilitates consideration of range of options and impacts and it is appropriate for ex-ante evaluation where data is poor, even if it works best when local information is available.

TEEMP focuses on estimating CO_2 and other emissions from specific project concerning passenger transport. It does not address freight transport, it cannot estimate the effects stemming from the combined implementation of different projects, and it does generate outputs related to transport planning and land-use patterns (but uses inputs on land-use modifications and its subsequent impacts on travel pattern, for BRT projects).

TEEMP also does not include the estimation of costs and benefits associated with the value of travel time. Finally, it does not evaluate fuel savings, effects on accidents and road safety, and other economic impacts.

Data requirements and accessibility

The TEEMP models as well as the user manual are freely available (CAI-Asia, 2012).

The inputs required by TEEMP models are linked to the relevant ASIF parameters for the corresponding project:

- Activity: number of trips, average trip lengths, average speeds;
- Structure: mode shares, average occupancies, vehicle fuel split, vehicle emission standards split;
- Intensity: fuel efficiencies of vehicles;
- Fuel: Emission Factors.

Moreover, inputs to determine emissions from constructions and operations are required, if applicable:

- Construction: amount of materials used, emission factors for materials;
- Operations: amount of electricity used, emission factor of the grid, fuels used for project vehicles.

The tool can run with conservative default values (based on research, observed results from similar projects, and expert opinion), but more accurate GHG emission estimates are achievable if local data inputted into the model.

TRANS-TOOLS

General information

TRANS-TOOLS (TOOLS for TRansport Forecasting ANd Scenario testing) is a European transport network model, covering passenger and freight transport on all modes (cars, trucks, trains, canal ships, sea ships and air transport) and also addressing intermodal transport. TRANS-TOOLS was first developed under the Sixth European Framework Programme for Research and Technological Development (FP6), and then improved in projects funded by the former European Commission Directorate General for Transport and Energy, as well as other project involving the EC Joint Research Centre's Institute for Prospective Technological Studies (IPTS). The IPTS is now coordinating the further development of the model and the support of its user community (EC JRC IPTS, 2008b, TKRC, 2009).

The model combines advanced modelling techniques in transport generation and assignment, economic activity, trade, logistics, regional development and environmental impacts. Its main components include:

- a passenger transport demand module, covering trip generation, the spatial trip distribution and modal split (using information on travel costs , travel time, frequencies and the number of transfers) (Burgess et al., 2008), addressed by two sub-modules looking separately at short strips (less than 100 km) and long trips (Rich et al., 2009);

- a freight demand module, using exogenous inputs (unlike previous TRANSTOOLS versions), operated at the regional level and divided further with a simple gravity model, capable to use fixed initial and final demands, to applying simple growths factors and/or elasticity of the fixed demands, as well as external freight models (Hansen, 2011)
- a freight transport module evaluating model choices and a logistic module estimating the changes in the number and location of warehouses for the distribution of goods and the impacts resulting on the costs related to the transportation of different commodities (Burgess et al., 2008);
- an economic module, taking into account the effects of transport policies on the accessibility of European regions and the consequences on their economic development (Burgess et al., 2008);
- the network assignment module, calculating the passenger and freight activity (traffic volumes) on the road, rail, maritime, inland waterway (freight) and air (passenger) networks (also accounting for congestion in the case of road) (Burgess et al., 2008).

In addition, impact modules calculate energy consumption, emissions, external costs and safety-related parameters on the basis of the outputs of the assignment module, as well as exogenous data on technical parameters (typically taken from TREMOVE, in the EU policy development context). The model components are integrated into GIS, which allows the user to edit, operate and illustrate results in a common platform (Burgess et al., 2008).

A number of model improvements have been delivered in the context of the TENCONNECT and the TENCONNECT 2 projects, leading to versions 2 and 2.5 of TRANS-TOOLS (Hansen, 2011). The TENCONNECT project led to the segmentation of passenger transport in two trip distance sub-modules (above and below 100 km), an improved evaluation of the modal choice selection for access and egress to and from airports, the improvement of the base year information concerning the origin/destination matrices for car, air and rail trips (transformed in generation/attraction matrices, focusing on people that conduct trips rather than the trips themselves), a more detailed spatial resolution for the economic model, the use of a trade model for the determination of freight demand, and the upgrade of the impact modules to reflect trade predictions resulting from the economic module (Rich et al., 2009). TENCONNECT 2 introduced exogenous freight demands (using information stemming from the WORLDNET project), as well as improved convergence and solution algorithms in assignment models (Petersen et al., 2011 and Hansen, 2011).

A new development phase, launched in 2011, aims to improve the methodological basis of the model. It is expected to improve and validate its data foundation, develop new freight models, re-estimate passenger demand model, include intercontinental air transport, improve rail assignment models, make the software more efficient, and develop a detailed model documentation and model validation (TransTools3, 2011 and Hansen, 2011).

Applicability

The model covers 42 countries (including all EU Member States). It is most detailed in Germany and Western Europe, and it does not include zones outside Europe and the Russian Federation (Hansen, 2011).

The European Commission services addressing transport issues have agreed to use TRANS-TOOLS as the main model for policy analysis, and have appointed IPTS as the model's Reference Centre (EC JRC IPTS, 2008b). Amongst other tasks, TRANS-TOOLS has been used by the EC for analysing aspects related to the TEN-T policy review. The IPTS is also applying TRANS-TOOLS in impact assessments for several policy measures.

Data requirements and accessibility

TRANS-TOOLS is available for free (upon request). It requires the commercial software ARC-GIS, Traffic Analyst, as well as other freeware software (Vensim Model Reader) to run (EC JRC IPTS, 2008b, TKRC, 2009 and Hansen, 2011).

TRANS-TOOLS requires a very large amount of data with a high disaggregation level.

The data required include information capable to characterise the transport infrastructure network (e.g. location of network nodes, network extension, average speed and capacity of network links) for all modes (air, rail passenger, rail freight, road, and waterways), geographical and socio-economic data (population, labour market participation, car ownership, gross domestic product, but also hotel capacity), freight transport demand (volumes, length, network links involved, total activity and modal choice), passenger transport specifications (trip distance, trip purpose, total activity and modal choice) passenger and freight transport costs (tolls, ticket fares, fuel cost per km by mode, costs by commodity group, costs associated to the value of time), and external costs (e.g. emissions, accidents, injuries) (Burgess et al., 2008 and Hansen, 2011). As TRANS-TOOLS has a much more aggregated structure on vehicle characteristics than models like TREMOVE (having a very detailed characterisation of vehicles both for road transport and non-road transport), it requires, in this specific area, less detailed information.

Even if no single source can provide the data needed by TRANS-TOOLS, the ETIS-BASE, a reference pan-European database developed using mathematical formulas and algorithms from national and international primary and secondary data sources (as well as methodologies elaborated to fill data gaps), covered the majority of the needs of the first version of TRANS-TOOLS (Burgess et al., 2008 and ETIS project, 2005). ETIS-BASE was developed for the year 2000. Following this first effort, the data foundation of TRANS-TOOLS was also addressed by the TENCONNECT project, with the update of the base year (to 2005) and the disaggregation of some zones in Eastern Europe, the Russian Federation and Turkey, and the update of network-related information (Rich et al., 2009). TENCONNECT 2 led to the recalibration and quality control of the data (both for traffic and network), the inclusion of new data from member states (Petersen et al., 2011 and Hansen, 2011) and, through the WORLDNET project, to the update of the freight transport matrix for 2005, its refinement to the country level in non-EU countries, and its refinement for aviation data (Newton, 2009). The version that will result from the TransTools3 project will feature a new update, to 2010, leveraging on the results of the ETISPlus (an EU research program having the same aims of ETIS-BASE, but including a number of innovations, like the use of intelligent transport systems to provide data feeds, the development of a business model in order to make the system self-supporting, the expansion of the geographical scope, a classification of freight transport into containers, the addition of 2005 and 2008 as new reference years, and other improvements) (ETISPlus, 2012).

TREMOVE

General information

TREMOVE is a policy assessment model initiated by the Katholieke Universitet Leuven and, later, developed by TML (Transport & Mobility Leuven), currently owned and used by the European Commission. It has been designed to study the effects of different transport and environment policies on the emissions of the transport sector (TREMOVE, 2012).

TREMOVE consists of three main modules: a demand, a stock, and an emissions module. These are accompanied by two additional modules, the well-to-tank and the welfare modules. These are add-ons on the main structure of the model, aimed at estimating the upstream (fuel production) costs of transport and the benefit (in monetary terms) of emission reduction to the society, respectively. These two modules perform ex-post calculations on the TREMOVE main outputs (cost, emissions, and consumption).

A short description of the model is available in TML (2007), and a full report on its 2007 version from De Ceuster et al. (2007). Other information are available in TREMOVE (2012) and EC JRC IPTS (2008a).

Applicability

TREMOVE covers all transport modes: road, rail, (road and rail vehicle fleet evolution is modelled using a classic scrap-and-sales approach), inland waterways (shares of different vessel types in total transport are exogenous), aviation (even though no vehicle fleet is modelled in this case) and maritime. It targets all EU27 member states plus Switzerland, Croatia, Norway, and Turkey (31 countries) and 8 sea regions (maritime transport is allocated to maritime regions, it is not linked directly to the different country models for the land-based transport). The model also covers the 1995-2030 period, with yearly intervals (TML, 2007).

Since COPERT 4 has been fully integrated in the model for calculating emissions from road transport, the same (very detailed) vehicle classes and the same GHG and air pollutants as in COPERT are included in TREMOVE. Similarly, the EX-TREMIS database has been fully integrated in TREMOVE for estimating energy consumption and emissions from the non-road modes.

TREMOVE contains a database with all country-specific vehicle fleet data necessary for running the model. However, it is not possible for the user to apply the model for running a different country than those already included in the database, and the level of detail required is such that TREMOVE in unlikely to be suitable for countries outside the European Union, unless detailed statistical databases are developed for this purpose. In addition, adding new information (e.g. more countries), can only be realized by the TREMOVE modelling team.

Data requirements and availability

TREMOVE, as well as databases with all TREMOVE baseline data, can be downloaded for free (TREMOVE, 2012).

Similarly to HBEFA and ARTEMIS, all necessary input data on the vehicle fleet in operation are included in the database of the model for the countries mentioned above. This includes very detailed data on the number of vehicles (distributed per fuel and sub-category down to technology level), travelling speeds for urban, rural and highway conditions, vehicle usage data like average annual mileage of each vehicle category, energy consumption statistics, macroeconomic data (GDP), and other information on emission factors and transport demand (EC JRC IPTS, 2008a).

5. Synthesis and definition of the characteristics of FORFITS

This concluding Chapter builds on the information collected and the considerations outlined earlier, providing recommendations for the development of the UNECE ForFITS model and the improvement of relevant statistics. It is structured around two main sub-chapters:

- the first focuses on statistics and policies: it contains a brief summarizing analysis of the contents of Chapter 2, as well as a list of the most relevant parameters that need to be considered, suggestions for the improved data collection and policy characterization;
- the second looks more closely at modelling issues, linking them with considerations on available statistics and relevant policy options, identifying the main challenges that derive from the adoption of approaches adopted in existing models once they are confronted with the constraints that are most likely to be concerning the ForFITS model, and suggesting solutions and proposing a way forward for its development.

Statistics

Key parameters and analysis of the current data availability

Table 28 to Table 36 include a list of the most important data necessary to understand and analyze existing and expected trends in the areas of passenger and freight mobility, energy use and GHG emissions in the transport sector, also taking into account key policy inputs. These tables also contain a brief summary of some of the main information sources that have been extensively analyzed in Chapter 2, helping understanding that a number data on transport, energy, and CO_2 emissions are monitored and published on a regular basis by a wide number of entities. Nevertheless, since the availability, detail, and accessibility of these data are actually very heterogeneous, the tables are supported by a qualitative analysis of the quality the parameters considered.

Chapter 2 and Table 28 to Table 36 also allow attempting a classification the main entities publishing information, including:

- international institutions such as Inter-Governmental Organizations (IGOs), sometimes active at a particular macro-regional level, and sometimes belonging to the United Nations family;
- national statistical offices, ministries and other institutional and governmental entities, active primarily at the national level;
- transport, energy and environmental agencies, and regulatory authorities active at different administrative levels (from national to regional, municipal, and local);
- industrial associations, and sometimes even single industrial actors, typically issuing information on their area of expertise and interest;
- Non-Govermental Organizations (NGOs) and interest groups active in these fields;
- Consulting companies, research institutes, academic institutions, as well as other entities active in the area of research, technical assessments, and market analysis (sometimes working for specific research projects funded and commissioned by governments).

Demographic, geographic and economic variables

Demographic, geographic and economic information are widely available from several sources. Looking at national data, demographic and geographic figures are published not only by national statistical offices, but also from research institutes working specifically on geographic or demographic issues. Economic data are almost universally released by national institutional sources. In addition, they are also available from a number of comparative analyses and databases released by international organizations such as the IMF, the OECD and the World Bank.

The information is more complex to obtain when looking at the level of cities, since available data tend to be affected by the nature and extension of the local administrative structure, even if a number of specific studies (partly resulting from academic research) tried to address the subject organically.

Table 28. Key parameters: demographic, geographic and economic variables

Subject	Relevant parameters	Main sources
Demographic data	- Population - Urbanization rate	• International organizations such as Eurostat, UN Population Division, the World Bank (and others) • National statistical offices, local administrations • Research institutes working on demography
Geographical data	- Total area - Land area (excluding water)	• International organizations (e.g. FAO) • National and local administrations • Institutes working on geography
	- Size of cities, urban areas, and metropolitan areas	• National and local administrations • Specific studies (e.g. from World Bank) • Scientific work (urban sensing) • Industrial subjects involved in urban development (including aspects related to public transport)
Densities	- Population density	• Calculated from demographic and geographical data • Specific studies and overviews (especially for urban areas)
Economic data	- GDP (real, nominal; national currency, USD; with purchasing power parities) - GDP per capita, household expenditure - Distribution across the population	• International organizations (e.g. Eurostat, IMF, OECD, UN Statistics Division, World Bank) • National and local administrations

Travel habits and transport-related budget

The analysis of drivers of passenger transport demand also requires information on travel habits, typically including parameters like the average travel time, the number of trips per day, the average trip length, the purpose of travelling, and the modal choice. Similar considerations can be extended to the relevance of transport and travel in the total household expenditure.

Data on the transport-related budget of households are typically published by national statistical offices. Institutions from developed countries tend to provide more information, while the details available are typically lower in developing countries.

Information on travel habits, requiring regular surveys to be gathered, is less frequently available, mainly because surveys are not conducted regularly and extensively in all countries and at all administrative levels. In some cases (especially in developing countries), data are only limited to specific cities and urban areas. In others, very little information exists. Luckily, however, a significant body of scientific literature built on the limited data available to identify important trends that highlight important analogies related to transport patterns and habits across different levels of income in very different countries.

Table 29. Key parameters: variables related to travel times and budgets

Subject	Relevant parameters	Main sources
Travel habits	- Travel time - Modal choice - Number of daily trips - Average trip length - Trip purpose	• Travel and mobility surveys (national statistical offices, local administrations, research institutes) • Scientific literature from research institutions, industry associations (e.g. UITP) and NGOs
Travel budget	- Share of household expenditure use for transport/travel	• International organizations • National statistical offices

Vehicles

Table 30 lists the most important data concerning vehicles and vehicle characteristics.

In addition to these data, it is important to mention the necessity to adopt a common vehicle classification. For road transport, this classification shall distinguish between a number of vehicle classes, such as (i) passenger light duty vehicles (eventually distinguishing in weight-based sub-classes, such as passenger cars and passenger light trucks), (ii) light commercial vehicles; (iii) freight trucks (eventually splitting medium and heavy-duty vehicles), (iv) buses (eventually separating minibuses, buses, coaches and vehicles used in bus rapid transit corridors), (v) two wheelers (including mopeds and motorcycles), and (vi) three wheelers. These classes also need to be sub-divided according to the fuel used and, eventually, their capacity to comply with pollutant emission regulations.

A similar categorization is necessary for non-road transport modes. In the case of rail, vehicles can be divided in the three main categories, i.e. (i) locomotives; (ii) rail-cars; and (iii) high-speed trains, also distinguishing into traction (electric or diesel) and transport type (passenger, freight, shunting). Other possible classification are based on the type of rail transport covered (urban, metropolitan, intercity, and high-speed). Projects like EX-TREMIS, specifically developed for the characterization of data on non-road modes in transport, distinguish between three main categories for inland waterways: (i) dry cargo; (ii) push barge; and (iii) tanker.

Table 30. Key parameters: vehicles

Subject	Relevant parameters	Main sources
Transport vehicles, differentiating by vehicle class and powertrain technology	- New vehicle sales - New vehicle registrations	• Associations of vehicle manufacturers and component producers (e.g. ACEA, ANFAVEA, JAMA, JARI, Sindipeças) • Associations of vehicle importers • National statistical offices, ministries, tax administrations • Consulting firms
	- Vehicle stock - Scrappage rates and survival curves	• International organizations: CCNR, EEA, NATS, and Eurostat, ITF and UNECE (joint questionnaire) • National statistical offices, ministries, tax administrations • Consulting firms • Specific analyses (e.g. from research institutes), NGOs
	- International trade flows of used vehicles	• Associations of vehicle importers and exporters • Databases from trade-related organizations and institutions (e.g. UN COMTRADE) • Specific scientific literature • Legislation on second hand import restrictions
	- Vehicle ownership as a function of GDP per capita, its distribution and population density	• Comparative analyses carried out by international organizations • Specific analyses (e.g. from national statistical offices) • Scientific literature

When looking at different powertrain technology, it is necessary to consider existing and expected solutions for the forthcoming years, possibly differentiating between:

- Spark-ignition and compression ignition internal combustion engines, also taking into account the fuel blend they use (e.g. liquid – such as gasoline and diesel blends – and/or gaseous, such as LPG and natural gas/biogas);
- Hybrid powertrains, coupling ICEs and electrical (or hydraulic) motors, as well as different energy storage systems (as in the case of plug-in hybrids, for instance), depending on the fuel/energy carrier they need;
- Technologies requiring an electrical motor (such as electric vehicles using batteries and super-capacitors to store energy, fuel cell vehicles, and hybrid solutions using batteries, super-capacitors and fuel cell).

Looking at road transport, the published information on the number and basic characteristics (such as the powertrain technology) of new vehicles entering the market is certainly best characterized in developed countries. The data coverage also tends to be good in developing countries that are also important vehicle manufacturers, since these data are regularly released by vehicle manufacturers associations. Information is generally poorer in countries that are not producing vehicles. Key data sources include associations of vehicle manufacturers, associations of vehicle importers, national statistical offices, ministries, tax administrations, and consulting firms.

Table 31. Key parameters: vehicle characteristics

Subject	Relevant parameters	Main sources
Technical characteristics	- Fuel consumption - CO_2 emissions/km - Vehicle weight - Load capacity - Powertrain used - Other technical features	• Associations of vehicle manufacturers and component producers • Analyses and specific reports on energy efficiency indicators • Datasets from consulting firms looking at the automotive market • Environmental agencies (e.g. US EPA and EEA) • NGOs (e.g. ICCT) • Legislation on pollutant emission limits and year of enforcement • Legislation on average fuel consumption of vehicles
Life-cycle characteristics: manufacturing, maintenance, and disposal	- Materials used - Waste and recycling - Related energy needs and emissions	• Life-cycle inventories • Reports, studies, research activities, scientific literature • Information released by vehicle manufacturers (e.g. in sustainability reports)
Vehicle costs and taxation	Vehicle costs	• Technical assessments on the basis of vehicle technical characteristics • Analyses funded by specific industry associations (e.g. steel, aluminum industry) • Specific research projects (sometimes publicly funded) • Consulting firms
	Vehicle taxation	• Vehicle manufacturers and their associations (e.g. ACEA) • Legislation and tax administrations • Specific comparative analyses

Statistics on the number of vehicles belonging to the rolling stock (typically available from national statistical offices and other transport-related agencies, and sometimes also estimated by consulting firms looking primarily at the evolutions of the vehicle market) are not always characterized by the same degree of reliability, even if such data are more frequently available than other transport-related parameters. The quality of vehicle stock data is generally better in developed countries, while the information available for developing countries tends to be less reliable. This is because the vehicle stock needs to be evaluated on the basis of information on vehicle sales that go back in time, matching them with vehicle scrappage rates, and because the latter are not frequently available in developing countries. This is also some of the sources publishing vehicle stock data in developing countries tend to overestimate the vehicle stock (key examples in this respect are available, for instance, in Algeria, Brazil and India).

The degree of availability and reliability of the data tends to decline (especially in developing countries), when the data concern detailed vehicle characteristics, such as the average fuel consumption of passenger cars, their mass, advanced powertrain technologies, and their cost. Nevertheless, pieces of information (primarily focused on new vehicle sale, and also covering developed markets) are accessible in specific (and expensive) databases, typically issued by specialized companies and mainly targeting industrial clients.

The situation is significantly worse for the information on second hand vehicle trade (even if this is something that has a similar order of magnitude of new vehicle sales, in some countries). Few detailed data are systematically collected on this subject: possible sources of information include associations of vehicle importers and exporters, as well as and trade-related databases. The latter, however, are more likely to provide data on monetary rather than on physical flows, and may include the trade of new and used vehicles in the same category. As a result, most of the accessible information on international used vehicle flows is mainly stemming from specific analyses that hardly provide details distinguishing amongst different road modes.

Networks

The overall availability of information on the network at the national level tends to be better than the information available on the vehicle stock, even if, as in the case of vehicles, the data availability tends to be poorer in developing countries.

The international statistics published by industry associations and interest groups (like the International Road Federation and other modal organizations) include a number of basic indicators on the extension of the networks.

Unfortunately, this means that they tend to provide only a limited level of detail (few categories and sparse data), excluding information on the network usage and the traffic level on different network links (also reflected in changing average speeds).

The characterization of mean driving speed and the mileage allocation to different road classes are not easily available. In most cases, they need to be deduced and generalized from specific network and vehicle activity surveys, typically conducted at the local level. The speed ranges that are typically characterizing rural and highway driving are not expected to lead to significant variations of the emission levels. On the other hand, speed variations may have a more significant influence for urban driving. This is due to the higher dynamics involved in urban driving, resulting in more important effects on the emission and fuel consumption performances.

Unfortunately, coupling the aggregated network characterization data that are typically available at the international level with information on speed and vehicle flows is only likely to be sufficient to allow very crude analyses of the impact of speed on consumption and emissions (unless major improvements in the data collection are achieved).

Table 32. Key parameters: networks

Subject	**Relevant parameters**	**Main sources**
Network characteristics	- Length and capacity of roads, railways, inland waterway links - Length of lanes dedicated to public transport - Length and capacity of pipelines - Number and capacity of intermodal freight terminals - Number and capacities of ports - Length of cycle lanes and foot paths	• International Organizations: Eurostat, ITF and UNECE (joint questionnaire), NATS, World Bank, UN ECLAC, UN ESCAP • National statistical offices, local administrations, transport regulatory authorities • Industry associations and NGOs (e.g. IRF, UIC, UITP) • Construction industry (companies and their associations) • Fuel distribution industry • Service providers for freight transport, logistic companies (e.g. including port authorities)
Life-cycle characteristics	- Construction - Maintenance - Operation	• International Organizations (e.g. ROADEO, calculator by the World Bank) • Industry associations (e.g. IRF, UIC) • Reports, studies, research activities, scientific literature
Network usage and speed	- Indicators of use of network capacities (also for pipelines and intermodal transport) - Average speed on network links by type (e.g. highway vs. rural and urban roads) and mode (including public transport), speed distribution over time	• Network usage surveys from local administrations, network operators and transport regulatory authorities • Public transport and fleet operators • Linked to transport activity and network characteristics
Network taxation, access restrictions	- Road pricing - Other pricing policies related to the network usage (including parking) - Areas subject to access restrictions - Effects on network usage and other variables (e.g. vehicle ownership) due to pricing policies	• Local administrations, transport regulatory authorities and network operators • Tax administrations, ministries • Specific comparative studies (sometimes funded at the international level), scientific literature

Performing more detailed analyses (also looking at specific network links, for instance) currently requires very large resources because of the need to gather very large amounts of information. At the moment, such resources are only available for very specific projects (such as those linked with the TRANSTOOLS model in the European Union, or similar national and local models), and only in developed countries.

In the future, improved data collection may result from the increased diffusion of electronic devices based on information and communication technologies that target traffic. The access to this sort of information for researchers can be improved substantially if public administrations are willing to require the release of some of the information collected in this way.

Fuels

Table 33. Key parameters: fuel characteristics

Subject	Relevant parameters	Main sources
Fuel properties	- Energy content - Tailpipe (tank-to-wheel) emission factors - Parameters defining fuel quality	• International organizations (IEA, IPCC, UNECE, UNFCCC) • Fuel producers and industry associations (CONCAWE) • Vehicle manufacturers associations ACEA (World-Wide Fuel Charter) • Consultancies (e.g. International Fuel Quality Center)
Life-cycle characteristics of fuels	- Upstream energy needs - Efficiency of the fuel production pathways - Well-to-tank emission factors	• Analyses, studies, scientific publications and reports (e.g. joint study developed by JRC, EUCAR and CONCAWE) • Scientific literature from research institutions, industry associations and NGOs • Information released by the fuel industry (e.g. in sustainability reports)
Fuel prices, subsidies and taxes	- Spot prices of primary fuels - Import costs and export prices by fuel - End-user prices and taxes by product and sector	• International organizations: IEA, IMF, OPEC, World Bank, UN ECLAC • National statistical offices • Tax administrations • Reports from specialized research institutes and governmental entities: GIZ (prices), GSI (subsidies), AICD
	- Price elasticities of travel and energy use - Effect of fuel prices on urban densities	• Scientific literature

In the case of fuels, the basic variables required concern either fuel characteristics (Table 33) or fuel consumption (Table 34). The combination of these data also allows the estimation of CO_2 emissions (also included in Table 34**Error! Not a valid bookmark self-reference.**). In addition, it is necessary to underline that several different fuel options need to be taken into consideration. These include, in particular:

- liquid fuels, including petroleum fuels (such as gasoline, diesel, jet kerosene and fuel oil) as well as biofuels (e.g. ethanol, biodiesel and all relevant biofuels, also considering their different fuel production pathways), and synthetic fuels (like thise derived from natural gas and coal);
- gaseous fuels (natural gas, hydrogen, LPG, biogas), also taking into account different production pathways;
- other energy carriers (such as electricity), where the production pathways are again of extreme importance for the analysis of CO_2 and other emissions.

Table 34. Key parameters: fuel use and emissions

Subject	**Relevant parameters**	**Main sources**
Fuel use	- Fuel consumption (by mode and fuel type)	• International organizations (such as IEA, OAPEC, OLADE, UN ECE) • National statistical offices • Analyses and specific reports on energy efficiency indicators • Linked to transport activity, vehicle use, and vehicle stock
	- Mandates	• Policy documents at the national and regional administrative levels • Specific comparative policy assessments (e.g. from the IEA), research reports, scientific literature (e.g. GSI work on subsidies)
Emissions	- CO_2 - Other greenhouse gases (GHGs)	• Linked to transport activity, vehicle use, vehicle characteristics and vehicle stock • For CO_2,mainly due to fuel combustion, estimations based largely on fuel use and fuel properties • Estimations based on relevant drivers from national administrations • Statistics reported and published by international organizations (such as IEA and UNFCCC)
	- Local pollutants	• Assessments and publications resulting from the use of models

Looking at fuel properties, the information available typically link with the legislation in place. As a result, it can be clearly identified, even if there are only few data sources that provide comparative assessments.

The situation is more heterogeneous when the subjects of interest are well-to-wheel emissions and energy requirements. The considerations on the variable data quality the vehicle stock can be partly extended to data on the well-to-tank fuel characteristics. This type of information has been analyzed primarily in developed countries, where research funds have been allocated to this sort of task and where policy-related needs led to an active participation of industry organizations, consumer groups and environmental NGOs. Nevertheless, the importance of international trade also stimulated an effort to assure a representative coverage for all fuels produced. This is why several studies are not limited to the analysis of fuel production pathways taking place in the developed world, but cover also the main fuel production pathways taking place in developing regions.

Transport activity

Table 35 lists key parameters related to vehicle activity and load, and Table 36 considers how they link with demographic, geographic and socio-economic variables. The key data related to transport activity include annual mileage, distinguishing the data not only by vehicle class, but also by powertrain technology because vehicles powered with diesel fuel, as well as vehicle technologies resulting in higher vehicle costs compared to conventional gasoline options, are, on average, run for longer distances. In addition, since a number of studies have shown that annual mileage decreases as vehicles get older: this is why mileage data are best if expressed as a function of vehicle type and age.

In addition, data on the shares of mileage in different driving modes (urban, rural, highway), the related average vehicle speed would also be beneficial to the understanding of transport energy use and emissions, especially if there is a specific interest in extending the scope of the analysis to the emissions of local pollutants. Ideally, they should be complemented by as trip distributions (i.e. the probability density function of trip distance).

The availability and the quality of transport-activity data rather low if compare with figures that are matched physical entities (such as the number of vehicles and the volume of fuel). This is due to the fact that activity data are strongly affected by information that stem mainly from user behaviors and, as such, they need to be gathered as part of regular surveys.

For road transport, this is the case of parameters like the average travel per vehicle, the average vehicle load (or the average occupancy rate) and, in the case of freight, the average haul length, the average load on laden trips and the share of empty running. Similar issues also exist in other inland transport modes, where the same problem is even exacerbated by the lower availability of primary sources of information.

The difficulties in terms of detailed data collection on a bottom-up basis are also reflected in the aggregated information on total transport activity (expressed in passenger-km and tonne-km) and mirrored by relatively sparse (in terms of data availability) datasets concerning international and global transport statistics (with the exception, for recent years, of the European Union, where reporting of a wide range of data, for freight transport, is now a legal requirement).

In addition, since fuel consumption is collected on the basis of the fuel characteristics and the aggregate end-use (and not on the basis of the vehicles using the fuels), the association of fuel use with the corresponding kind of vehicle/fuel combination must also be gathered as part of regular surveys undertaken by transport, energy, environment, and commercial authorities at the national level. Unfortunately, this is not frequently happening, even in developed countries, unless specific programs (aimed primarily at the monitoring of energy efficiency characteristics) are in place (as in the case of Canada, for instance).

Table 35. Key parameters: vehicle activity and load

Subject	Relevant parameters	Main sources
Vehicle travel (differentiating by vehicle class and powertrain technology)	- Average travel (km/vehicle)	• Surveys carried out by national statistical offices and research institutes • International organizations: Eurostat • Linked to vehicle stock and passenger transport activity
	- Usage rates (function of the vehicle age)	• Surveys carried out by national statistical offices and research institutes • Specific analyses and reports
	- Average daily time of vehicle operation (freight, public transport)	• Public transport operators • Freight transport operators • Scientific literature from research institutions, industry associations and NGOs • Linked to passenger transport activity
	- Average haul length (also by type of goods transported)	• Vehicle usage surveys carried out by national statistical offices and research institutes • Freight transport companies • Scientific literature from research institutions, industry associations and NGOs • Linked to freight transport activity
Average vehicle load	Average load (light duty passenger vehicles)	• Vehicle usage surveys carried out by national statistical offices and research institutes • Scientific literature • Linked to passenger transport activity
	Public transport: average occupancy rates, distribution over time (e.g. day, week)	• Vehicle usage surveys carried out by national statistical offices and research institutes • Public transport operators and their industry associations • Specific analyses, reports and scientific literature
	Freight: share of empty running, average load on laden trips (also by type of goods transported)	• Vehicle usage surveys carried out by national statistical offices and research institutes • Freight transport companies • National statistical offices and international organizations (such as Eurostat) (especially freight) • Scientific literature from research institutions, industry associations and NGOs • Linked to freight transport activity

Table 36. Key parameters: overall activity and links with demographic, geographic and socio-economic variables

Subject	Relevant parameters	Main sources
Overall vehicle, passenger and freight transport activity	- Vehicle activity (vkm) - Passenger transport activity (passenger-km) - Freight transport activity (tonne-km) - Weight of goods transported (t), weight of goods produced (t), handling factors (ratio)	• International organizations: joint questionnaire by Eurostat, ITF and UNECE, CCNR (inland waterways) • National statistical offices, research institutes • Statistics on material flows (national statistical offices, international organizations, specialized research groups) • Companies and industry associations, NGOs: IRF, OSJD, UIC, UITP • Linked to vehicle stock, average vehicle travel and average loads
Links between activity indicators, demographic, geographic and socio-economic variables	- Effects of density (rural, urban and other areas) and fuel prices on transport activity and modal choice - Effects of economic and industrial structure on handling factors	• Comparative analyses carried out by international organizations • Specific analyses from national statistical offices and research institutes • Scientific literature

Holistic view

Overall, a number of elements can help explaining the heterogeneity of the data availability in subjects related to transport, energy use and climate change:

1. The effect of socio-economic differences amongst countries, since the data coverage tends to be better in countries with higher average levels of income per capita. This reflects increasing benefits stemming from a better monitoring of transport-related statistics (e.g. because of growing safety concerns with increasing motorization), as well as the larger availability of public resources for their collection.
2. The complexity of the data collection procedures in place, since the coverage and quality of the statistical information tend to be better for parameters that can be physical nature (such as fuel sales and the number of vehicles) than for variables that are describing user behavior (e.g. with respect to modal choices, travel times and travel purpose, but also with respect to parameters like travel per vehicle and the average vehicle load).

3. The presence of clear economic incentives for the collection of specific subsets of data, as in the case of a better understanding of market trends of vehicle sales and characteristics for industrial actors competing in the automotive sector, unmatched by similar economic interests for collective passenger mobility and public transport, and only partly matched by interests in the area of freight transport and logistics.
4. The situation concerning organizational and regulatory aspects, since data quality tends to be better:
    a. when there is a clear legislative framework requiring the collection, communication and publication of specific pieces of information (such as vehicle sales and vehicle characteristics with respect to their specific fuel consumption);
    b. in the presence of effective cooperation procedures between entities working with statistics at different administrative levels (including the legal obligation to collect and disseminate data to trans-national bodies);
    c. in global areas where common data collection procedures have been established (e.g. because of the presence of international entities coordinating national activities with respect to data collection).

Recommendations

Establish a legislative framework and structural funding mechanisms for data collection

Data collection has a high value for development purposes and better policy definition. In addition, the costs due to the improved data collection resulting from mandatory reporting are likely to be more than counterbalanced, in developing countries, not only by the opportunity to improve the effectiveness of their policy action, but also by the increased likelihood to access international climate-related funding, since this requires rigorous monitoring, evaluation, reporting, and verification of emissions.

Since data quality is better in countries that have a legislative framework requiring mandatory reporting, setting up a legislative framework allowing effective data collection is an essential steps to ensure successful results. Funding is a second essential requirement to make sure that the process if effective. Apart from capacity building efforts, funding should be structural (e.g. raised from small taxes on transport-related activities, such as fuel sales) and not dependent on foreign assistance.

National coordination

Many of the data required for good regional/local transport policy (well represented by the framework suggested here) are important to transport planning, environment assessment, and energy planning, as well as national climate policy, The coordination of the work of local, national and even international authorities is therefore needed. Given the potential to deliver multiple outputs at once, such coordination is also likely to result in overall benefits.

Harmonization and coordination of data collection, analysis, and publication

IGOs like Eurostat, the ITF and the UNECE, as well as industry associations (such as ACEA, the IRF, and the UIC) shall intensify their effort to harmonize definitions, weight and power classes, and other vehicle characteristics with the aim to achieve a better comparability of statistics.

IGOs are also best placed for top-down initiatives capable to lead to a better coordination of data collection, analysis, and publication of statistics.

The key parameters outlined here provide a good reference framework for the definition of common data requirements.

These activities shall also include the analysis and publication of indicators, and it should be driven by the need to improve the quality of the existing databases. Such an effort shall be led by an institution with a good background in both statistics and transport, as well as credibility in the transport community. A long-term commitment, as well as institutional mandates (capable to assure the effectiveness of the data collection process) and operating budgets are required to conduct this work.

Maximize the use of existing information

Making sure that IGOs can assure a better coordination of data collection, analysis, and publication is likely to take time and bears important resource-related implications.

This creates a good window of opportunity for NGOs to contribute to improve data coverage and quality. Being more dynamic and having more freedom than IGOs, NGOs active in the fields of transport and environmental protection can publish comparative overviews on parameters such as those suggested here, building on the collection of published information.

If the framework proposed is further expanded to safety-related parameters, the same role can be extended to NGOs looking at issues such as road safety and health.

Also on this case, the key parameters outlined here provide a good reference framework for the definition of common data requirements.

Benchmarking and support for the visibility and dissemination of best practices

Benchmarking efforts can build on the results emerging from comparative overviews and provide opportunities, for NGOs and other institutions capable to provide and leverage financial resources, to identify, promote, disseminate and support the work of national administrations that are adopting best practices with respect to the data collection and its publication.

Particular care should be taken to reward data collection carried out in a way that allows to explain transparently the evaluation of aggregated data such as those concerning the total vkm, passenger-km and tonne-km, also paying attention to the clear definition of what is included and what collection method used.

Capacity building and the provision of seed grants

For countries where the development of a statistical database and the associated surveying tools is not yet started, seed grants and specific capacity-building initiatives could help start the process. Having established a data collection and dissemination process could be a prerequisite for all transport-related assistance after a number of years.

Since the diffusion of ForFITS could be a good opportunity for these purposes, efforts should be made to foster the cooperation of IGOs and institutions institutions providing development funds, like development banks.

Characteristics and recommendations to develop ForFITS

The ForFITS model is expected to provide a robust and transparent framework, capable of analysing strategies capable to foster the development of sustainable transport, and to link these strategies with policy-making decisions.

The model should pay particular attention at CO_2 emissions and the facilitation of climate change mitigation. In addition, it should be ready to be expanded to address other transport externalities (often referred to as co-benefits, in climate change related literature), such as those due to the emission of local pollutants (e.g. because of their impact on health), those linked to noise, and those stemming from accidents and injuries (associated with safety features).

The model shall be developed as a software tool, it shall be freely available for users (e.g. national and local governments, general public), and it shall be developed between 2011 and 2013. It is expected to be a sectoral model, focused on inland transport.

General characteristics

Chapter 4 clearly showed that the goal of measuring CO_2 mitigation policy impacts in transport is requires measuring changes from a moving (usually growing) baseline. The analysis of existing modelling efforts, also included in Chapter 4, also suggest that evaluating the consequences of policy interventions like those reviewed in Chapter 3 (including measures that affect only a fraction of the many variables related to CO_2 emissions) requires a bottom-up approach to be satisfied. In addition, the discussion on statistics highlights the importance of a transparent approach for measuring, reporting and verifying information concerning the transport sector. Nevertheless, the limited availability of statistics, clearly illustrated earlier, also results in the need to select an approach that must remain relatively simple.

All these considerations suggest that a model like ForFITS shall maximise the possibilities to analyse policy impacts on CO_2 emission while remaining relatively simple and flexible, especially because it needs to adapt to the level of information available. As a result, the modelling methodology needs to results from a reasonable compromise between the level of detail required in order to produce meaningful results and the limited data availability in the various countries/regions targeted.

Main features

In order to fulfill its objectives, the model needs to perform the following main operations:

- evaluate fuel consumption from transport activities and vehicle characteristics;
- convert information on fuel consumption into emission estimates;
- estimate the total transport activity and fuel consumption (especially relevant for projections).

This requires the historical estimation of a range of variables, as well as their projection into a future timeframe. This implies also that the effects of policies should be additional to the evolution of transport activity and emissions with respect to a baseline evolution with no measures.

Policy coverage

Even if ForFITS needs to assure the coverage of the broadest possible range of policies, it is unlikely to be able to consider all options at all administrative levels. Given that the mandate for the development of ForFITS is ultimately imputable to governments, and given the main focus on climate change-related aspects of transport, the primary focus should be the country-level.

Key policy instruments that shall be effectively handled include, in particular, the effect of changing fuel prices, economic measures like fuel and vehicle taxation (and/or subsidies), and regulatory instruments like mandates on vehicle technologies and/or biofuels.

In addition, the model should attempt to consider polices driven by change of demographic and land-use variables (e.g. resulting in higher urban densities): the distinction between rural and urban areas (further distinguished on the basis of their size, if possible) is important in this respect.

The ability to include instruments aimed at improving the logistical system (e.g. affecting the handling factors that characterize freight transport) would also be an asset.

Finally, even if its primary focus is on policies related to the mitigation of CO_2 emissions, ForFITS shall be open to development sand improvements capable to take into account co-benefits due to the effects of policies targeting other transport externalities.

Structure

A number of reasons suggest the adoption of the ASIF (Activity, Structure, Intensity, Fuel consumption) structure for the development of ForFITS:

- A proven record of use, since the ASIF approach has already demonstrated to be effective for the evaluation of transport activity, fuel consumption and fuel-based emissions (CO_2) (as well as travel-based emissions, eventually on the basis of a limited number of inputs) in some of the models reviewed in Chapter 4;
- The capacity to guarantee transparency (avoiding the black-box effect characterising some other approaches), since the ASIF approach leverages on relationships that are based on data that can be clearly identified with measureable information and/or statistics;
- The possibility to be complemented by different modules looking at specific variables, opening the way to modular model improvements, which guarantees flexibility to handle information on the basis of different levels of details.

Given the important limitations in terms of data availability, ForFITS should also generate projections on the basis on relatively aggregated inputs, such as projections on demographic and macro-economic parameters.

The use of relationships linking demographic and socio-economic data to transport activity and modal shares (e.g. total tonne-km expressed as a function of GDP, total passenger-km as a function of GDP per capita, car ownership linked to GDP per capita, density of population, urbanization, and fuel prices) seems the most adequate for this purpose, even if this approach is likely to require a progressive development to assure a good responsiveness of the model to policy inputs and a good reliability of modelling outputs.

The need for relatively simple underlying relationships is especially clear if this solution is compared with more traditional solutions, such as the generation of transport activity by origin and destination (whose accuracy depends very much on the data available), or with very data-intensive network models, since both these approaches are unlikely to be viable, unless a much greater data coverage can be assured (unlikely, at least in the near term).

The data availability limitations also suggest that ForFITS should use default values (or ranges, allowing for some calibration on specific cases in historical years) when some of the information is not available. At the same time, the need to assure accuracy leads to the need to characterize the model with clear and specific minimum data requirements. The key parameters defining common statistical data requirements that have been outlined earlier in this Chapter provide a good reference framework for the type of variables that are needed in ForFITS. They can be helpful also for the definition of these minimum requirements.

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Annex 1

List of countries and organisations that replied to the UNECE questionnaire

Country/Organization
The Islamic Republic of Afghanistan
The Republic of Albania
The Principality of Andorra
The Republic of Armenia
The Republic of Azerbaijan
The Kingdom of Bahrain
The Republic of Belarus
The Republic of Bulgaria
Canada
Caucasus Environmental NGO Network
The People's Republic of China
Comité des Constructeurs Français d'Automobiles
The Republic of Cyprus
The Czech Republic
The Kingdom of Denmark
Energy Research Centre of the Netherlands
The Republic of Estonia
The European Commission
Fédération Internationale de l’Automobile
The Republic of Finland
Georgia
The Federal Republic of Germany
The Republic of Iraq
Ireland
The State of Israel
The Republic of Italy
Japan
The Hashemite Kingdom of Jordan
The Republic of Korea
The State of Kuwait
The Lebanese Republic
The Republic of Lithuania
The Grand Duchy of Luxembourg
The Former Yugoslav Republic of Macedonia
Malaysia
Matter Aerosol
The Republic of Moldova
The Principality of Monaco
Montenegro
The Republic of the Union of Myanmar
Natural & bio Gas Vehicle Association Europe
The Kingdom of the Netherlands
New Zealand
The Kingdom of Norway
The Islamic Republic of Pakistan

Country/Organization
The State of Palestine
The Republic of the Philippines
Romania
The Russian Federation
The Kingdom of Spain
The Kingdom of Sweden
The Swiss Confederation
The Syrian Arab Republic
The Kingdom of Thailand
The Republic of Turkey
The United Kingdom of Great Britain and Northern Ireland
The Republic of Uzbekistan
Voith Turbo