Energy Analysis and Modelling Transport

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Transport & energy use:
Historical overview & main parameters

- Transport and total energy consumption
- Transport activity (pkm, tkm, vkm)
- From activity to energy: modal choices & vehicle technologies
- ASIF (Activity, Structure, Intensity → Fuel use) approach
- Data: requirements, collection, uncertainties, and analysis
Content

Session II

From historical observations to projections: the IEA Mobility Model (MoMo)

• The drivers of demand in transport
• ASIF (Activity, Structure, Intensity → Fuel use) approach
• Pollutants, Greenhouse Gases (GHG) and costs
• Influencing the evolution of energy demand in transport
  ▪ The role of transport and energy policies: Avoid, Shift, Improve
  ▪ Evaluating policy impacts in transport & energy models

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Transport & energy:

overview of historical trends
and
main parameters

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Key Parameters: $vkm$

- Vehicle-kilometres = $vkm$
- Number of vehicles $\times$ kilometres (per vehicle)
- Stock $\times$ Mileage
Transport *activity* - from vkm to pkm

- Vehicle-kilometres (vkm) $\times$ number of people/vehicle = (Occupancy rate)

- passenger-kilometres (pkm)
Vehicle-kilometres * average load = tonne-kilometres
Transport activity grew from 2000-2013 (56% passenger and 51% freight)

Growth in non-OECD countries is faster than in the OECD.
Key parameters: energy intensity

- Energy needed to move a vehicle
- In transport, fuel economy or specific fuel consumption
- Measured as
  - Litres/100 km (Europe)
  - km/energy used (Japan)
  - MPG (miles per gallon) (United states)
- Energy use = vehicle-kilometres * energy intensity
Specific fuel consumption of cars

Evolution from 2005 to 2010, light passenger vehicles (cars)

- The evolution of the specific fuel consumption of vehicles influences the way energy demand develop with respect to transport activity
- Light passenger vehicles experienced some improvement in recent years
Energy consumption in transport

1973

- Total: Industry 35%, Transport 25%, Residential 25%, Services 8%, Other 7%

2013

- Total: Industry 32%, Transport 30%, Residential 25%, Services 9%, Other 4%

Oil products

1973

- Transport 52%

2013

- Transport 76%

Source: IEA World Energy Balances. 2015
Road transport modes account for most energy consumption

The share of road in total transport final oil use has grown from less than 50% in 1973 to 76% in 2013
Transport energy demand grew by more than 28% from 2000-2013

The share of non-OECD countries increased from 33% to nearly 47%
Modal choices affect final energy demand

Energy intensity of different modes of transport, 2015

- Air and light road passenger modes are more energy-intensive than public or ‘mass’ passenger transport modes.
- Air and light road freight modes are also more energy intensive than large road vehicles, rail and shipping.
Modal choices affect final energy demand

National Passenger transport activity (passenger kilometres [pkm]) in 2015, by mode
Energy consumption in transport

Transport energy use by country, 2013 snapshot

Transport final energy use per capita (gigajoules per year)
Linking activity and fuel use

**TOP DOWN**

Energy statistics (based on fuel sales) → Energy use and GHG emissions

- Transport activity
- Transport structure
- Carbon intensity data
- Energy intensity data

**BOTTOM UP**
Linking activity and fuel use - **ASIF** approach

- **Vehicle Activity**
- the **Structure** of the organization of vehicle across services, modes, vehicle classes and powertrain groups
- the energy **Intensity** of each of the vehicles in this structure

... allow to calculate **Fuel consumption**

The calculation is based on Laspeyres identities

\[
F = \sum_i F_i = A \sum_i \left( \frac{A_i}{A} \right) \left( \frac{F_i}{A_i} \right) = A \sum_i S_i I_i = F
\]

- **F** total Fuel use
- **A** vehicle Activity (expressed in vkm)
- **F_i** fuel used by vehicles with a given set of characteristics (i) (e.g. segments by service, mode, vehicle and powertrain)
- **A_i/A = S_i** sectoral Structure (same disaggregation level)
- **F_i/A_i = I_i** energy Intensity, i.e. the average fuel consumption per vkm (same disaggregation level)
Data requirements (1/2)

The ASIF equation requires key parameters:

Vehicle activity (expressed in $vkm$)
- $vkm$ are the product of number of vehicles and average mileage
- $vkm$ are linked to $pkm$ (passenger activity) and $tkm$ (freight activity) by occupancy rates / load factors

Structure (percentages of $vkm$)
- Requires the knowledge of vehicle activity by mode and service (possibly more: different motorizations do not travel the same distance...)

Energy intensity (expressed in energy units per $vkm$)
- Requires the knowledge of the specific energy consumption by mode and service (possibly more)
- Vehicles have a limited lifetime, and the vehicle stock is renewed through new registrations and scrappage: newly registered vehicles and scrappage profiles are part of the information required, if one wants to reproduce the dynamics of the stock

Fuel consumption (measured in energy, mass, or volumetric units)
- The IEA collects statistics on fuel consumption by end-use sector and fuel type
- If data are in mass or volume units, fuel consumption needs to be coupled with information on the (low) calorific value of the energy carrier
Transport activity data

Vehicle stock
- Generally available (e.g. from ministries, statistical offices)
- Can be calculated from new registrations & scrappage
- Available data may not be corrected for scrappage (e.g. Brazil, Algeria)
- Vehicle classification is not the same everywhere

Mileage and occupancy rates
- Household surveys, travel diaries, odometer readings, public transit operators
- Information less frequently available than data on vehicle stock
- Geographical coverage limited to regions where the surveys are performed
- Mileage: estimated using analogies with similar modes in geographical areas with similar fuel taxation and population densities
- Occupancy rate of personal vehicles: estimated by analogies / assumptions within geographical areas with similar socio-economic and taxation characteristics
Disaggregating modes: example of Commercial Vehicles (CVs)

- The CV subsector is very diverse: vehicle classification is not uniform across countries

**UN Regulations**

<table>
<thead>
<tr>
<th>Passenger transport (buses)</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>M2</strong></td>
<td>Class 2: 2 700 kg and less</td>
</tr>
<tr>
<td>&gt; 8 seats + driver, maximum mass &lt; 5 t</td>
<td>Microvan</td>
</tr>
<tr>
<td><strong>M3</strong></td>
<td>Class 3: 4 500 kg to 6 300 kg</td>
</tr>
<tr>
<td>&gt; 8 seats + driver, maximum mass &gt; 5 t</td>
<td>Cargo van</td>
</tr>
<tr>
<td><strong>Class I</strong></td>
<td>Class 4: 6 300 kg to 7 200 kg</td>
</tr>
<tr>
<td>with areas for standing passengers</td>
<td>SUV</td>
</tr>
<tr>
<td><strong>Class II</strong></td>
<td>Class 5: 7 200 kg to 8 000 kg</td>
</tr>
<tr>
<td>principally seated passengers, standing possible</td>
<td>Pickup truck</td>
</tr>
<tr>
<td><strong>Class III</strong></td>
<td>Class 6: 8 000 kg to 12 000 kg</td>
</tr>
<tr>
<td>seated passengers only</td>
<td>Bevage truck</td>
</tr>
</tbody>
</table>

**Goods transport (trucks and trailers)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N</strong></td>
<td>Class 7: 12 000 kg to 15 000 kg</td>
</tr>
<tr>
<td>Trucks</td>
<td>School bus</td>
</tr>
<tr>
<td><strong>N1</strong></td>
<td>Class 8: 15 001 kg and over</td>
</tr>
<tr>
<td>maximum mass &lt; 3.5 t</td>
<td>Truck tractor</td>
</tr>
<tr>
<td><strong>N2</strong></td>
<td></td>
</tr>
<tr>
<td>maximum mass &gt; 3.5 t and &lt; 12 t</td>
<td></td>
</tr>
<tr>
<td><strong>N3</strong></td>
<td></td>
</tr>
<tr>
<td>maximum mass &gt; 12 t</td>
<td></td>
</tr>
<tr>
<td><strong>O</strong></td>
<td>Class 9: 15 001 kg and over</td>
</tr>
<tr>
<td>Trailers</td>
<td>Furniture</td>
</tr>
<tr>
<td><strong>O1</strong></td>
<td>Class 10: 16 001 kg and over</td>
</tr>
<tr>
<td>maximum mass &lt; 0.75 t</td>
<td>City transit bus</td>
</tr>
<tr>
<td><strong>O2</strong></td>
<td></td>
</tr>
<tr>
<td>maximum mass &gt; 0.75 t and &lt; 3.5 t</td>
<td></td>
</tr>
<tr>
<td><strong>O3</strong></td>
<td></td>
</tr>
<tr>
<td>maximum mass &gt; 3.5 t and &lt; 10 t</td>
<td></td>
</tr>
<tr>
<td><strong>O4</strong></td>
<td></td>
</tr>
<tr>
<td>maximum mass &gt; 10 t</td>
<td>Sleeper</td>
</tr>
</tbody>
</table>

Source: Consolidated Resolution on the Construction of Vehicles

- Fuel use of CVs depends on *mission profile* and *load*
- An appropriate balance of *detail* vs. *data availability* needs to be found
Transport activity data

Occupancy rates and load factors

- Difficult to measure
  - Public passenger transport
    - Peak versus off-peak (evenings, weekends)
    - Route types
    - Surveys and legal obligations of public transit operators
  - Goods transport
    - Average load factors calculated as:
      a) Average load on laden trips
      b) Share of empty running
    - Load of laden trips varies both among journeys and during a single journey
    - Average loads dependent on mission profile, value of goods
    - Surveys and legal obligations of public transit operators
Energy intensity data

- Energy intensity = fuel use per vkm
- This is measured in different units around the world
  - “fuel economy” (travel/consumption, e.g. MPG)
  - “fuel consumption” (consumption/travel, e.g. L/100 km)
Comparing bottom-up and top-down approaches

France

Indonesia

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Linking activity, fuel use and GHG emissions

Extended ASIF approach

The same methodological approach used for the calculation of fuel consumption (ASIF) can be extended to evaluate CO$_2$ emissions.

This extension is suitable to the case of where several energy carriers need to be considered:

$$E = \sum_i E_i = A \sum_i \frac{A_i}{A} \times \frac{F_i}{A} \times \frac{F_{ij}}{F_i} \times \frac{E_{ij}}{F_i} = A \sum_i S_i I_i EF_{ij} = E$$

- $A$: activity (in vkm)
- $E$: emissions
- $E_i$: emissions due to the vehicle $i$
- $F_{ij}$: fuel (energy carrier) $j$ used in the vehicle $i$
- $EF_{ij}$: emission factor for the fuel (energy carrier) $j$ used in the vehicle $i$
Well-to-wheel versus Tank-to-wheel

Using the example of biofuels...

- Emissions (GHG emissions and local air pollutants)
- energy use
- LCA - Other material and natural resource (e.g. water) use
Carbon intensity varies by fuel type and over time

Substantial differences

- **Tank-to-wheel (TTW):**
  Emissions due to fuel combustion
  IPCC: biomass-based fuels have zero TTW emissions (to avoid double counting with emissions from energy transformation and agriculture, forestry and other land use)

- **Well-to-wheel (WTW):**
  Emissions due to fuel combustion and fuel production
  Biomass-based fuels do not have zero WTW emissions

Transport activity data

**TOP DOWN**

- passenger km (pkm), tonne km (tkm) from international statistics

**BOTTOM UP**

- passenger km (pkm), tonne km (tkm) by mode, vehicle etc.
- Vehicle stock
- Vehicle mileage
- Occupancy rate
Data requirements

Beyond the extended ASIF equation...

Occupancy rates
- In passenger transport, this is the average amount of people per vehicles
- This information is needed to link vkm and pkm

Vehicle loads
- In freight transport, this results from taking into account for the average load on laden trips and the share of empty running
- This is needed to link vkm and tkm

Transportation infrastructure
- Linking vehicle activity with the network extension is helpful to better understand congestion issues and investment needs to avoid it

Costs, prices and taxes
- Vehicle, infrastructure and fuel prices and taxes, revenues from ticket sales
- Information on the household expenditures for transportation, governmental and private expenditures for transportation infrastructure and vehicles, governmental revenues from road tax and fuel taxes, public and private expenditures for public transport services...

Other data
- Safety- and noise-related, e.g. needed to estimate the social cost of transport (including externalities)
- Related with material demand, e.g. to allow the assessment of life-cycle energy use and emissions
Exercise 1: Filling the gaps

Are total CO$_2$ emission rising or falling over time?

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>New car sales</td>
<td>570000</td>
<td>600000</td>
<td>630000</td>
</tr>
<tr>
<td>Retirements</td>
<td>150000</td>
<td>165000</td>
<td>185000</td>
</tr>
<tr>
<td>Total car stock</td>
<td>4600000</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Average travel per vehicle (km/year)</td>
<td>9780</td>
<td>9875</td>
<td>9950</td>
</tr>
<tr>
<td>Total travel, all vehicles (bil km)</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>New car fuel economy (L/100km)</td>
<td>8.5</td>
<td>8.2</td>
<td>8</td>
</tr>
<tr>
<td>Stock avg fuel economy L/100km</td>
<td>8.8</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>fuel consumption (bil L)</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>CO2 emissions factor (kg/L)</td>
<td>3.6</td>
<td>3.5</td>
<td>3.4</td>
</tr>
<tr>
<td>CO2 emissions (million tonnes)</td>
<td>?</td>
<td>?</td>
<td>?</td>
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### CO₂ emissions are rising!

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<td>9875</td>
<td>9950</td>
</tr>
<tr>
<td>Total travel, all vehicles (bil km)</td>
<td>45.0</td>
<td>49.7</td>
<td>54.5</td>
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<td>8.2</td>
<td>8</td>
</tr>
<tr>
<td>Stock avg fuel economy L/100km</td>
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<td>8.7</td>
<td>8.6</td>
</tr>
<tr>
<td>Fuel consumption (bil L)</td>
<td>4.0</td>
<td>4.3</td>
<td>4.7</td>
</tr>
<tr>
<td>CO₂ emissions factor (kg/L)</td>
<td>3.6</td>
<td>3.5</td>
<td>3.4</td>
</tr>
<tr>
<td>CO₂ emissions (million tonnes)</td>
<td><strong>14.3</strong></td>
<td><strong>15.2</strong></td>
<td><strong>16.0</strong></td>
</tr>
</tbody>
</table>
Data collection

Methods

Four methods are mainly used to collect and deal with data on transport activity and transport energy use:

1. Administrative sources
2. Surveying
3. Measuring & metering
4. Modelling & using ‘big data’
Administrative sources

Make use of existing information and data:

- Annual transport fuel use from national energy balances (collected via questionnaires sent to ministries and national statistical offices)
- Transport activity statistics from public transport operators and government agencies – e.g. railway operators
- Vehicle registration data with detailed characteristics from respective government bodies and the private sector (e.g. associations of vehicle manufacturers)
- Vehicle import/export data with detailed characteristics (e.g. from trade offices/border control services/private sector vehicle trade associations)
- Vehicle characteristics (by size/fuel) from government organizations (e.g. US EPA or EU EEA) and comparative studies issued by NGOs (e.g. ICCT, T&E)
- Activity patterns: mode share, travel, trip, fuel content, fuel consumption, travel patterns from specific studies (e.g. mobility in cities, published by UITP)

Great way to get comprehensive, often official data, however:

- Collection methodology (and data quality) sometimes unclear
- Comparisons between providers may be difficult
Surveying

- Data collection via direct observation or questionnaires regarding travel activities, energy use, etc.
- Can be labour intensive, require large sample sizes, etc.
- Estimates, not hard data
- Can provide very rich information, useful for understanding variation, correlations, and other aspects of the sample

Examples:

- National travel survey
- Household surveys, focus groups
- Survey of fleets, trucking companies
- Observational (e.g. roadside) surveys
Measuring and metering

Direct observation, usually of a physical phenomenon
Can use existing metering systems or involve creating new ones
- Roadside car counters
- Vehicle fuel economy testing
- GPS data and vehicle location monitoring
- Vehicle fuel economy computers (in use performance)
- Portable Emissions Monitoring (PEMS)
- Speed detection systems
- Atmospheric concentration monitoring

Typically reliable but often expensive
- Based on scientific and replicable tests
- Sample size and data processing requirements affect costs
Measuring

Example of fuel consumption and pollutant emission from cars
Example of fuel consumption and pollutant emission from cars

Different test cycles in US, Japan & Europe exist

Conversion formulas to make tested data comparable

On-road fuel economy often higher than tested fuel economy (approx. 15% - 30%) due to:

- Climate conditions
- Use of auxiliary aggregates
- Road conditions
- Nature of driving cycles (e.g. not realistic)
- Vehicle preconditioning
Estimating with data uncertainties

What if data shows gaps?

- Statistical methods: interpolation, curve fitting etc.
- Use of correlations/elasticities
- Elimination of degrees of freedom and reality check, e.g. the least certain parameter is adjusted to match certain data

\[
\text{Energy use} = \text{Vehicle stock} \times \text{Fuel consumption} \times \text{Mileage}
\]

What if reality is too complex and diverse?

- Modelling/simulation e.g. heavy duty vehicle fuel economy
The IEA Mobility Model comprises an historical database:

- Stock data
- Travel data (pkm)
- Mileage data (km/y)
- Fuel consumption data (L/100 km)

- Primarily based on the collection and comparison of published information
- Bottom-up results on the energy consumption are checked against historic fuel consumption by sector and fuel type (from import/export/production balances: remember the examples of France and Indonesia?)
- Fitted adjusting the least reliable data (mileage)
Simulation of HDV fuel economy

- Hardware In the Loop System (HILS)
  - Running the internal combustion engine on the test bench using the heavy duty engine test cycle
  - Calculate the engine operating conditions by performing a simulated run

Estimating with data uncertainties

Analogy and patterns - Regressions

Road network speed versus population density

Average Road network speed (km/hr)

Urban density (People per hectare)

Fuel price level
- High
- Low

Source: Analysis of Millennium Cities Databases (UITP)

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Analyses and patterns - Regressions

Key determinants

Urban form (population density)
Income (GDP per capita)

Source:
IEA analysis using data from the *Millennium City Databases*
Union internationale des transports publics (UITP) (2015), Millennium City Databases for Sustainable Transport, database, UITP, Brussels.
Estimating with data uncertainties

‘Big data’ and statistics

Example of Paris

Median: 36.6
Mean: 37.6

Median: 26.5
Mean: 27.35

Friday afternoon – Inner Paris

Wednesday mid-morning – Inner Paris

Open source data: Open Street Map; Google and MapQuest APIs, GIS data
Estimating with data uncertainties

Example of Paris

- Open Street Map
- Google, MapQuest, and other APIs
- Other GIS data sources – mostly free
Conclusions

- Substantial data requirements
- Vehicle stock, fuel economy, and energy use are key parameters
- Reality checking is possible
- Bottom-up estimates can be done with limited investment
- Need to compromise between detail and available resources
- The better the historical data set, the more reliable are models
- A good model is an important basis for the definition of effective policy instruments!
Feedback & Discussion

The goal of this introductory day is to introduce key concepts that will be explored in far greater detail in the coming days.

- How new or familiar was the material we covered?
- How was the level of detail?
- What important issues have we not addressed?
- What other examples from your countries are relevant?
Session II
From historical observations to projections
Session one showed

- How to derive total transport energy use from basic transport indicators
- What data is necessary
- How baseline fuel use can be calculated
- Where data can be gathered / how it can be estimated

Session two will show

- What links transport activity with other socio-economic parameters
- Which policy levers influence transport activity, transport-related energy demand, the emissions of GHG and local pollutants
- How links between transport activity and other socio-economic are exploited in projecting transport activity in the future
- How this is combined with stock models and technical characteristics to model future energy demand and emissions in transport
- How policy levers can be taken into account in models
Transport activity (pkm, tkm), vehicle activity (vkm), and vehicle stock are largely determined by:

- **Relationships linking GDP and population with transport activity and modal choice**
  - GDP per capita $\rightarrow$ personal vehicle ownership & modal choice
  - Economic output (GDP) $\rightarrow$ tonnes transported

- **Changes in the cost of driving and moving goods**
  - *Effects* of price changes on average passenger travel and loads

- **Structural changes in the transport system**
  - *Passenger*: role of public transport in urban areas
  - *Freight*: economic and trade structures

- Transport demand and modal choices are subject to a travel time budget (TTB) constraint
Drivers of demand for transport activity

Motorized personal vehicles for passenger transport

- Structural effect
- Income effect
- Cost (USD/km) influences the evolution of vehicle mileage

Sources: elaboration of national and international databases, building on the information referenced in UNECE, 2012

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Drivers of demand for transport activity

Public passenger transport

Modal share of personal vehicles in total personal and public transport

- **Structural effect**
  - Cost (USD/km) influences the evolution of pkm on public and personal motorized transport

- **Income effect**

Source: elaboration of UITP, quoted by IEA, 2008

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Spotlight on aviation
The fastest growing transport mode

- Aviation is the transport mode that experienced the fastest growth in the past decade
- Aviation is also the transport mode projected to grow the most in the coming years
Drivers of demand for transport activity

Travel time budget (TTB)

- Average travel time constant
- Invariant across a wide range of variables (income, working hours, etc.)

Source: Schäfer, 2005
Drivers of demand for transport activity

Shares of pkm on different modes across the world

- Passenger cars dominate in high income countries
  - Fuel taxation, population density, urban environments
  - Lower income countries see much larger importance of two wheelers and collective transport modes

Transport policies implemented in cities

<table>
<thead>
<tr>
<th>Pricing</th>
<th>Regulatory instruments</th>
<th>Public transport and walking and cycling support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congestion charging, cordon pricing, tolls (e.g. London, Milan,</td>
<td>Access restrictions (e.g. “yellow label” restrictions in Chinese cities).</td>
<td>Shared bicycle systems and bicycle parking (e.g. Vélib’ in Paris, Citi Bike in New York).</td>
</tr>
<tr>
<td>Shanghai, Singapore, Stockholm).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parking pricing (widespread in North American, European and Japanese</td>
<td>Low-emission zones (e.g. time-of-day restricted access for freight trucks, as in many</td>
<td></td>
</tr>
<tr>
<td>cities, most prevalent in the central business districts of densely</td>
<td>European cities).</td>
<td></td>
</tr>
<tr>
<td>populated cities).</td>
<td>Registration caps (e.g. in Singapore, Shanghai and other Chinese cities).</td>
<td></td>
</tr>
<tr>
<td>Parkings restrictions/reductions in parking supply (e.g. progressive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>elimination of off-street parking in Copenhagen, Paris and other</td>
<td></td>
<td></td>
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<tr>
<td>European cities).</td>
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<td></td>
</tr>
<tr>
<td>Investments in cycling and walking paths, and sidewalks.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit infrastructure projects/ extensions (e.g. the Paris Métro;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bogotá’s Transmilenio).</td>
<td></td>
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</tr>
<tr>
<td>Transit fare subsidies (e.g. local, regional and federal subsidies pay</td>
<td></td>
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</tr>
<tr>
<td>for roughly half of fares on systems in many European and Chinese</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cities).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Drivers of demand for transport activity

Large freight

Transport activity (tkm) proportional to GDP

\[ tkm = \text{load (also proportional to GDP)} \times vkm \text{ (constant by distance class)} \]

- The trade-related nature of the economy (e.g. free trade vs. low imports and exports)
- the origin/destination of goods (e.g. changes in sourcing and/or destination of exports)
- the type of goods transported (e.g. change of importance of the manufacturing industry with vs. primary material extraction and trade)
- modal competitiveness (e.g. changes due to construction of new network links)
- Tkm and loads are also subject to the influence of the cost of moving goods (through elasticities)
Discussion

- Do you see other important factors affecting transport activity in your country?
Transport & energy policies

Why are they needed?

- To attenuate negative impacts of transport activity on others (externalities)
  - Damage to the environment – GHG, local pollutants
  - Health related issues – Local pollutants, noise
  - Time loss - Congestion / Queuing / Waiting

- To (try to) provide equal access to mobility
  - Basic principle that individual should be able to move freely
  - Social equity

- To have safe and secure trips – reduce accidents

- To make transport sustainable
Transport & energy policies

Why are they needed?

Observed change in surface temperature 1901-2012

°C
Transport & energy policies

Fundamental concepts

- AVOID unnecessary trips
- REDUCE km
- SHIFT modes
- IMPROVE vehicles
  - low carbon fuels
Fundamental concepts

Avoid unnecessary travel

- Urban design & transport integration in land use planning: shorter trips in high density, mix-use cities
- Congestion pricing and other fees (e.g. parking): higher transport costs reduce total pkm
- Logistics: better use of available capacity reduces total tkm
Transport & energy policies

Fundamental concepts

**Shift** travel to more efficient modes

- Urban design & transport integration in land use planning: transit-oriented developments promoting walking, cycling and the use of public transport
- Congestion pricing, access restrictions, parking fees targeting primarily more energy-intensive modes, combined with subsidies for public transport
- Travel demand management to avoid traffic peaks
- Logistics and intermodal terminals: wider potential for co-modal goods transport
Transport & energy policies

Fundamental concepts

**Improve** the energy efficiency of each mode

- Standards/regulations (e.g. on fuel economy, pollutant emissions, vehicle speed) and fiscal charges/incentives to promote the introduction of energy efficient and more sustainable technologies on vehicles in all modes (market pull)

- Support research to reduce the costs of advanced vehicle technologies (technology push)

- Support behavioral changes resulting in more efficient use of vehicles (high occupancy, energy efficient driving) and virtuous consumer choices to contain costs (e.g. smaller vehicles)
Avoid/Shift

- Urban design & transport integration in land use planning
- Compact development policy
- Long term goal but near term planning
Avoid/Shift from land use planning

Example: Carbon footprints (residential emissions only) in different neighborhoods in Toronto, Canada

- East York - 1.31 tCO2e/cap (residential only)
- Etobicoke - 6.62 tCO2e/cap (residential only)
- Whitby - 13.02 tCO2e/cap (residential only)

High-density apartment complexes within walking distance to a shopping center and public transit: 1,31 tCO2e/capita

High-density single family homes close to the city center and accessible by public transit: 6,62 tCO2e/capita

Suburbs with large, low-density single family homes that are distant from commercial activity and public transit: 13,02 tCO2e/capita

Source: GIZ
Avoid/Shift

- Road/congestion pricing
- Environment zones
- Parking fees
Avoid/Shift

- Increasing the public transport capacity
- Improving the quality of public transport
- Pricing policies targeting primarily more energy-intensive modes can be combined with subsidies for public transport
Shift

- Shift to energy efficient modes
- Constraints
Avoid

Example: Curitiba, Brazil

Innovative land use planning integrated with transport planning

- Result:

  Modal share

  - Car 22%
  - Walking 27%
  - Bicycle 5%
  - Bus 46%

Source: IPPUC, 2009

Source: ESMAP
Bus rapid transit (BRT)

Avoid/Shift

• Bogota’s BRT a reference: 100+ systems in world today (including cities in Colombia, Ecuador, China, India, Brazil....)

• Significant CO₂ reduction 25% - 39% (IEA estimate).

• Advantages: improved fuel efficiency, higher speeds and less stop-and-go traffic on dedicated routes.

More on BRT planning and development:

Rail carries 9% of global transport activity – but only accounts for 3% of transport energy/emissions.

Rail energy intensity (MJ per pkm) decreased 30% between 2000 and 2010 – and can improve more in the future.

HSR is excellent alternative to short flights – but only a handful of countries are planning new HSR lines.

Car sharing (commuting)

Avoid/Shift

- Limitations: requires users to be within convenient distance
- Participation in car sharing on average reduces car travel by 3000 km/year
- More formal programmes, like Paris Autolib’ entering market. Risk is attracting non-drivers to programme.
Cycling

• Infrastructure provisions: lanes, parking, traffic signals

• Funding / cycling mode relationship:
  ▪ Amsterdam: US$ 39/resident, Cycling 35%,
  ▪ USA: US$ 1.5/resident, Cycling 1%.

• Bicycle “sharing” (rental) services

• Viable alternative for short trips

• Best suited for densely populated city centers
Avoid/Shift

Walking:

• Pedestrian infrastructure, amenities and services are often neglected.

• Pedestrian friendly policies:
  ▪ Safe sidewalks
  ▪ Well marked, respected crossings
  ▪ Car-free zones
  ▪ Traffic calming measures

• Walkability Index
Avoid/Shift

- Logistics
- Information technology
- Intermodal terminals/hubs
- Road pricing & access restrictions

Source: Dinalog
Avoid/Shift – Wrap up

- High-density environments with good transit use less energy
- Building cities from scratch is not often possible
- Fast-growing countries can (and need to) do that (leapfrogging)
- Time frame to alter urban design is very long: > 50 years
- Integrated measures needed for effective results
- Bigger effects to be seen over the long term
- Local regulations should not inhibit beneficial forms of teleworking

⚠️ In depth action takes time but investment is worth it!
## Improve

### Policy instruments

<table>
<thead>
<tr>
<th>Regulation</th>
<th>Monetary incentives</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel efficiency standards</td>
<td>Energy efficiency or CO₂ emission based element in the annual circulation tax</td>
<td>Car labelling based on fuel use or emissions</td>
</tr>
<tr>
<td>Pollutant emission regulations</td>
<td>Tax incentives for the purchase/first registration of efficient vehicles</td>
<td>Tyre labelling</td>
</tr>
<tr>
<td>Speed limits</td>
<td>Feebates (combination of taxation and incentives)</td>
<td>Eco driving campaigns</td>
</tr>
<tr>
<td></td>
<td>Inclusion/exclusion in/for road pricing/congestion charging schemes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fuel taxation, <strong>full removal of energy subsidies</strong></td>
<td></td>
</tr>
</tbody>
</table>
Transport & energy policies

Improve

- Fuel economy standards have been enforced in several countries

Net benefits from:

- Reduced energy bills
- Promotion of technological development and innovation
- Reduced GHG emissions
Global Fuel Economy Initiative

• **GOAL:** reduction of fuel consumption per km of 50% by 2050
  Roughly equivalent to a 50% improvement by 2030 for the fuel consumption of new vehicle sales, worldwide

• **Engagement with governments, including developing countries**
  – National baseline setting
  – Definition of fuel economy trends and scenarios
  – Assessment of impact of policy packages
  
  Fuel economy standards, feebates/bonus-malus tax-subsidies, labelling schemes, interaction with local pollution control, influence of 2nd hand import of vehicles

#EnergyEfficientWorld
Improve

- Regulations on the emission of pollutants from road vehicles have been enforced in several countries.
- The parallel introduction of clean fuels is also progressing.

**Pollutant emission limits for passenger cars**

**Sulfur content in fuels**

Source: [Daimler](https://www.daimler.com)

Source: [UNEP](https://unep.org)
Transport & energy policies

Improve

- Fuel prices have strong influence on “driving culture”
- Countries with higher fuel prices drive smaller cars at lower annual mileages

Worldwide retail prices of gasoline and diesel (US$ cents per litre)

The removal of fuel subsidies is a policy priority
**Transport & energy policies**

*Improve*

- Labelling schemes for consumer information on fuel economy
- Can be linked to feebates (combined use of taxation on energy/CO₂ intensive vehicles and incentives for clean vehicles)
Example: the French Bonus-Malus

- Initially designed to be cost neutral – neutrality failed: French consumers have reacted strongly to financial incentives created by the policy
- The policy has been revised in several occasions up to 2014
- Special bonus for hybrid-electric vehicles <110 g CO₂/km (3300 €)
- Special LPG conversion bonus suppressed in 2011

Source: Ministère de l’Ecologie, du Développement durable et de l’Énergie
Transport & energy policies

Improve

- CO₂-differentiated purchase tax,
- registration & ownership fees,
- annual circulation (mileage) taxes
- Scrappage schemes
- Feebates
- Tax credits for hybrid / electric vehicles

Change in sales by CO₂ classes (5 main EU markets) (Source AAA – Renault)
**Improve**

**Rebound effect**

- More efficient cars tend to have higher investment costs, and lead to falling travel cost per km

- There is a risk of “rebound” towards higher mileage (which, in turn, leads to higher energy demand)
  - Lower cost per km is typically associated with higher mileages (via “elasticities”)
  - High up-front costs might provide incentives for an increased use of the vehicle, but higher vehicle costs tend to be associated with lower ownership rates
  - Changes in mileage and ownership have counter effective impacts on speed

- Technological measures may have to be implemented together with accompanying measures counter balancing negative effects
  - Fuel taxation and speed limits may need to be adapted
  - Support for energy efficient transport modes (e.g. redistributing part of the revenue from feebates, making them revenue-neutral across modes)
# Transport & energy policies

## Improve

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Technology switch</th>
<th>Fuel switch</th>
<th>Behavioural aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine efficiency</td>
<td>Plug-in hybrids</td>
<td>Natural gas</td>
<td>Ecodriving</td>
</tr>
<tr>
<td>Light weighting</td>
<td>Battery electric vehicles</td>
<td>Biofuels 1\textsuperscript{st} generation</td>
<td>Awareness</td>
</tr>
<tr>
<td>Downsizing</td>
<td>Fuel cell vehicles</td>
<td>Biofuels 2\textsuperscript{nd} generation</td>
<td></td>
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<tr>
<td>Hybridisation</td>
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<tr>
<td>Improved aerodynamics</td>
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<tr>
<td>Reduced auxiliary power</td>
<td></td>
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<tr>
<td>Reduced rolling resistance</td>
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Transport & energy policies

**Improve**

Focus on vehicle technology

- Technology cost curves: what improvement at what cost

- Technology learning
  How do costs improve with increased capacity?

- Market penetration
  At what pace new technologies can be scaled up?
Discussion

- How does this fit with policies that would deliver reduced energy use in transport in your country?
- Are any of these policies in place?
  - Land use change
  - Modal shift
  - Improvement of fuel economy?
- What are the main barriers to achieving this?
Transport roadmaps

- Biofuels for transport
- Electric and plug-in hybrid vehicles
- Fuel economy of road vehicles
- Hydrogen (in preparation)

Transport policy pathways

- Improving the fuel economy of road vehicles
- A tale of renewed cities
## Comparing technologies and costs

### Calculate the cost of each km travelled

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Gasoline ICE PLDV</th>
<th>Diesel ICE PLDV</th>
<th>Battery electric vehicle</th>
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<tbody>
<tr>
<td>Price (USD)</td>
<td>23500</td>
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<td>28000</td>
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<tr>
<td>Annual mileage (km/year)</td>
<td>14000</td>
<td>16100</td>
<td>14000</td>
</tr>
<tr>
<td>Fuel consumption (L/100 km; kWh/100 km)</td>
<td>7.5</td>
<td>5.6</td>
<td>18</td>
</tr>
<tr>
<td>Life time (year)</td>
<td>14</td>
<td>14</td>
<td>14</td>
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</tbody>
</table>

| Fuel costs (USD/Lge; USD/kWh) | 1.3  | 1.2   | 0.1   |
| Fuel consumption (Lge/100 km) | ?    | ?     | ?     |
| Fuel costs (USD/Lge)         | ?    | ?     | ?     |

| Total fuel cost (USD)        | ?    | ?     | ?     |
| Average cost of travel (USD/km) | ?    | ?     | ?     |

### Energy conversion

<p>| | |</p>
<table>
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<tr>
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<tr>
<td>Gasoline (MJ/L)</td>
<td>33.5</td>
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<td>36.1</td>
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</tr>
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<td>6.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Fuel costs (USD/Lge)</td>
<td>1.3</td>
<td>1.0</td>
<td>0.93</td>
</tr>
<tr>
<td>Total fuel cost (USD)</td>
<td>19110</td>
<td>16228.8</td>
<td>3528</td>
</tr>
<tr>
<td>Average cost of travel (USD/km)</td>
<td>0.22</td>
<td>0.19</td>
<td>0.16</td>
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The IEA Mobility Model
The IEA Mobility Model

What is it?

- MoMo is a spreadsheet model of global transport
  - Mainly focused on vehicles and energy use, but also covering emissions, safety, infrastructure and materials use
  - Analysis of a multiple set of scenarios and projections to 2050
  - Based on hypotheses on GDP and population growth, vehicle fuel economy, fuel costs, travel demand, and vehicle and fuel market shares

- World divided in 29 regions, including several specific countries
  - USA, Canada, Mexico, Brazil, France, Germany, Italy, United Kingdom, Japan, Korea, China, India

- Tracking of urban and non-urban transport

- MoMo contains a large amount of information (data) on technology and fuel pathways
  - Full evaluation of life cycle greenhouse gas emissions
  - Cost estimates for new light duty vehicles (LDV), fuels and fuel taxes
  - Valuation of transport sector expenditures to 2050: vehicles, fuels and infrastructure
  - Module on material requirements for LDV manufacturing
The IEA Mobility Model

Key modelling steps

- Generation of transport activity (pkm, tkm, vkm) and vehicle stock
- Evaluation of new vehicle registrations by powertrain and characterization of the vehicles by age
- Calculation of the energy use
- Estimation of CO₂ and pollutant emissions
The IEA Mobility Model

Modes covered

- 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 duty vehicles
  - Minibuses
  - Buses and BRT systems
  - Medium freight trucks
  - Heavy freight trucks
- Rail (Intercity, High-Speed and Freight)
- Air (passenger, new module under development)
- Water transport (freight, new module under development)
Fuel pathways

- **Liquid petroleum fuels**
  - Gasoline
  - Diesel (high- and low-sulphur)

- **Biofuels**
  - Ethanol: grain, sugar cane, and advanced technologies (lignocellulose)
  - Biodiesel: conventional (fatty acid methyl esters, FAME or biodiesel obtained from hydrogenation of vegetable oil in refineries) and advanced processes (BTL, fast pyrolysis, hydrothermal upgrade)

- **Synthetic fuels**
  - Gas-to-liquids (GTL) and coal-to-liquids (CTL)

- **Gas**
  - Compressed natural gas (CNG), liquefied petroleum gas (LPG) and biogas

- **Electricity**
  - Treated separately for electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) and other modes, by generation mix and region

- **Hydrogen**
  - From natural gas (with and without CO2 sequestration), electricity and point of use electrolysis (with and without CO2 sequestration), biomass gasification and advanced low-GHG hydrogen production
The IEA Mobility Model

Structure

- Country Historic Data Files
- Global Historic Database
- Fuels
- Air
- 2 and 3 Wheelers
- Passenger LDVs
- Road Freight
- Buses
- Rail
- Shipping
- Materials
- Infrastructure
- Master Interface
- Costs and Investments

Data: Local Pollutants
Data: GDP and Population
Data: Electricity Mix Input
Data: Batteries
Data: Fuel Economy Potential
The IEA Mobility Model

Project history

2003  World Business Council for Sustainable Development and the Sustainable Mobility Project (SMP) transport model
Scenarios exploring transport energy use, CO₂ and pollutant emissions, safety and materials use

2004  SMP model developed further as IEA Mobility Model (MoMo)
MoMo data used for the IEA ETP analysis and ETP 2006

2006-2008  Deeper analysis of vehicle technology potential, including plug-in hybrid electric vehicles (PHEVs)
Elasticities of travel and ownership with respect to GDP and oil prices
Integration of significant historical data in MoMo
Development of scenarios for the IEA Energy Technology Perspectives (ETP) project in 2008

2008-2012  Improved user friendliness and detailed modular approach
Expanded coverage of countries and regions
Development of modal shift scenarios
Vehicle, fuel and infrastructure costs associated to scenario

2013+  Assessment of urban transport activity
Integration of city-level data and GIS data
Demand generation module to model policy-driven modal shift
The IEA Mobility Model

Analytical capabilities (1/2)

- LDVs and freight trucks
  - A stock and sales model has been developed
  - Activity, intensity, and energy use are estimated
  - CO₂ emissions are calculated (well-to-wheel and tank-to-wheel, using ETP modelling framework)
  - Pollutant emissions (CO, VOCs, PM, lead and NOₓ) estimated
  - Vehicle and fuel costs are tracked

- Buses and 2/3 wheelers
  - MoMo tracks stock, stock efficiency, travel, energy use, and emissions

- Rail and air
  - Total travel activity, energy intensities, energy use, and emissions are tracked

- Shipping
  - To date, MoMo tracks sectorial energy use and emissions
MoMo has a user interface that allows

- “What-if” scenario building
- Backcasting
- Use of elasticities for ownership and mileage
- Mode shift scenario building for passenger travel

MoMo also estimates material requirements and emissions:

- Analysis of future vehicle sales (e.g. fuel cells) and how they impact materials requirements (e.g. precious metals) is possible
- Full life-cycle analysis for GHG emissions from LDVs (including manufacturing) can be calculated

Recent MoMo capacity developments include

- Urban and non-urban travel splits applying data from a global set of mobility surveys
- Land transport infrastructure requirements in support of travel demand growth
- Fuel cost, T&D, storage and distribution infrastructure assessment
- Cost estimations from vehicle, fuel and infrastructure investments
Scenarios enabling emissions from transport consistent with limiting global projected temperature rise to 2 degrees Celsius
Activity must be decoupled from emissions

**Well-to-wheel transport emissions in the 2DS, 4DS, and 6DS, OECD and Non-OECD**

**Needed actions:** Avoid & shift, improve, and low-carbon fuels

**OECD transport emissions have peaked**
- Stabilized population
- Vehicle and systems efficiency
- All three measures can contribute
- Total well-to-wheel emissions can be cut in half by 2050 (2DS compared to 4DS)

**Non-OECD transport emissions can be brought back to current levels in 2050**
- All three measures can contribute
- Avoid/shift measures – crucial to avoid lock-in of car and sprawling urban form
- Vehicle efficiency measures – calls for early intervention and continuous improvement
Pathways to the 2DS vary by region

Final energy demand in the 2DS in major world regions, by energy carrier
Who supports this work?

- MoMo is supported by a partnership comprising 18 institutions
- Eight companies (BP, Honda, Nissan, Shell, Statoil, Toyota, Michelin and Petrobras) have been financing the project development since the end of the SMP