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Regional Capacity Building Activity on Measurement of Inland Transport CO_2 Emissions and Mitigation Policies – Technical Workshop

8-10 October 2013, Geneva, Switzerland

Evaluating CO_2 emissions in inland transport and climate change mitigation

ForFITS

A monitoring and assessment tool "For Future Inland Transport Systems"

General overview

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ForFITS
Model requirements

Key requirements

Allow the estimation/assessment of emissions in transport
Allow the evaluation of transport policies for CO_2 emission mitigation

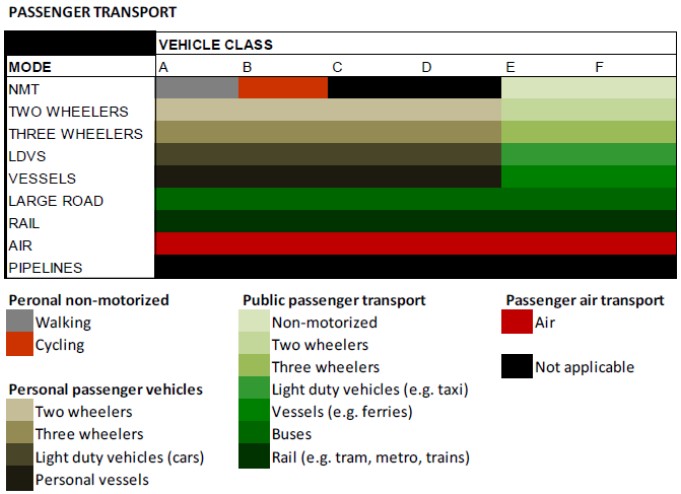
} Convert information on transport activity into fuel consumption and CO_2 emission estimates considering the influence of the demographic and socio-economic context, including policy inputs

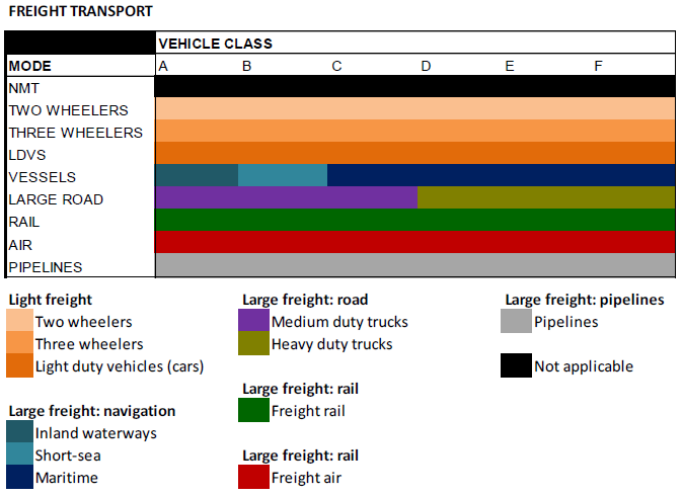
Be developed as a software tool
Be freely available for users (e.g. national and local governments, general public)
Be developed between 2011 and 2013

Sectoral model (focused on inland transport only): we do not expect it to target the evaluation of overall effects on the economic growth

ForFITS model Coverage

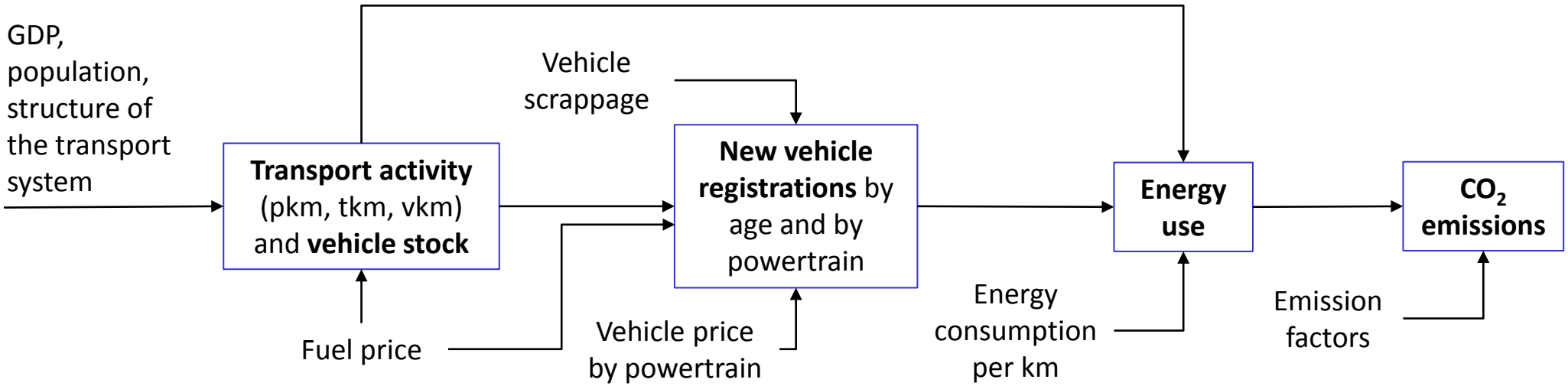
- Passenger and freight transport services
- Two different areas (e.g. to define the transport systems: urban, non-urban, non-spec.)
- Nine transport modes: non-motorized transport, two wheelers, three wheelers, light road vehicles, medium and heavy road vehicles, rail, navigation (inland, short-sea and deep-sea/maritime), air and pipelines
- Different vehicle subsets within each mode (organized in six vehicle classes – A to F) (figures)





- 31 powertrain technologies (e.g. internal combustion engines, hydraulic hybrids, electric hybrids, plug-ins, fuel cell, electric)
- 10 fuel blends, some of which are associated with specific modes and/or powertrains

ForFITS model
Key modelling steps



Four 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 **CO_2 emissions**

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ForFITS model
Demand generation

Transport activity (pkm, tkm), vehicle activity (vkm) and vehicle stock are largely determined by:

- Relationships linking GDP and population with transport activity
  - GDP per capita with vehicle ownership and pkm
  - Economic output (GDP) with tonnes lifted
- Effects of changes in the cost of driving and moving goods
  - Elasticities of pkm, tkm, average travel and average loads
- Structural changes in the transport system
  - Passenger transport system (mainly with respect to the role of public transport, to assess policies related with modal shift)
  - Freight transport system (and related economic structure, and especially the impacts this has on modal choice and the average length of hauls)

Behavioral aspects (environmental culture) are also taken into account for passenger transport (elasticities on key passenger transport parameters)

Coherence due to related inputs (such as GDP growth and economic structure, or the effect on GDP growth due to changes in the cost of driving) needs to be assured by users

ForFITS model: demand generation

Passenger transport

(1/3)

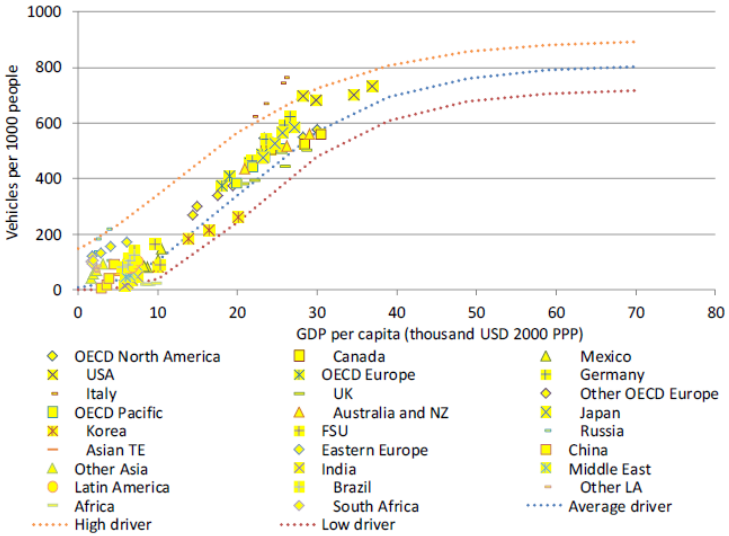
Motorized personal vehicles

- Vehicle stock primarily a function of GDP per capita (figure)
- Annual vehicle travel (km/year) affected by changes in the cost of driving (through direct and cross elasticities)
- Vehicle load affected by changes of vehicle ownership (lower ownership associated with higher average loads)

Shifts to/from personal from/to public transport are considered as structural changes having an effect on:

- the vehicle stock (vehicle ownership is lower in areas with high shares of public transport)
- the average travel per vehicle (the average travel of personal vehicles is lower in areas with high shares of public transport)

Motorized personal vehicles ownership



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

Vehicle ownership is also assumed to be influenced by environmental culture (behavioural aspect)

ForFITS model: demand generation

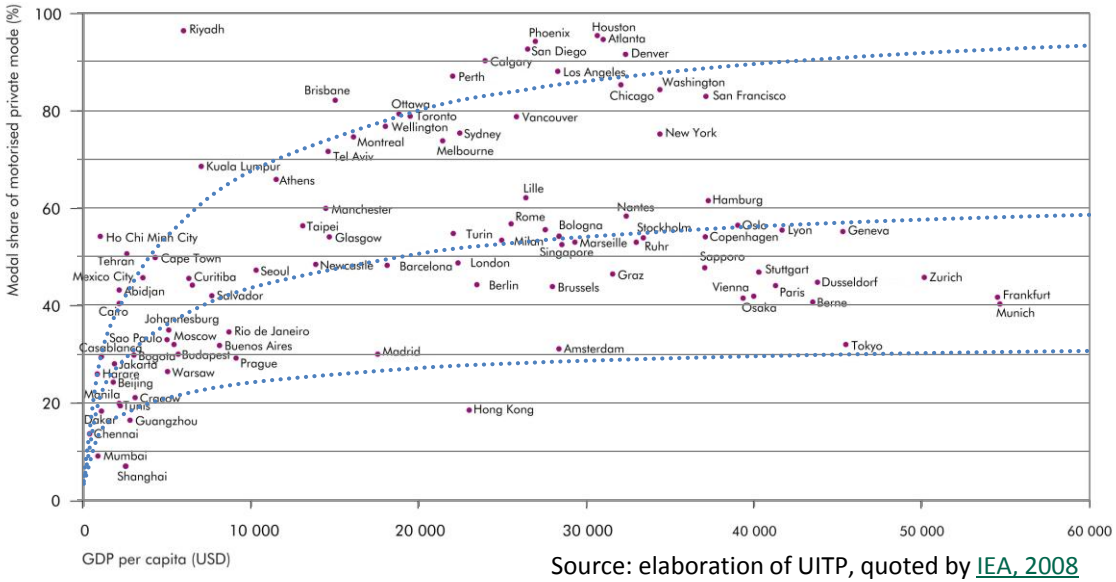
Passenger transport

(2/3)

Public transport (except air)

- Pkm share on public transport modes (in total personal and public transport, excluding air) primarily a function of GDP per capita (figure), also assumed to be influenced by environmental culture (behavioural aspect)
- Pkm affected by changes in the cost of driving (direct & cross elasticities)
- Pkm influenced by modal shifts to/from personal from/to public transport
- Vkm from pkm and annual travel
- Vehicle stock from vkm and loads

Modal share of personal vehicles in total personal and public transport



Source: elaboration of UITP, quoted by IEA, 2008

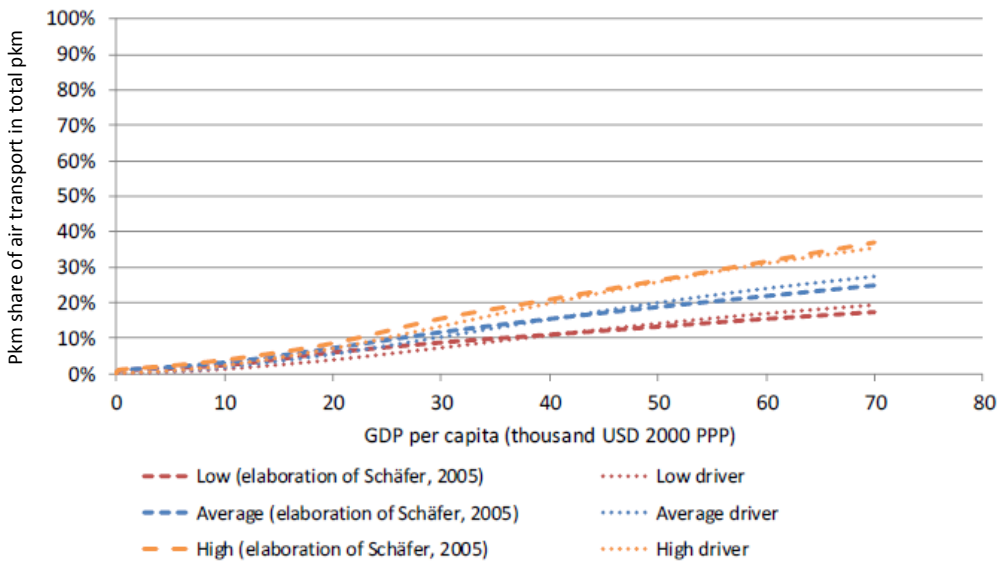
ForFITS model: demand generation

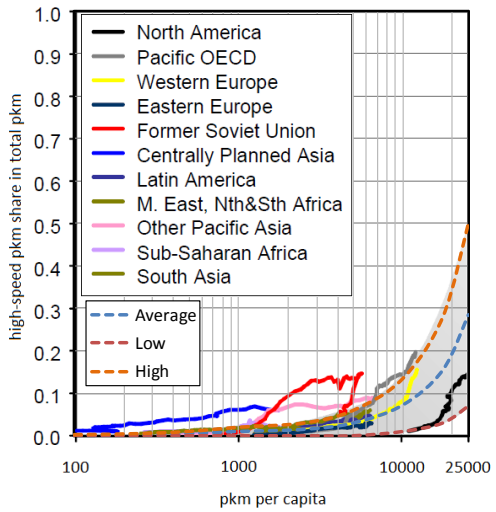
Passenger transport

Air transport

- Pkm share of air transport (in total pkm) pimarily a function of GDP per capita (figure), also assumed to be influenced by environmental culture (behavioural aspect)
- Pkm affected by changes in the cost of driving (direct & cross elasticities)
- Vkm from pkm and annual travel
- Vehicle stock from vkm and loads

Modal share of air transport in total transport





Source: elaboration of Schäfer, 2005

ForFITS model: demand generation

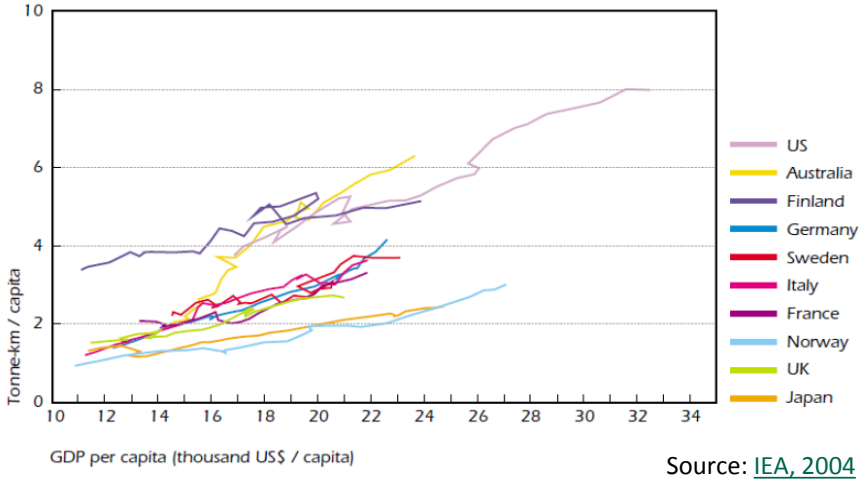
Freight transport

(1/2)

Large-freight

- Transport activity (tkm) proportional to GDP (figure)
- Tkm is the product of tonnes lifted (also proportional to GDP) and haul length (constant by distance class)

Freight transport activity and GDP



Source: IEA, 2004

Tonnes lifted by mode are subject to structural changes, driven by:

- 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)
- the modal competitiveness (e.g. changes due to the construction of new network links)

Tkm and loads are also subject to the influence of the cost of moving goods (through elasticities)
Vkm from tkm and annual travel
Vehicle stock from vkm and loads

ForFITS model: demand generation

Freight transport

(2/2)

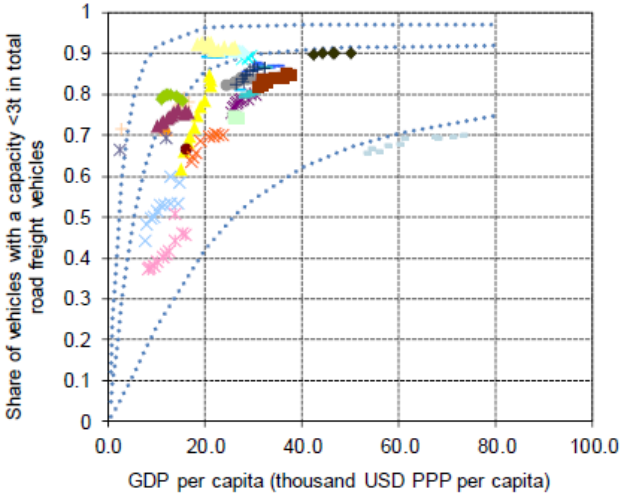
Light road freight

- Light commercial vehicles (<3.5 t)
- Typically out of freight transport statistics
- Transport activity (tkm) built bottom-up from vehicle stock, travel and loads

Vehicle stock deduced from:

- vehicle stock of large road freight
- historical share of light road freight vehicles in total road freight, function of GDP per capita (figure)

Light road freight vehicle share in total road freight



Source: Eurostat

Annual vehicle travel (km/year) affected by changes in the cost of driving (through direct and cross elasticities)

Vehicle load affected by changes of vehicle ownership (lower ownership associated with higher average loads)

ForFITS model
Powertrain selection

Multinomial logit: used when the "endogenous powertrain selection" is activated

Choice based on the maximization of consumer utility

- corresponds to the maximization of savings from the powertrain selection

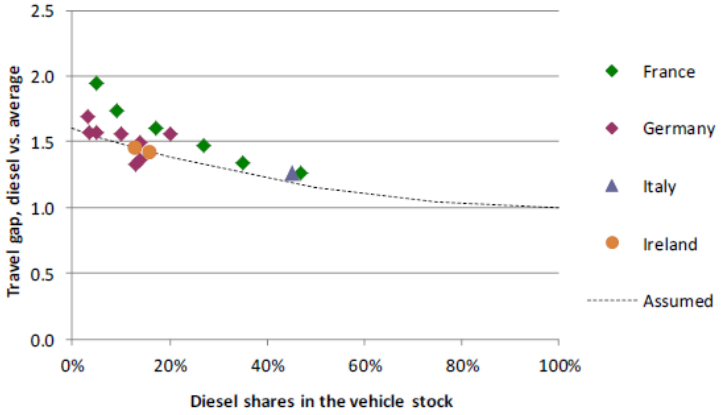
Requires the characterization of the utility of all options (powertrains of each vehicle class)

- Vehicle and fuel prices - including costs, margins and tax rates
- Vehicle fuel consumption
- Discount rates

Information on average vehicle travel (km/year) is needed to characterize fuel costs

- average vehicle travel assumed to decrease with vehicle age
- alternative technologies to gasoline-powered positive-ignition powertrains assumed to travel more if their market share is close to zero (figure)

Average travel and share of diesel powertrains in selected countries



Sources: various datasets and publications, including Bodek and Heywood (2008), Eurostat, Howley et al. (2007), Caputo et al. (2008)

Users are assumed to consider constant fuel prices when taking into account future expenditures (this is justified by the volatility of fuel prices)

ForFITS model
Fuel consumption

The fuel consumption is calculated from:

- 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

ASIF: Activity, Structure, Intensity → Fuel consumption

The calculation is based on Laspeyres identities (frequently used for the development and the analysis of energy efficiency indicators)

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

F	total Fuel use
A	vehicle activity (expressed in vkm)
F_i	fuel used by vehicles with a given set of characteristics (by service, modes, vehicle class and powertrain)
$A_i/A = S_i$	sectoral structure (expressed as shares of vkm by service, modes, vehicle class and powertrain)
$F_i/A_i = I_i$	energy intensity, i.e. the average fuel consumption per vkm by service, modes, vehicle class and powertrain)

ForFITS model
CO_2 emissions

Extended ASIF

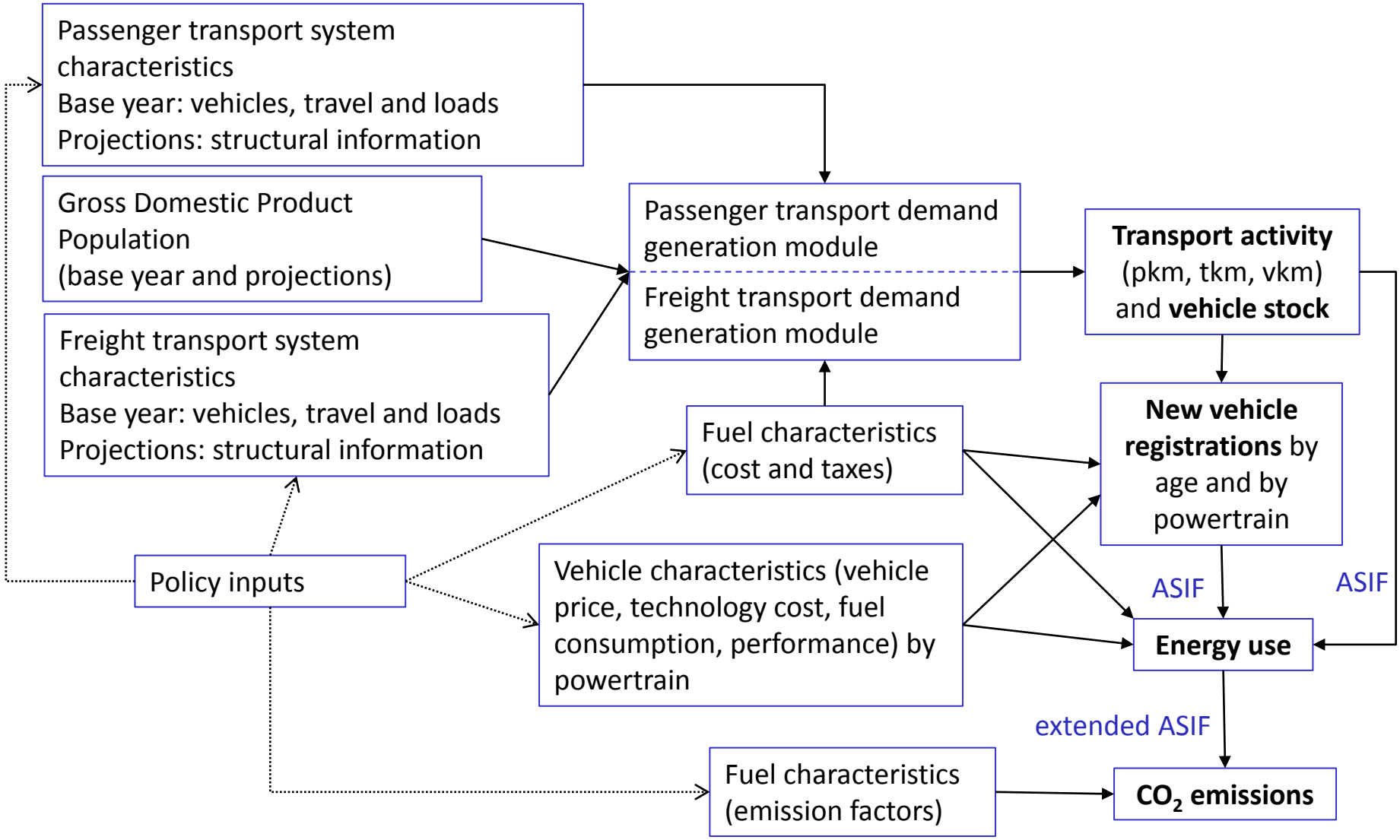
The same methodological approach used for the calculation of fuel consumption (ASIF) can be extended to evaluate CO_2 emissions

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

$$E = \sum_i E_i = A \sum_i \left(\frac{A_i}{A}\right)\left(\frac{F_i}{A_i}\right)\left(\frac{F_{ij}}{F_i}\right)\left(\frac{E_{ij}}{F_{ij}}\right) = \boxed{A \sum_i S_i I_i EF_{ij} = E}$$

E	emissions
E_i	emissions due to the 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*

ForFITS model
Simplified structure



ForFITS model
File structure

ForFITS was developed in the Vensim modelling environment

Two components

- Vensim Packaged Model (.vpm file) ForFITS.vpm
- Excel interface (.xls file) ForFITS Inputs.xls

VPM file

- Model, structured in a set of "views" showing portions of the model
- This file can be opened with the Vensim Model Reader, a free software downloadable here: http://vensim.com/vensim-model-reader

Excel file

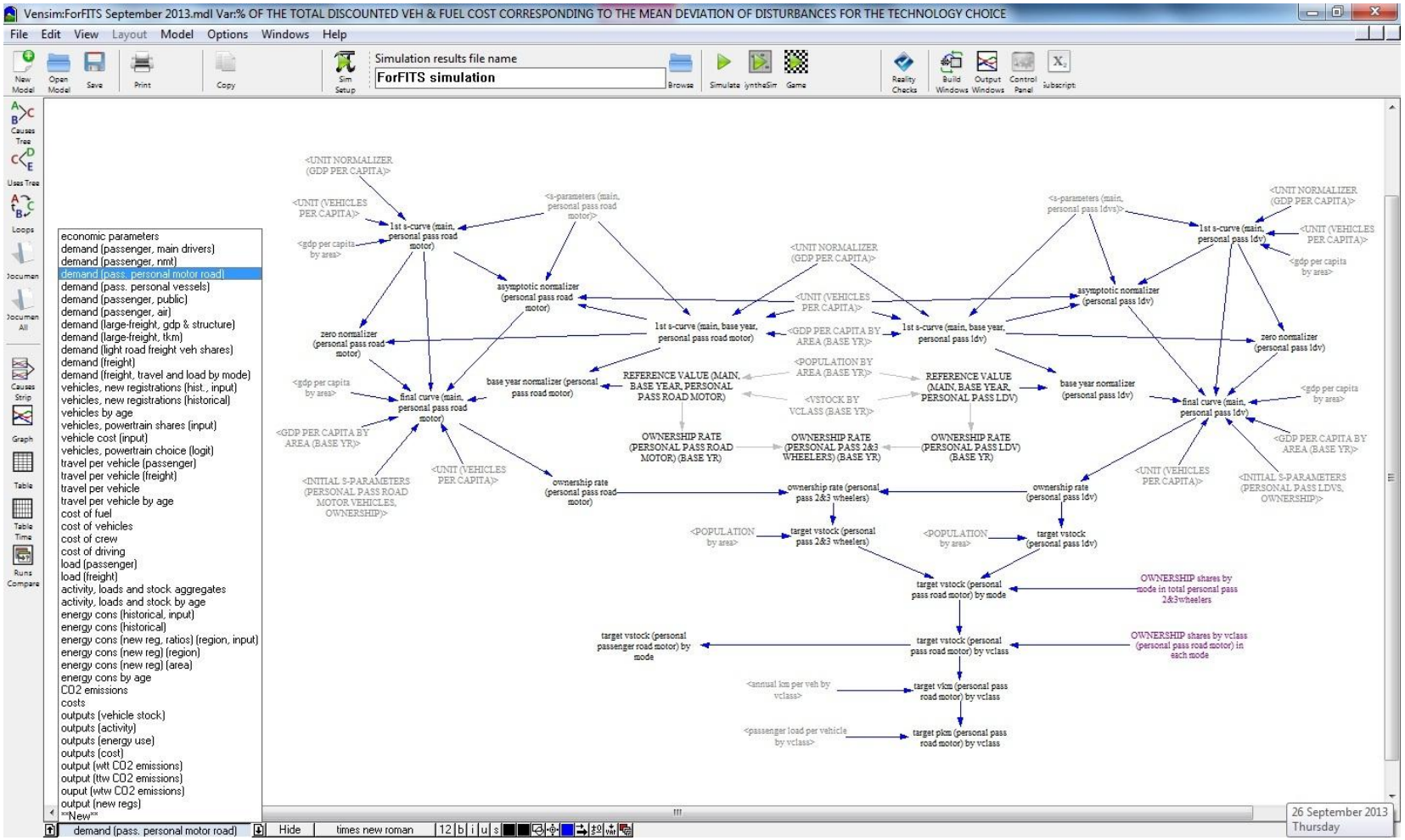
- Interface allowing users to enter inputs, communicating with the VPM file.

Both the files are freely available and can be downloaded on line on the UNECE web site: http://www.unece.org/trans/theme_forfits.html

The ForFITS user manual is also accessible on the UNECE web site: http://www.unece.org/trans/forfits_user_manual.html

ForFITS model
VPM file

Example of a “view” of the VPM file



Coding

Purple text: input from XLS file

Black text: variables calculated in the view

Grey text: variables calculated in another view

Blue arrows: connection variables

NAME IN CAPITAL LETTERS: base year variable

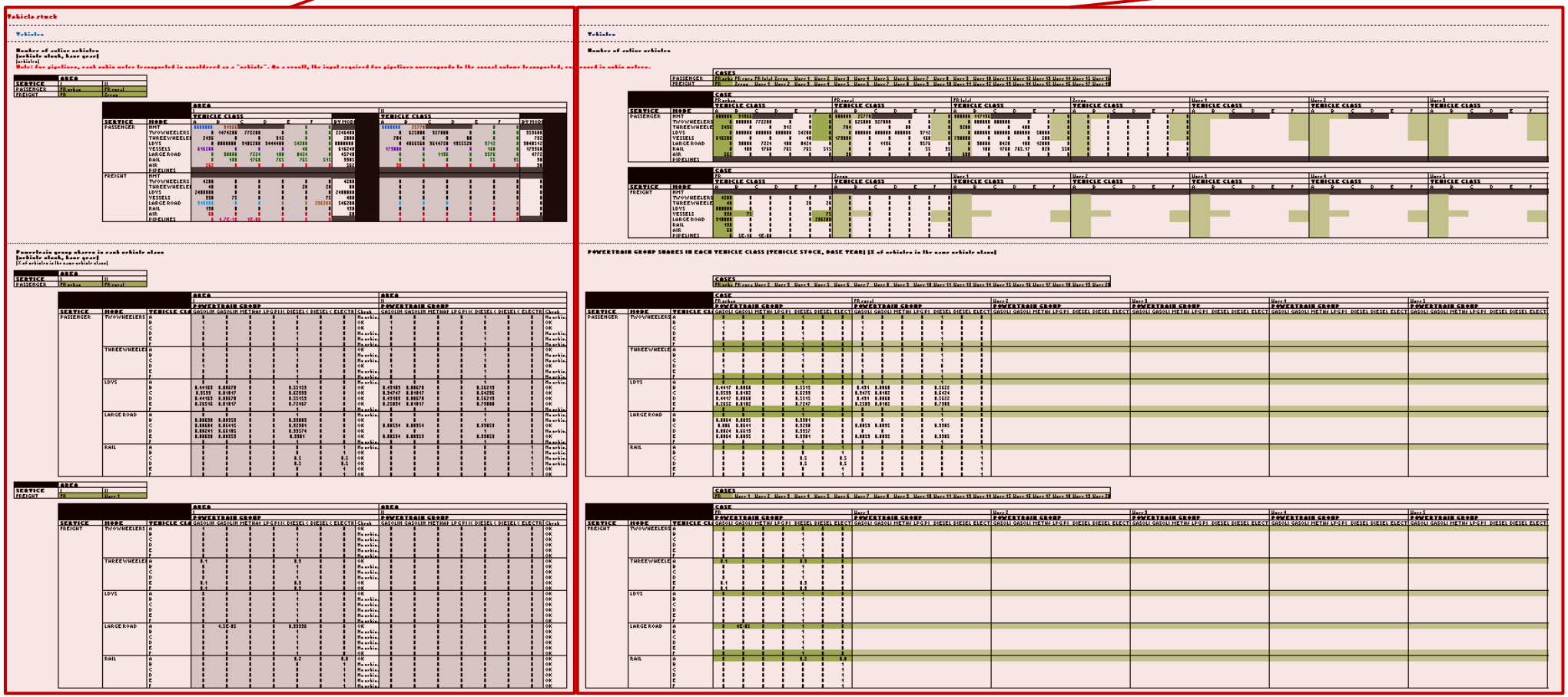
FIRST word in capital letters: input over time

ForFITS model
XLS file

Example of input tables in the XLS file

Selection section
Inputs entered in the database section are activated here

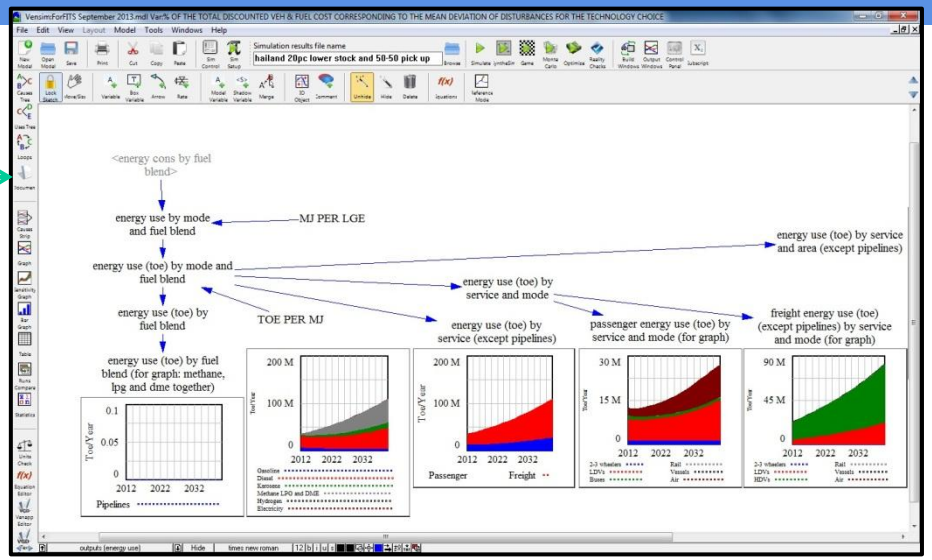
Database section
Data for new scenarios shall be entered here

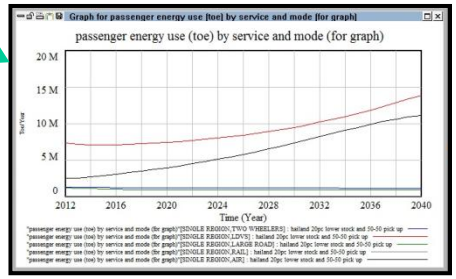


ForFITS model
Results

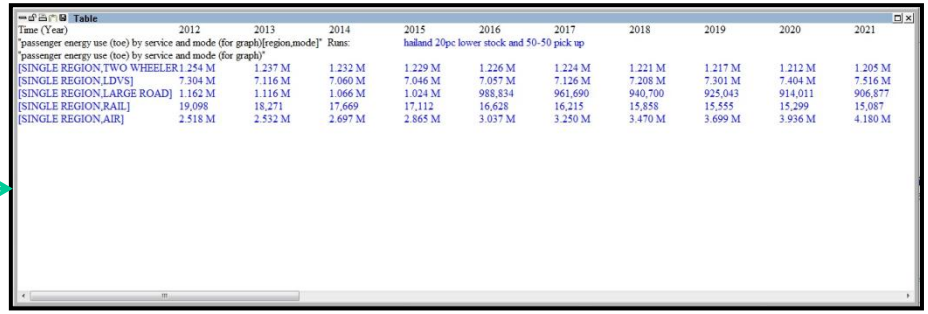
Results can be visualized in several ways:

- Using the "output" views of the VPM file
- With a graphical interface in the VPM file (up to 16 variables, including subscripts)





- As a table in the VPM file (any amount of subscripts and variables)



Table

Time (Year)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
"passenger energy use (toe) by service and mode (for graph)[region,mode]" Runs:				hailand 20pc lower stock and 50-50 pick up						
"passenger energy use (toe) by service and mode (for graph)"										
[SINGLE REGION,TWO WHEELER]	1.254 M	1.237 M	1.232 M	1.229 M	1.226 M	1.224 M	1.221 M	1.217 M	1.212 M	1.205 M
[SINGLE REGION,LDVS]	7.304 M	7.116 M	7.060 M	7.046 M	7.057 M	7.126 M	7.208 M	7.301 M	7.404 M	7.516 M
[SINGLE REGION,LARGE ROAD]	1.162 M	1.116 M	1.066 M	1.024 M	988,834	961,690	940,700	925,043	914,011	906,877
[SINGLE REGION,RAIL]	19,098	18,271	17,669	17,112	16,628	16,215	15,858	15,555	15,299	15,087
[SINGLE REGION,AIR]	2.518 M	2.532 M	2.697 M	2.865 M	3.037 M	3.250 M	3.470 M	3.699 M	3.936 M	4.180 M

- Extracting tables in .txt files, readable and editable in Excel

The visualisation as graphs and table is possible for each of the model variables

Comparative results on multiple runs (e.g. to different scenarios, before and after one or more policy interventions) can also be visualized in graphs and tables

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ForFITS model
Policy impacts or scenarios?

ForFITS may be used to evaluate policy impacts and to consider the effect of certain assumptions/scenarios

Examples:

- Socio-economic growth scenarios (e.g. strong vs. weak GDP and/or population growth)
- Fuel cost scenarios (e.g. high vs. low oil price)
- Fuel taxation policy, including carbon taxes (need for proper characterization)
- Road pricing policies (caution needed when it is applied to portions of the network)
- Assumptions/scenarios on the evolution of the cost and performance of vehicle technologies
- Differentiated vehicle taxation (e.g. based on the vehicle technology)
- Assumptions/scenarios related to structural changes of the transport systems

  Passenger: modal shift policies, e.g. towards public transport from private vehicles

  Freight: modal shifts, e.g. due structural changes in the economy (such as relevance of imports & exports) and in the logistic system (such as local vs. long-distance sourcing)

In the case of assumptions/scenarios, the coupling with policies has to be worked out be the user aside from the model

ForFITS model
Data requirements

Even if ForFITS has the capacity to adapt to different levels of data availability, the model does require a substantial amount of data, for:

- the characterization of the transport system in the base year (historical inputs)
- the definition of the context in which the transport system should evolve (projections)

Information on the initial and final times, the characterization of the areas, and the selection of the modelling approach for the powertrain choice (exogenous or endogenous), are also firm needs

Minimum data requirements (other inputs are defined by default data and can be modified)

Historical inputs

- GDP, population
- Vehicle stock: number of vehicles by powertrain, average travel and loads, average fuel consumption
- New vehicle registrations: same detail used for stocks needed for the base year, 5 and 10 years earlier (data in between are taken into account with linear interpolations)

Projections

- GDP and population
- Fuel prices (cost and taxation)
- Vehicle shares between two and three wheelers
- Pkm shares for different public transport modes (e.g. due to the construction of urban rail)
- Modal shares of light road freight vehicles
- Evolution of the network extension for pipelines
- With endogenous powertrain selection (optional), discount rate and powertrain shares

Need for coherence for inputs on each AREA, SERVICE, MODE, VEHICLE CLASS and POWERTRAIN

ForFITS model
Data requirements

A wide set of default data are included in the ForFITS Excel file

These default data are used to characterizing several parameters of the ForFITS model

They concern the following input categories:

M Data absolutely required
Corresponding to the minimum data requirements

A Inputs expected to be introduced by the user
The default value in ForFITS is for guidance only
This category includes policy inputs that allow exploring different scenarios

B Input containing technical information (e.g. technological potential and costs by powertrain)
These data may be maintained unchanged
The defaults are set on the basis of research activities involving literature reviews and statistical analyses (further information on this is provided in the relevant section of the ForFITS manual)

C Inputs on structural characteristics of the model
Unless the users acquired significant experience with the model, these inputs shall not be modified: changes to these inputs will result in significant modifications to the model behaviour

ForFITS model
Data requirements

(3/3)

Full data requirements

TIME PERIOD ANALYZED	
Initial and final projection times	
Base year and final year	
INITIAL CONDITIONS	
Initial transport system	
Vehicle stock	
Vehicles	
Number of active vehicles	M
Powertrain group shares in each vehicle class	M
Travel	
Annual travel per vehicle	M
Load	
Vehicle load	M
Fuel consumption	
Vehicle fuel consumption	M
Fuel consumption gap by powertrain group	C
New vehicle registrations	
Base year	
Vehicles	
Newly registered vehicles	M
Powertrain group shares in each vehicle class	M
Fuel consumption	
Vehicle fuel consumption	M
Fuel consumption gap by powertrain group	C
Base year-5	
Vehicles	
Newly registered vehicles	M
Powertrain group shares in each vehicle class	M
Fuel consumption	
Vehicle fuel consumption	M
Fuel consumption gap by powertrain group	C
Base year-10	
Vehicles	
Newly registered vehicles	M
Powertrain group shares in each vehicle class	M
Fuel consumption	
Vehicle fuel consumption	M
Fuel consumption gap by powertrain group	C
Economic & demographic data	
Base year	
Population	M
GDP	M
GDP deflator	M

ECONOMIC AND DEMOGRAPHIC INPUTS (PROJECTIONS)	
Economic & demographic data	
Over time	
Population growth	M
GDP growth	M
TRANSPORT SYSTEM CHARACTERISTICS	
Transport system over time	
Passenger	
Area characterization	M
Passenger transport system index	A
Environmental culture index	A
Freight	
Constant parameters	
Haul length	B
Vehicle capacity ratios	B
Load factor ratios	B
Hauls per vehicle ratios	B
Base year	
Shares of tonnes lifted by good type	M
Shares of tonnes lifted by transport distance	
Short & medium distance / all	A
Short distance / short + medium	A
Very large distance / large + very large	A
Shares of tonnes lifted by transport zone	A
Over time	
Shares of tonnes lifted by transport zone	A
Tonnes lifted by haul distance	A
Shares of tonnes lifted by good type	A
Shares of tonnes lifted by large-freight sub-mode	A
PRICES AND TAXES (BASE YEAR AND PROJECTIONS)	
Fuel prices and taxes	
Fuel cost	
Base year	M
Over time	M
Fuel taxes	
Base year	M
Over time	M
Road pricing	
Cost of vehicle-km	A
FUEL CHARACTERISTICS (BASE YEAR AND PROJECTIONS)	
Fuel characteristics: CO2 emission factors	
Base year	M
Over time	A

FUEL CONSUMPTION (PROJECTIONS)	
All modes but air, NMT and pipelines	
Fuel consumption characteristics	
Index of performance	A
Fuel consumption characteristics by powertrain	
Passenger two wheelers	B
Passenger three wheelers	B
Passenger LDVs	B
Passenger vessels	B
Passenger large road	B
Passenger rail	B
Freight two wheelers	B
Freight three wheelers	B
Freight LDVs	B
Freight vessels	B
Freight large road	B
Freight rail	B
Air transport	
Fuel consumption per km	A
Pipelines	
Energy consumption per km	A
TECHNOLOGY CHOICE (PROJECTIONS)	
Powertrain technology choice switch	
Choice switch (endogenous / exogenous)	M
Discount rate	M
A) EXOGENOUS TECHNOLOGY CHOICE INPUTS	
Powertrain technology & ICE fuel: shares	
Powertrain technology	M
ICE fuel	M
B) ENDOGENOUS TECHNOLOGY CHOICE INPUTS	
Powertrain technology & ICE fuel: availability	
Powertrain technology	M
ICE fuel	M
Vehicle costs by powertrain group	B
VEHICLE & POWERTRAIN COSTS (PROJECTIONS)	
All modes but air, NMT and pipelines	
Vehicle costs by powertrain group	
Passenger modes	A
Freight modes	A
Air transport	
Air vehicle cost (base year)	B
Air vehicle cost (over time)	B
MODAL SHARES (EXOGENOUS PROJECTIONS)	
Modal shares	
Modal shares between 2- and 3-wheelers	M
Pkm shares in public transport modes	M
Vehicle shares in light road freight modes	M

VEHICLE CLASSES (EXOGENOUS PROJECTIONS)	
Vehicle shares within modes & sub-modes	
Personal passenger two wheelers	A
Personal passenger three wheelers	A
Personal passenger LDVs	A
Personal passenger vessels	A
Public passenger NMT	A
Public passenger two wheelers	A
Public passenger three wheelers	A
Public passenger LDVs	A
Public passenger vessels	A
Public passenger large road	A
Public passenger rail	A
Air passenger	A
Medium road freight vehicles	A
Heavy road freight vehicles	A
Freight two wheelers	A
Freight three wheelers	A
Freight LDVs	A
Freight vessels (maritime/deep sea)	A
Freight rail	A
Freight air	A
Freight pipelines	A
OTHER INPUTS (PROJECTIONS)	
Pipelines	
Distance travelled/network extension	M
Crew costs	
Crew cost per day (base year)	B
Crew cost per day (over time)	A
DEMAND GENERATION PARAMETERS	
Passenger	
Drivers as fucntions of GDP per capita	
Personal passenger vehicles (PPV) per capita	C
Pkm share on PPV in PPV + public transport	C
Pkm share on air mode in total pkm	C
People per active bike	C
Personal vessels (boats) per capita	C
Environmental culture multipliers	
Personal passenger vehicles (PPV) per capita	C
Personal passenger LDVS	C
Pkm share on PPV in PPV + public transport	C
Pkm share on air mode in total pkm	C
People per active bike	C
Vehicle travel cost multipliers	
Personal passenger vehicles (PPV) per capita	C
Personal passenger LDVS	C
People per active bike	C
Personal vessels (boats) per capita	C
Elasticities as functions of GDP per capita	
Annual personal vehicle travel to cost of driving	C
Pkm on public transport vehicles to cost of driving	C
Pkm on air vehicles to cost of driving	C
Freight	
Drivers as fucntions of GDP per capita	
Share of light vehicles in total road freight	C
Elasticities	
Tkm to the cost of tkm	C
Load factors to the cost of tkm	C

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ForFITS users

Who may be interested in using ForFITS?

- Someone willing to understand the transport system he is concerned about (typically a geographical region), its impacts in terms of energy consumption and CO_2 emissions
- Someone having access to a sufficient amount of statistical information
- Someone having some degree of specific competence (transport, transport policies, energy policies, environmental policies)
- Someone having sufficient financial means to support his/her ambitions
- Someone from…
  - a national administration and/ore a local government
  - an Inter-Governmental Organization
  - a Non-Governmental Organization
  - an Academic institution and/or a consulting company
  - the industry sector (company/corporation, industry association)

UNITED NATIONS
ECONOMIC COMMISSION
FOR EUROPE

Links and contact information

Links

Model download/UNDA project page
http://www.unece.org/trans/theme_forfits.html

User manual, including methodological information
http://www.unece.org/trans/forfits_user_manual.html

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