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Mobility, Vehicle fleet, Energy use and Emissions forecast Tool (MOVEET)

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Abstract

MOVEET is a System Dynamic based analytical tool that addresses the policy problems related to transport and climate change. The tool is capable of estimating transport demand and emissions, as well as forecasting the impacts of policy and technological measures in transport-related sectors, covering all transport modes from the different regions in the world up to 2050. The model consists of 57 regions, many of them representing single countries, i.e. all the European countries and other world major economies. In the model, we consider all transportation modes (road, air, rail, and maritime) that interact through four interrelated modules: Transport Demand, Fleet, Environmental, and Welfare.

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Keywords: transport demand; emissions; energy use; vehicle fleet size; welfare; consumer surplus; world transport model

1. Introduction

Transportation models play a crucial role in assessing the implementation schemes of carbon abatement measures. More precisely we need a policy assessment model that is designed to study the effects of different transport and environment policies on the emissions of the transport sector in Europe. The unquestionable importance of energy-intensive sectors, the prominent effect that the Kyoto Protocol could have on them, and the need of a reliable tool to support policy making, motivate the development of models specifically addressing these sectors.

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The interest in having good sector-wise details is also justified (amongst other reasons) by the necessity of estimating with accuracy sector-wise marginal abatement curves at global level. Introducing technology characterization on a sector basis helps in the creating alternative scenarios assuming accelerate technology substitution and analyzing the impact of these changes over a baseline technological projection, not only within the European markets, but also at a global level.

In this paper, we present the concept behind MOVEET model and provide example of its potential applications.

Firstly, we show results of the baseline projection. These results will be compared to other transport outlooks that are produced by the different world institutions and bodies. Secondly, we demonstrate the impacts of policy and technological measure implementation. We will analyze the impacts of four types of measures, i.e. improvement of fuel quality, implementation of emission trading in Europe, application of additional motorway road toll and improvement of carrying capacity of heavy duty vehicles (HDV).

2. Model Overview

The MOVEET model has been developed at Transport & Mobility Leuven. MOVEET is a System Dynamic based analytical tool that addresses the policy problems related to transport and climate change. The tool is capable of estimating transport demand and emissions, as well as forecasting the impacts of policy and technological measures in transport-related sectors, covering all transport modes from the different regions in the world up to 2050. The model consists of 57 regions of the world, many of them representing single countries, i.e. all the European countries and other world major economies. In the model, we consider all transportation modes (road, air, rail, and maritime) that interact through four interrelated modules: Transport Demand, Fleet, Environmental, and Welfare.

It is the first transport model that:

- generates and project demand endogenously for the whole world regions,
- splits this demand into the different most intensive energy consuming modes of transport,
- makes use of the existing fleet data and project the world fleet dynamic in high level of detail into the future, and
- produces global impact assessment in term of emission and welfare.

The model is partial equilibrium. Its main assumption is that economic and demographical growth will incite transport demand. Utility maximization is the main principle used in breaking down further transport demand into the different modes as well as in breaking down the vehicle fleet into the different types in the purchasing decision making.

MOVEET's four modules exchange information in order to provide a consistent picture of the different aspects modelled. Within the transport demand module, motorised transport demand is endogenously generated and segmented according to several dimensions (e.g. national/international, long or short distances, etc.). In addition, the choice of mode and road type for each specific context is carried out taking into account demand-supply interaction. Transport demand by mode is then used as input for calculating vehicle-kilometres by type and technology according to the fleet structure estimated in the fleet module. In the environmental module, fuel consumption and emissions are calculated on the basis of vehicle-kilometres (from the fleet module) as well as average speed of each transport mode (from the demand module). Finally, the welfare module takes its input from both the transport module and the environmental module in terms of consumer utility and, respectively, external costs.

In the following sub-sections, we give a more detailed explanation of each module. We will show that MOVEET's innovative character lies in four main aspects, namely the endogenous transport demand generation and split which are based on two distinct circumstances namely 'macro' and 'micro', the inclusion of congestion effects, the detailed level of vehicle fleets' techno-economic features and the calculation of welfare impacts which take into account consumer surplus, external effects and distortion effects due to taxes and subsidies.

2.1. Transport demand module

MOVEET distinguishes transport demand into continental and intercontinental, each having its own specific and independent demand generation procedure.

MOVEET generates its motorized 'continental' transport demand endogenously. At first, based on 'macro' context, the model splits this demand into:

- geography based (national vs international),
- distance based (long vs short),
- purpose based and,
- period based (peak vs off-peak) dimensions.

The 'macro' context means this split is not determined by individual (transport user) decisions. Rather, the demand generation phase is modelled using mathematical equations that depend on a set of policy-sensitive variables coming from exogenous data such as population, trade, GDP, or from other parts of the model i.e. motorization rate.

Secondly, the model classifies demand further according to 'micro' decisions, namely into transport modes and road types. In this second step we use a discrete choice algorithm which is mainly based on the generalized costs of transport for each alternative.

Total motorized passenger demand generated by zone is estimated in three steps: first, demand at the base year is estimated, then the estimated trend is applied to reproduce the development over the simulation period, finally a multiplier parameter is applied for splitting demand depending on the purpose.

The overall process for the generation of total demand by purpose over the simulation period is based on two main drivers: GDP per capita and motorization rate.

In general terms, the equation applied is:

$$Pdem_{zm}^{T} = \left(\alpha_1 \cdot \frac{GDP_z^{T0}}{POP_z^{T0}} + \alpha_2 \cdot \frac{Car_z^{T0}}{POP_z^{T0}} + \gamma_1\right) \cdot \left(\alpha_3 \cdot \frac{\frac{GDP_z^{T}}{POP_z^{T}}}{\frac{GDP_z^{T0}}{POP_z^{T0}}} + \alpha_4 \cdot ln\left(\frac{\frac{Car_z^{T}}{POP_z^{T}}}{\frac{Car_z^{T0}}{POP_z^{T0}}}\right) + \gamma_2\right) \cdot \beta_{zm} \quad (1)$$

Where:

$Pdem_{zm}^{T}$= number of passengers-km at the year T from the zone z for the purpose m

GDP_z^{T0}/POP_z^{T0} = Gross Domestic Product per capita at base year in region z

Car/POP = Car ownership (number of cars per 1000 inhabitants)

T = Year

T_0 = Initial (base) year of the simulation

z = region

m = purpose

α_i, γ_i= parameters to be calibrated

β_{zm} = multiplier parameter for splitting demand by purpose m (differentiated by zone z)

After generating total demand for a particular zone and purpose, the module splits demand between intra-regional or national at most cases and inter-regional or international demand. One of the most significant drivers of this split is the trend of the generalized cost of long distance modes, namely train and air. If inter-regional travels become cheaper compared to the baseline e.g. for fiscal/pricing measures, a larger share of total demand is expected to be international.

A similar approach where travel generalized cost is the endogenous element used, is applied further for the segmentation of intra-regional demand into the distance travelled namely between short distance and long distance. It is assumed that if long distance travels become cheaper a larger share of total demand is expected to be long-distance, but this effect will be smoothed in case the short distance travels become cheaper as well.

Finally, the module splits demand into urban and non-urban passengers-km and into peak and off-peak period.

The amount of demand belonging to the urban context is supposed to be influenced by changes in travel costs as well as in motorization rate, because car ownership gives rise to sprawling and therefore to a larger share of non-urban trips.

Traffic in peak time and off-peak time does not depend on the variables simulated in the model and it is not expected that the kind of policy measures that the tool is designed to simulate can change it significantly. Therefore simple fixed share are implemented.

Freight transport demand generation applies the same approach described for passenger demand, even though other variables are considered as drivers of tonnes-km calculation: at the upper level freight demand is the result of a multiplicative model based on the value of external trade, GDP and generalized cost of transport.

Still, total motorized demand is estimated at first at the base year, then the estimated trend is applied to reproduce the development over the simulation period, finally a multiplier parameter is applied for splitting demand depending on the cargo type.

In general terms, the equation applied is:

$$Fdem_{zc}^{T} = \left(\alpha_{1_z} \cdot GDP_z^{T0} + \alpha_{2_z} \cdot Trade_z^{T0} + \gamma_{1_z}\right) \cdot \left(\alpha_{3_z} \cdot \frac{GDP_z^{T}}{GDP_z^{T0}} + \alpha_{4_z} \cdot \left(\frac{Trade_z^{T}}{Trade_z^{T0}}\right) + \gamma_{2_z}\right) \cdot \beta_{zc} \quad (2)$$

Where:

$Fdem_{zc}{}^{T}$= number of tonnes-km at the year T from the zone z for the cargo type c

$GDP_z{}^{T}$ = Gross Domestic Product in region z at the year T

$Trade_z{}^{T}$ = Trade within the same macro-region (in terms of export, in value) at the year T

T = Year

T_0 = Initial (base) year of the simulation

z = region

c = cargo type

$\alpha_{N\,z}$, $\gamma_{N\,z}$ = parameters to be calibrated, by region z

β_{zc} = multiplier parameter for splitting demand by cargo type c (differentiated by zone z)

Demand is further split into intra-regional, in most cases national and inter-regional or international demand. Here, the trend of the generalized cost of all long distance modes is supposed to have some influence on the split of total freight demand among intra-regional (in most cases national) and inter-regional (international) trips. Accordingly the model is sensitive to changes of costs due to e.g. policy measures. Therefore, in the model the share of inter-regional trips is computed as a function with sensitivity to the change of of the generalized cost of the different inter-regional trips.

The same as for passenger trip generation, for freight the demand module also calculates shares of short and long distance demand at intra-regional level. Again, the explanatory elements for this segmentation are mainly outside the domain of model (e.g. land use) and the relative trend of generalized cost for long distance and short distance trips is supposed to play a role: the effect is simulated in the same way as for passenger.

At last the module estimates the amount of urban/non-urban demand at short distance level as well as the breakdown according to the peak and off-peak periods. In both segmentations simple fixed shares are implemented since the share of urban and non-urban as well as peak and off-peak demand depends on the location of production and retailers as well as on logistics which are exogenous to the model.

After demand has been generated according to the "aggregate" dimensions, those aspects that can be interpreted as the result of individual decisions, i.e. the choice of mode and of network type, are modelled.

Mode split is based on random utility approach, i.e. it is assumed that the consumer prefers the alternative with the highest utility over the others (utility maximization).

$$U_{nj} = V_{nj} + \varepsilon_{nj} \quad (3)$$

where:
V_{nj}= the deterministic part of the utility
ε_{nj}= the random term

A nested logit algorithm is used to compute mode shares. Such algorithm is assumed, i.e. there has not been a process of statistical estimation based on choice data to make a selection between alternative models and alternative specifications. Indeed, this estimation process would need a large amount of data and resources to be carried out. Therefore, also the value of the parameters used in the algorirthm for the various segments come from literature (e.g. value of time) or are the result of a calibration process (see documentation on calibration).

The sequence of choice modelled through the nested logit in the demand model is: first between transport modes and secondly, provided that a road mode is chosen, between road type. An example of the applied two-level nested logit structure is given in the following Figure 1.

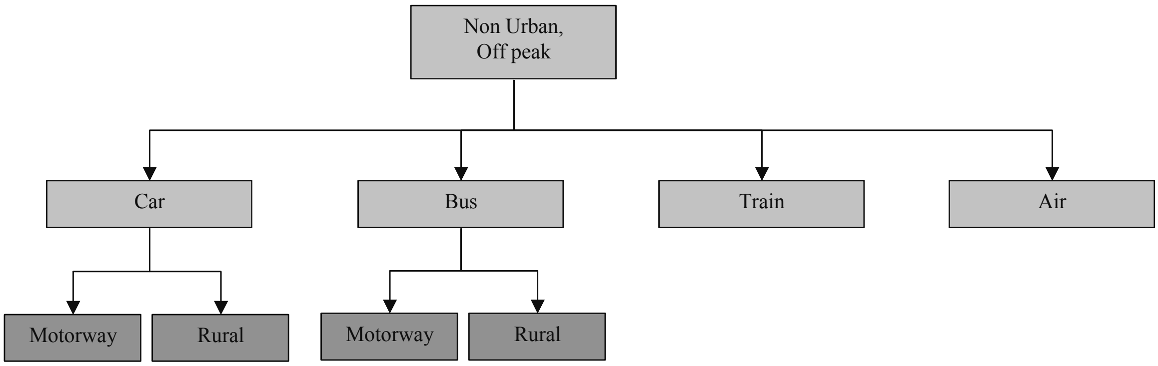

Figure 1Example of nested logit tree structure

The deterministic part of the utility function consists mainly of generalized cost, i.e. transport cost plus time weighted with value of time. An additional term is used, representing reliability and/or extension of transport network and consequent availability of a specific mode. This term has been added to the definition not only for taking into account aspects not covered by the cost and time terms, but also for computational reasons: the value of this terms has been set in order to calibrate the elasticity of the model and to maintain the magnitude of the utility function of the logit model within an acceptable range for Vensim (which cannot handle too large or too small numbers) and large enough that the inclusive values do not change sign due to the log transformation.

Intercontinental demand modelling is generated in a more simple way. We define this demand as transport activity between zones related to different continents, namely macro-areas, where inland modes cannot physically be used or are unrealistic alternatives. In general, the algorithm for estimating intercontinental demand is a two-steps procedure: the model generates the overall inter-continental demand in each macro-region by means of a regression function that is based on ‘macro’ circumstances variables such as GDP or trade. MOVEET then assigns this demand into the different destinations with some attraction measure, i.e. producing a simple O/D matrix between regions (countries) to macro regions. As in the case of continental demand, in the second step the model further splits intercontinental demand according to ‘micro’ decisions, i.e. into transport modes and road types.

2.2. Fleet module

The fleet module receives the following inputs from the demand module: passengers-kilometres (pkm) distinguished by zone, purpose, region, distance, urban level, time period, mode and network, tons-kilometres (tkm) distinguished by zone, car type, region, distance, urban level, time period, mode and network, and average load factor by demand segment.

In return, this module sends back the following information to the demand module: total amount of fleet per mode and zone, total vehicles-kilometres by demand segment, vehicle-kilometres (vkm) per vehicle type and demand segment, operating cost per vehicle type, feeds the environmental module with: vkm by vehicle type and demand segment, fleet structure by vehicle type and technology (emission standard), usage by vehicle type and technology, and the welfare module which includes: vkm by vehicle type and demand segment, taxes and subsidies.

The main goal of the fleet module is to convert aggregate estimations of transport demand, in terms of pkm, tkm and/or vkm, into a more detailed vehicle classification and generation (cohort) which directly relates to technology in terms of vehicle performance and characteristics, fuel use and emissions.

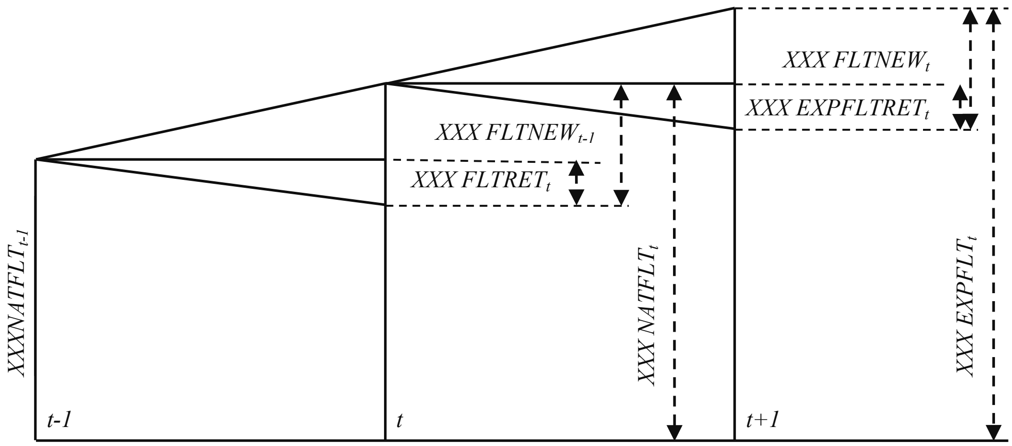

Figure 2: capacity planning

Figure 2 shows graphically how the capacity planning procedure works. In any year ***t***, the fleet existing in ***t-1***, minus the fleet retired in ***t***, equals the fleet in ***t*** minus the new fleet planned in ***t-1*** (to be added in ***t***):

$$XXX\ NATFLT_{allc,xxx\ vehicles,t-1} - XXX\ FLTRET_{allc,xxx\ vehicles,t} = XXX\ NATFLT_{allc,xxx\ vehicles,t} - XXX\ FLTNEW_{allc,xxx\ vehicles,t-1} \quad (4)$$

In ***t*** also, the existing fleet minus the fleet to be retired in ***t+1*** equals the expected fleet in ***t+1*** minus the new fleet planned in ***t*** (note that all the "expected" values are calculated in ***t***):

$$XXX\ NATFLT_{allc,xxx\ vehicles,t} - XXX\ EXPFLTRET_{allc,xxx\ vehicles,t} = XXX\ EXPFLT_{allc,xxx\ vehicles,t} - XXX\ FLTNEW_{allc,xxx\ vehicles,t} \quad (5)$$

For the purpose of studying the effects of different transport and environment policies on the emissions of the transport sector, we distinguish transport modes into seven vehicle categories which are further split into types, i.e. road passenger (11 types), road freight (8), rail passenger (6), rail freight (5), air passenger (7), air freight (3), and maritime freight (22). Vehicles types have a direct relationship with techno-economic characteristics, represented by vehicle size, gasoline type, specific use, and/or propulsion system.

2.3. Environmental module

In the environmental module fuel consumption emissions are calculated for all modes. In general, the fuel consumption and the emissions are calculated by multiplying disaggregated vehicle kilometres, calculated in the demand module, by an appropriate factor for the pollutant or fuel of interest. Alternatively, for some pollutants like CO_2 the vehicle kilometres are sometimes used to first calculate the energy or fuel consumption and then perform the multiplication by an appropriate emission factor.

For road and rail modes, emissions such as CO_2, H_2O, SO_2 are assumed to be proportional to the fuel consumption. The pollutants considered in the air transport module are CO_2, H_2O, SO_2, NO_X, CO and HC. Emissions of NO_X, CO and HC depend not only on the fuel consumption but also on flight altitude and other operation conditions (Sutkus et al., 2001, and 2003). For maritime transport, average daily consumption of bunker fuels per vessel is calculated by taking into account all changes in average sailing speed, with respect to the design speed and the design fuel consumption driven by changes in the freight rates. The total yearly demand of bunker fuels by vessel class is obtained by multiplying the average bunker consumption by the ratio between the active fleet divided and the average ship tonnage (a proxy of the number of ships). CO_2 emissions by vessel class are the result of multiplying marine bunker consumption by the carbon content of the fuel.

We ensure demand-supply interaction through the inclusion of three means of congestion effects, namely the use of speed-flow functions of US Bureau of Public Roads (BPR) in road transport, assumption of service reliability reduction due to network saturation in non-road modes, and the use of the Mohring effect for public transport. For road modes, in principle we use the BPR speed-flow functions to calculate the congestion effects that are used as the average travel time multiplier. For non-road modes and public transport, we implement a simple mechanism such as for example when non-road modes demand grows beyond a given capacity threshold, a negative impact on service reliability is caused, which is part of the (dis)utility function used for mode split.

2.4. Welfare module

This module takes inputs from the demand segmentation, energy demand and emissions from the rest of the model and is based on the nested-logit (NL) tree structure used in the demand module. In this 'top-down approach' structure, the module calculates the absolute values of each element: consumer surplus, external effects, distortion effect due to taxes and subsidies.

The nested logit tree structure in the demand module of MOVEET consists of two to three levels of choices. Consumer surplus is calculated using the Logsum approach (De Jong et al, 2005) based on Ben-Akiva and Lerman, 1979. Consumer surplus (CS) is derived from a Marshallian (uncompensated) demand curve. In case of price change, this Marshallian curve captures only the substitution effect (from one good to the other) and not the income effect (more or less purchasing power for all goods because of an expansion or contraction of the budget).

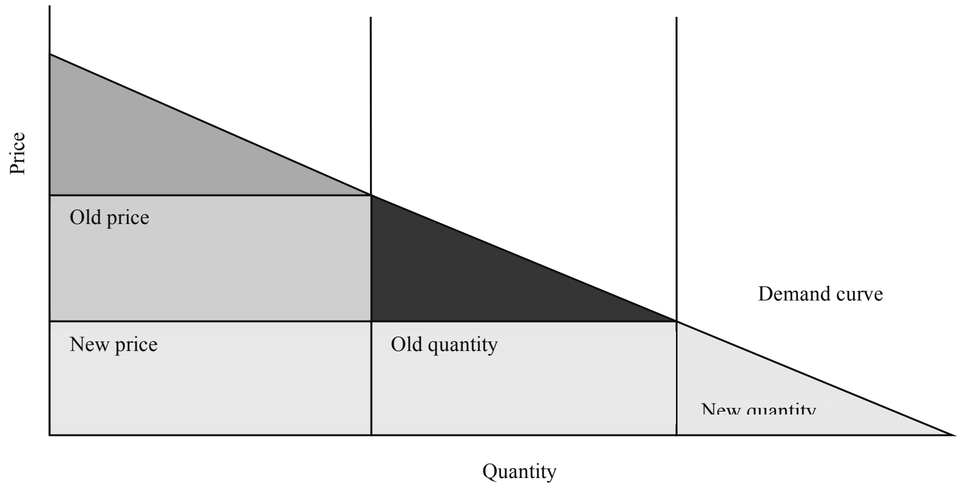

Figure 3: Marshallian demand curve

According to De Jon et al. 2005, a person's consumer surplus is the utility in monetary terms that a person receives in the choice situation. The decision maker $\boldsymbol{n}$ chooses then the alternative $\boldsymbol{j}$ that provides the greatest utility ($\boldsymbol{U_{nj}}$). Thus, consumer surplus, in monetary terms, is an utility maximizing function divided by the marginal utility of income ($\boldsymbol{\alpha_n}$):

$$CS_n = \frac{1}{\alpha_n} \cdot \max_j \left(U_{nj} \right)$$
$$\alpha_n = \frac{dU_{nj}}{dY_n} \quad (6)$$

where Y_n is the income of person n.

Utility is decomposed into an observed and unobserved (random) component:

$$U_{nj} = V_{nj} + \varepsilon_{nj} \quad (7)$$

The expected consumer surplus is given by the following equation:

$$E\left(CS_n\right) = \frac{1}{\alpha_n} \cdot E\left(\max_j \left(V_{nj} + \varepsilon_{nj}\right)\right) \quad (8)$$

where the expectation is over all possible values of the term ε_{nj}.

If each ε_{nj} is of extreme value and utility is linear in income, the the expectation becomes:

$$E\left(CS_n\right) = \frac{1}{\alpha_n} \cdot \ln\left(\sum_{j=1}^{J} e^{V_{nj}}\right) + C \quad (9)$$

where C is an unknown constant representing the fact that the absolute value of utility cannot be measured.

The term between parentheses is the denominator of a logit choice probability function:

$$P_{nj} = \frac{e^{V_{nj}}}{\sum_{j=1}^{J} e^{V_{nj}}} \quad (10)$$

Thus, the expected consumer surplus in a logit model is simply the log of the denominator choice probability and this is often called as the “logsum term”.

Still according to De Jong et al. 2005, under the standard interpretation of distribution of errors, $E(CS_n)$ is the average consumer surplus in the subset of people who have the same representative utilities as person n. Total consumer surplus in the population can be calculated then as the weighted sum of $E(CS_n)$ over a sample of decision makers, with the weights reflecting the number of people in the population who face the same representative utilities as the sampled person.

The change in consumer surplus is calculated as the difference between the calculation of $E(CS_n)$ under the conditions before the change and the calculation of $E(CS_n)$ after the change (e.g. introduction of policy):

$$\Delta E\left(CS_n\right) = \frac{1}{\alpha_n} \cdot \left(\ln\left(\sum_{j=1}^{J^1} e^{V_{nj}^1}\right) - \ln\left(\sum_{j=1}^{J^0} e^{V_{nj}^0}\right) \right) \quad (11)$$

where the superscripts 0 and 1 refer to two different situations (for instance, before and after, or two alternative scenarios). The results of the welfare module can only make sense when comparing two different scenarios.

MOVEET considers externalities in term of pollution, accident, noise, and wear and tear. The welfare module takes generalized prices calculated in the demand module. The private time cost for each vehicle-kilometre is incorporated. The total time costs for all vehicle-kilometres (congestion cost) have thus already been taken into account in the calculation of the consumer surplus through the utility function in demand split model. As a result, no further correction for congestion needs to be made for the welfare calculation.

Finally, to estimate the effect of distortion, all taxes and value added tax (VAT) are calculated and summed up for all lowest nodes of the nested-logit tree. Apart from taxes and VAT, the cost of public funds is calculated taking into account the regime of tax redistribution.

3. Other model assumptions

The most important assumptions of the model relate to how society behaviour in relation to transport system is represented in the model, and especially in the demand module. The demand module is a schematic representation of reality which relies on certain assumptions of how people and firms behave "on average". The key underlying assumption in this module is the distinction between 'macro' and 'micro' circumstances as explained previously in sub-section 2.1.

As MOVEET is not a network based model, further important assumptions can be found in relation to the representation of transport infrastructure network. The first type of assumption in this sense concerns the network capacity. In order to represent network capacity constraint, we make proxies of network capacity of the different transport modes to estimate congestion effects that in turn affect the mode or network attractiveness impacting the users' choice.

The second type concerns the segmentation of trip into the different categories. For example we assume that all interregional demand use motorway network only, that interregional and intraregional long distance demand is evenly distributed between peak and off-peak period, etc. These assumptions, resulting in the simplification of the network, are based on several studies of the European Commission, for example in the development of TREMOVE model (De Ceuster et al., 2007), REFIT (van Rooijen et al., 2008) and iTREN-2030 (Schade & Krail, 2010) projects. In those studies and projects, transport demand from European network based models such as SCENES and TRANS-TOOLS were aggregated and transformed into data set used by non-network transport model of TREMOVE.

Finally, as the model aims to cover all 57 zones of the world, the unavailability of data is also a main issue. In order to complete the data set for each zone we made assumptions based on studies over the relevant zones or in its surrounding area. For each assumption taken, we have conducted a statistical analysis and check in order to guarantee comparable model reactions of the concerned zone with regards to the other (surrounding) zones that have more or less similar socio-demographic and or economic characteristics.

4. Baseline scenario

4.1. Baseline scenario background

We developed the baseline scenario using several main exogenous demographic and economic assumptions that are in line with the Transport White Paper 2011 of the European Commission (EC, 2011). Based on these resources, we can expect that world population to grow steadily from 6.3 billion people in the year 2005 to 8.9 billion in 2050. Expressed in constant rate of euros of 2005, the total world GDP would rise from 31.5 T€ in 2000 to 128 T€ in 2050.

Oil price would rise according to World Energy Outlook (International Energy Agency, 2009) from 100 $/bbl in 2010 to 120 $/bbl in 2030 to 300 $/bbl in 2050. We also assume that carbon tax in the 33 European countries will increase linearly from 1 €/ton CO_2 in 2013 to 38 €/ton CO_2 in 2050. This tax is assumed to be zero in the rest of the world.

4.2. Preliminary results of the baseline scenario

Based on the above assumptions the world passenger transport demand will increase by 120% between 2005 and 2050 from 34.2 trillion passenger-kilometres (pkm) to 73 trillion pkm. Freight transport demand is also expected to grow remarkably, increasing globally from 26.3 trillion ton-kilometres (tkm) in 2005 to 50.8 billion tkm in 2050. More than 75% of the world freight demand is maritime shipping. The shares of road and rail freight are comparable during the whole projection period, i.e. around 10%-11% of the total each. The share of the inland shipping volumes would remain slightly higher than 2% during the whole period. Air freight is expected to grow as well although the volumes are negligibly in comparison with other modes.

The world fleet of passenger cars will double, changing from 735 million vehicles in 2005 to 1400 million vehicles in 2050. Most of them (around 85%) are gasoline powered. New vehicle technologies (electric and hydrogen based) begin to appear only from 2030 onwards and they are expected to account for less than 0.5% of the global fleet by 2050.

In the case of road freight vehicles, the model foresees a growth in the global fleet from 107 million in 2005 to 160 million vehicles in 2050. More than 40% of that fleet are vans. The share of heavy duty trucks will remain around one third, while the rest of the fleet, i.e. around one quarter are light duty trucks.

Rail transport growth in transport volumes will double the amount of rail vehicles, changing from 297 thousand vehicles in 2005 to 622 thousand in 2050. Locomotives, which currently account for around 74% of the global fleet, will increase their share to nearly 80% by 2050, while the amount of railcars is expected to diminish remarkably (from 26% to 20% of the world total). Around 58% of the global rail fleet will be diesel powered, being most of the remaining fleet electric-powered. Obsolete steam powered locomotives disappear completely around 2020.

Maritime transport volumes are expected to grow fast, from 901 million deadweight tonnage (dwt) in 2005 to 2027 million dwt in 2050. Oil tanker tonnage, remaining one third of the world fleet, increases from 287 million dwt in 2005 to 1002 million dwt in 2050.

The rapid growth of air transport demand induces a growth in the amount of aircrafts in service from 13410 in 2005 to around 21335 aircrafts in 2050. Most of these (91% in 2005, 86% in 2050) are for passenger transport. With regards to aircraft size, there are no significant changes to be expected. Narrow body aircraft make up most of the fleet (51% in 2005 vs. 58% in 2050). The share of wide-body and regional jets is expected to be around 28% of the total, while jumbo jets account for approximately 7.5% of the global fleet. In terms of propulsion technology, most aircrafts (88% in 2005 and 93% in 2050) are expected to be jet engine.

The total energy use will grow from 2100 million toe in 2005 to around 3700 million ton of oil equivalent (toe) by the year 2050, which is a yearly increase of 1.7%. As a comparison, the baseline scenario of IEA/OECD (International Energy Agency, 2008) that has a similar world economic background, predicts a growth of transport energy use from around 2200 million toe (2005) to 3855 million toe (2050). The energy use from road passenger modes will increase by only 0.8% per year while energy use from sea freight and air passenger transport show the strongest growth with yearly 5.1% and 3.0% respectively. It is expected that the share of road modes will decrease but remains higher than 50% during the whole period.

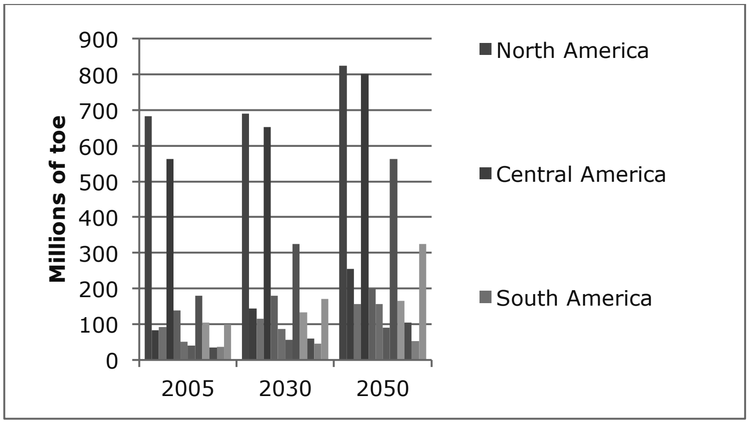

Figure 4 Transport energy use in the world

Contribution of North America and Europe regions to the energy use of transport remains the highest but will decrease significantly from nearly 60% in 2005 to 44% in 2050. China's share will almost double during the observed period, from 8% in 2005 to 15% in 2050 meaning a yearly growth rate of 4.8%. The South West Asia region with India as its motor will come up as the region with the strongest yearly growth rate (5%). Central America, Africa and South East Asia have almost the same yearly growth rates of 4.5%.

5. Example of alternative scenarios

5.1. Example 1: improvement of fuel quality

In this policy test the carbon content of gasoline and diesel is reduced worldwide by 3% during the whole simulation period, at the cost of increasing the corresponding fuel prices by 3%. That increment is arbitrary since the cost of improving fuel quality cannot be estimated with the MOVEET model. As a result of this policy, transport demand would be reduced due to the increments in transport costs. The 3% increment in the cost of fuels would result in an increment of the total average car cost from 0.3% to 0.4%. Therefore, the impact of this policy on transport demand would be quite small. Passenger car demand is expected to be reduced by less than 0.1%. On the freight side, the increase of the total average truck cost is expected to be even smaller (around 0.1%), resulting in negligible variations of truck transport demand.

Table 1 Global CO_2 emission changes with respect to the baseline simulation (%)

Transport mode	2000	2010	2020	2030	2040	2050
Road passenger	-3.09	-3.11	-3.11	-3.13	-3.14	-3.15
Road freight	-0.73	-0.67	-0.63	-0.64	-0.63	-0.60
Rail	0.00	-0.01	0.01	0.02	0.03	0.04
Maritime	0.00	0.00	0.00	0.00	0.00	0.00
Air	0.00	-0.01	0.01	0.01	0.01	0.01

Since the impacts of this policy on transport demand are projected to be small, the size and composition of the vehicle fleets would not be affected significantly. Despite this, the use of cleaner fuels would lead to a decrease in emission levels. The policy is assumed to affect only to fuel properties and not to energy efficiency, therefore energy consumption levels would be the same as those calculated in the baseline scenario. Most of the emission abatement would take place in the road passenger transport sector, where emissions would be lowered around 3% annually with respect to the baseline scenario. In the case of road freight, the emissions would be reduced approximately by

0.65% between 2000 and 2050. Rail-related emissions would increase slightly during the simulation period, being 0.04% higher in 2050 in comparison to the baseline scenario. The emissions from other modes would remain virtually unchanged.

Improvement of fuel quality shows positive effects for welfare with regards to the baseline scenario. The increase of consumer surplus which is mainly due to the decrease of transport demand and the decrease in the total externality costs due to the fall in the CO_2 emission contribute the most to this positive welfare impact.

5.2. Example 2: emission trading

We have also implemented a policy consisting of the inclusion of all transport modes in a Euro-wide ETS from 2012 onwards. We set the carbon value initially to 200 €/ton CO2 in 2012 and increase it yearly by 5 €/tCO_2 up to the year 2050. The carbon values for the rest of the world remain equal to zero for the whole simulation period. As a result, the overall continental passenger demand in Europe is reduced by 0.9% in terms of pkm, while freight continental demand in terms of tkm is reduced by 0.2%.

In the case of road passenger cars, globally there would be a small decrease with respect to the baseline simulation, excepting the number of light diesel vehicles, which would experiment a stronger decrease ranging from 2% (in 2020) to 4.7% (in 2050). In Europe, this effect is stronger, i.e. from 0.06% (2020) to 5.6% (2050). The number of road freight vehicles would also be reduced at the global level, around 0.25% annually in comparison to the baseline scenario. In Europe, this policy would also lead to an increment of around 3% by 2050 in the number of rail vehicles.

Freight transport demand would also be shifted towards the maritime mode. As a result, initially (by 2020) there would be a slight increase in the tonnage for all vessel types. Towards the end of the simulation period the fleet sizes are expected to be slightly lower than in the baseline case.

Air passenger transport demand is expected to decrease as a result of the implementation of the ETS. Overall, the number of passenger aircraft is therefore expected to be smaller especially than in the baseline simulation, excepting a small increase in the number of passenger narrow-body jets by 2050. With regards to air freight, there would not be noticeable changes in comparison to the baseline scenario. Within the EUR region this policy would reduce the total number of aircraft by approximately 4% annually with respect to the baseline simulation.

With regards to energy use at world level, the maritime transport sector is the only one that would experience a significant reduction in energy consumption levels in the short term (21.34% in 2012), but the reduction in energy demand would be much smaller by 2050 (0.17%). Energy consumption from air transport is also expected to be reduced by more than 1% each year.

At the European level, the policy would achieve a reduction in energy consumption of approximately 2.5% per year during the whole simulation period. Reductions would be higher in the road passenger and freight transport sectors (2.09% and 1.66% respectively by 2050) and in the air transport industry (3.09% reduction in 2050 with respect to the baseline). Energy use would increase only in the case of rail, up to 2.97% by 2050. The effect of this policy on global emissions would follow a similar path to the changes in energy use, especially in transport sectors dominated by a single fuel such as maritime and aviation. Globally, this policy is expected to decrease emissions with respect to the baseline simulation by 2.75% in 2012 and 0.36% by 2050. Within Europe, the policy would lead to a reduction in CO_2 emission of 2.95% in 2012 in comparison to the baseline simulation. By 2050 the reduction is expected to reach 1.50%. Most of the reductions would be achieved within the air and road transport sectors. Only rail-related emissions would increase (3.08% in 2050).

The ETS scenario also gives positive welfare impacts in comparison to the baseline scenario. The main components of these positives impacts are the increasing tax revenue obtained from the payment of each ton of CO_2 emitted followed by an increase in consumer surplus mainly due to significant transport activity decreasing.

5.3. Example 3: application of additional motorway road toll

Two simulations have been made to test the model's elasticity with respect to tolls on motorways: one toll for passengers and another for trucks.

For passengers, an additional toll of 0.05 €/vkm has been implemented on motorways for cars from the year 2015 to 2050. As a result, overall car transport demand is slightly reduced with elasticity around –0.02 to –0.08 depending on the zone. The share of car vkm on the motorway network in EU27 countries is reduced from 13.1% to 11.6% at the year 2020.

For freight, an additional toll of 0.15 €/vkm for vans and 0.30 €/vkm for heady duty vehicles (HDV) has been implemented on motorways from the year 2015 to 2050. As a result, overall truck transport demand is slightly reduced with elasticity around –0.07 to –0.40 depending on the zone. The share of truck vkm on the motorway network in EU27 countries is reduced from 60.8% to 60.2% at the year 2020.

In total, the application of additional motorway road toll will give a positive welfare impact during the whole simulation period with regards to the baseline scenario. The increase in consumer surplus and the increase in tax income collected from the toll payment contribute relatively evenly to this positive impact.

5.4. Example 4: improvement of carrying capacity of heavy duty vehicles (HDV)

Improved freight logistics could be simulated within MOVEET by means of load factors modification. In particular, improved logistics can be introduced in the model as a direct impact on base load factors for road vehicles, differentiated by vehicle type. The model has been tested under the assumption that the ratio between load factor and carrying capacity is increased by 20% for HDV starting from the year 2015. As a result, the total amount of vehicle-km is reduced by 13% on average at European level at the year 2020. Overall demand transported by truck is increased by 4.1% at the same year, thanks to the reduction of average transport cost per tkm of about 17%.

As in other scenarios, improvement of carrying capacity will also give positive welfare impacts in comparison to the baseline scenario. The contribution of increasing consumer surplus is clear as more ton-kilometres can be transported by using the same number of vehicle fleets. The increasing tax income also contributes significantly to the positive welfare impact as more ton-kilometres induced by the carrying capacity improvement bring more road freight tax payment.

6. Elements of conclusion

MOVEET is a System Dynamic based analytical model to address policy problems related to transport and climate change that covers road, rail, air, and maritime modes for all world regions up to 2050. The model is able to forecast transport demand, vehicle fleet size, energy use and emissions from transport activity. The model also has the capacity to estimate the impact of welfare between the different future scenarios in the transport system.

The model has four main innovative aspects, i.e. the endogenous transport demand generation and split which are based on two distinct circumstances namely ‘macro’ and ‘micro’; the inclusion of congestion effects, the detailed level of vehicle fleets techno-economic features and the calculation of welfare impacts which take into account consumer surplus, external effects and distortion effects due to taxes and subsidies.

We have produced a MOVEET baseline scenario. Using similar scenario background as the EU Transport White Paper 2011, the results of MOVEET world energy consumption is comparable to IEA/OECD results. We use MOVEET to assess the different impacts of policies measures at different levels, i.e. world, regional (groups of regions or countries such as European Union) and national level. In particular MOVEET can assess the impacts of the following types of policy measure: policies related to vehicle technologies, policies related to the fuel quality, policies related to fiscal instruments in the transportation sector, policies related to traffic management, and policies related to maritime and air transport, where modal substitution is more limited and the international traffics are relatively more important.

Finally, MOVEET is not a network based transport model. It has some limitations such as the inability to forecast detailed impacts of policy intervention at location specific transport infrastructure. Another limitation is in relation to its nature as a partial equilibrium model: MOVEET does not take into account activities in other sectors than transport. As a consequence the welfare impacts captured by the model are not complete as it does not take into account the effects of transport policy measures in secondary markets.

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