A System Dynamics Energy Model for a Sustainable Transportation System

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ABSTRACT

The transportation sector is one of the most resilient to the shift away from oil. Policies have been put in place in different regions to introduce alternative fuels and reduce the road transportation heavy dependency on oil products and the related environmental impacts; results, however, are in most cases disappointing. The system is resilient and goes back to the historical dichotomy gasoline-diesel. If from a policy maker perspective, a system dynamics model of the automotive sector can lead to the development of effective policies to achieve sustainable mobility, from an energy company perspective, such a model could be used to analyze possible threats and design optimal adaptation strategies for a highly volatile and market that is always on the edge of starting a new major transition. The model here presented can serve both purposes, and the results obtained show how a similar instrument can really make the difference in highly dynamic sectors with ongoing major transitions.

KEYWORDS
System Dynamics, Decision Support System, Energy Crisis, Energy Modeling, Road Transport, Energy Sustainability, Environmental and Energy Policy Evaluation,

1. INTRODUCTION

The market of Energy and Oil Companies is continuously evolving. Strategic choices have to be taken according to a clear analysis of incumbent threats and to an evaluation of likely consequences of the undertaken actions.

It is thus necessary to identify the various actors or stakeholders in the business environment, or in other words to fully understand the different interconnected parts of this system, in order to be able to infer the possible future outcomes of today's choices. Understanding change and being able to identify it over time and "in time", means being able to react to possible overthrows in existing equilibrium by devising a strategy which is coherent with the implications of the new scenario and through which may be possible to achieve a competitive advantage. If, on one hand, systemically

understanding the present and being able to anticipate future trends have a fundamental role for these companies to be competitive on the market, on the other hand, these aspects have a vital importance for the environment and the society, with a particular significance in terms of the policies that the policy maker is called to put in place.

The transportation sector plays a fundamental role in many European countries' sustainable development policies: the White Book on Transports shows that they constitute 30% of the total EU energy consumption (which is 71% of the total EU oil use), with a 98% dependence on the oil sector; at the same time, the European Commission evidences the impossibility of postponing the international engagements in matter of environment, with particular reference to the commitments agreed with the Kyoto Protocol on transportation policies (the environmental cost is evaluated at 1.1% of the communitarian GDP). Further adverse effects of the road transportation include those from roads congestion (1% of the GDP, and growing), acoustic pollution and vehicles' accidents.

Inside the transportation sector, road transport (on which we focus our analysis) constitutes 60% of total oil consumption and is the main responsible of atmospheric pollution: alone, it generates around 84% of CO_2 emissions, one of the main responsible for the greenhouse effect.

It clearly emerges from above that the definition of energy and transportation policies cannot be adequately performed without some modeling tool, that in turn allows industrialized countries to be first mover in anticipating either more stringent measures on CO_2 emissions or on certain fuels, or oil companies in setting up measures to adjust their strategies to the changing business environment.

In this paper, we propose a System Dynamics model representing the private road-transport sector in the EU, in order to simulate and forecast alternative scenarios which on one side may allow energy and oil companies to maintain (or increase) their own competitive advantage on the market and on another side may support the development of public national and international energy and transportation policies. This model has been developed in collaboration with the Centre for Economic and Energy Studies (StuEcEn) at ENI SpA (Italy), in order to forecast the demand of road fuels in UE countries.

2. LITERATURE REVIEW

The approaches to the development of strategic planning practices in the Energy sector have quite often made use of the System Dynamics (SD) methodology. The first relevant study, called "Limits to the Growth", was carried out at the Massachusetts Institute of Technology (MIT): its main results were two models, WORLD2 and WORLD3, as well as several publications about the results obtained from the models (Forrester, 1971; Meadows et al., 1972; Meadows and Meadows, 1973, Meadows, 1974). The MIT group study, commissioned by Aurelio Peccei and the Club of Rome, aimed at forecasting the future developments of the Energy sector, analyzing both the long-term socioeconomic interactions that were causing global population and industrial production to grow, as well as assuming an eventual natural resources unavailability (Meadows and Meadows, 1973).

Based on the same methodology, Roger Naill developed one of the first disaggregated models (1972), trying to focus on a specific natural resource. Naill modeled natural gas discovery and production processes. The model was based on the life cycle theory by M. King Hubbert (1950). Hubbert used his theory in order to simulate future US oil production and was able to forecast the production peak between 1966 and 1971. This fundamental result brought energy model-makers to analyze the impact of energy limits on US economical growth. A new model, called COAL1, was proposed again by Naill (1976), within the Resource Policy Group at the Dartmouth College. COAL1 considered all US energy resources and consumption sectors. Parallel to the upgrade of COAL1 to COAL2 (Naill, 1977), the US Energy Research and Development Administration supported the development of the FOSSIL1 model (Budzik and Naill, 1976; Backus, 1977). FOSSIL1 was used to assess the new National Energy Plan by the Carter Administration White House staff (Naill and Backus, 1977). Naill later upgraded the model to FOSSIL2 (EEA, 1980), which then became the main evaluation tool used by the US Energy Department between the Seventies and the Nineties. Among the most relevant results of the FOSSIL2 model, there were policy testing, taxes effects forecasting, renewable resources investment and CO_2 reduction policies evaluation, oil price simulation. FOSSIL2 was recently integrated with the electric and transport sectors and was renamed IDEAS - Integrated Dynamic Energy Analysis Simulation (AES, 1993).

John Sterman, that had already participated to the development all FOSSIL models, later proposed a new model in order to analyze the iterations between energy and economic sectors (Sterman, 1981). Sterman aimed at solving FOSSIL models gaps: GDP, interest rates, non-conventional energy technologies costs and other important relevant variables treated as endogenous; no connections between US energy prices, production and policies and global oil prices and inflation. Sterman analyzed US energy transition and integrated these elements in his model, highlighting several implications not considered in previous models.

Sterman model was later improved by Tom Fiddaman's (1997). His model, called FREE (Feedback-Rich Energy Economy model), also included externalities modeling (e.g. climatic changes). There are also other relevant, more focused models, such as ELECTRIC1 (Andrew Ford, 1975) and its subsequent versions (EPPAM models).

This literature review clearly shows that the SD methodology is strongly suitable to approach modeling in the energy sector, which is inherently characterized by a large number of interactions between several variables, in order to predict consequences and compensation effects, otherwise unpredictable.

3. PROPOSAL OF A MODEL

Causal map

Our model concerning the transport sector is a first experiment on our path towards developing a tool that is able to forecast scenarios and meaningful hypotheses on oil and gasoline consumptions, as well as on related consequences in terms of CO_2 emissions on EU countries up to year 2020. We first developed a causal map in order to understand the relationships among the various main variables in the private road transport sector as well as among the main dynamic system drivers and leverages.

The main driver on fuel consumption is represented by the transportation demand in terms of passengers per kilometer in each year. The strong link between the GDP and the general level of transportations, poses an important question concerning the growth of the transportation demand. As it emerges by looking at the literature, many economic studies, while focusing on this relationship, have hypothesized a growth of demand as strictly in line with the growth of the GDP, but did not factor in many other aspects that, as a matter of fact, determine a stabilization in the system due to physical and structural constraints. Such constraints would thus necessarily bring to a saturation in transport demand while the GDP can keep on growing.

Such a relationship is obviously also influenced by the characteristics of the geographical area which is the focus of our analysis. Rapid developing and emerging countries in the middle of their industrial, economic as well as also demographic development, are about to reach the pro-capita annual revenue levels (about 5000$/year) beyond which, historically, it is possible to note a great increase in car use and thus an acceleration in oil products demand for transportation. In the same way, many countries in Eastern Europe are having an important economic growth, which thus influences the transportation demand.

As previously mentioned, efficiency must be considered as the key element in fuels and oil consumption. EU has an overall vehicle fleet average efficiency that is far higher than USA's one. This depends of course on the average vehicle's construction characteristics as well as on various factors that, as a matter of fact, have determined market dynamics over the years. Among the most relevant aspects, we cannot neglect the fuel price, which has historically been much cheaper than in Europe, thus allowing citizens to choose larger and more powerful cars (i.e.: SUVs), which generally have an higher fuel consumption. The graph below (Figure 1) relates the average efficiency of EU to US fleets from 1985 to 2007.
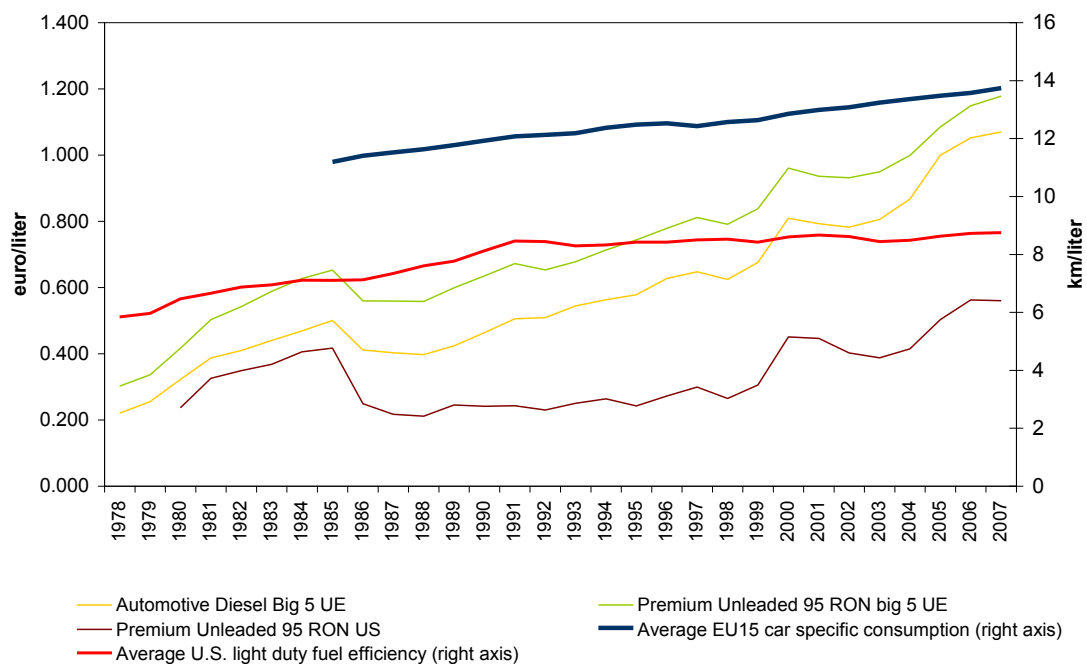

Figure 1: Comparison of US and EU average fleets efficiency

As we can see from the data behaviour, vehicles' efficiency has played a fundamental role: the UE trend underlines an improvement in efficiency due to lower costs sustained to satisfy the yearly transportation demand of passengers. As an example, it is today well known how, over the last decade, diesel engines have reached a great percentage in new vehicles' registrations, due to their better efficiency and thus by the straightforward lower consumption.

Such a market tendency is quite important and has to be carefully accounted for by the great oil companies in order to sketch out a possible trend from today until the next decades. The demand for fuel may in fact bring, on a short to medium term, to an increase in diesel demand and a relative decrease in gasoline use. However, other various aspects have to be accounted for: at the moment, diesel vehicles' penetration rates are quite different in each EU country, just like the pro-capita welfare level. Also, it must be accounted for the possibility of a surge and diffusion of new alternative engine technologies (hybrid or fully electrical vehicles), of small and light cars, thus having more efficient engines, of different fuel price dynamics and relative taxations, which may balance back the growing trend in diesel use.

Another important issue influencing fuel use is the average distance travelled per vehicle (measured in kilometres per year): also in this case, we can notice a gap between the US and EU given by the substantial differences that arise from the different contexts, from the average inhabitants density (higher in the EU) and from the fuel prices (lower in the US). The decrease of petrol use in the US from its peak in 2005, later also amplified by the economic crisis, is partly explained by the higher prices to the final consumer at the gas stations during the last years.
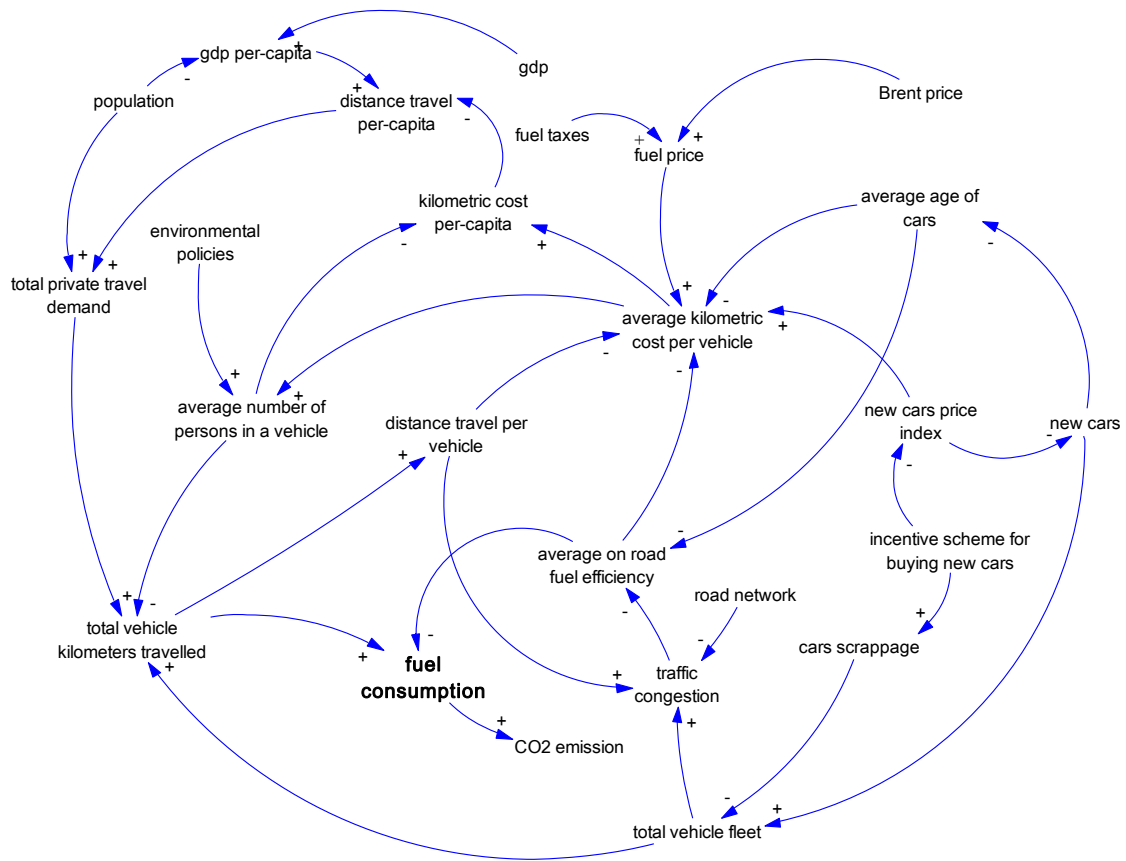
Figure 2: Overall causal map

So, given the overall causal map in Figure 2, which depicts the situations explained above, we can identify four different feedback loops, three of which are evidenced in figure 3 and the fourth, a reinforcing one, is identified by the external path to our map. When we later got to the quantitative modelling phase, by neglecting the road congestion effects on the average vehicles' efficiency, we evidenced the presence of only two feedback loops with different polarity, whose interaction determined a "limits to the growth" archetype.
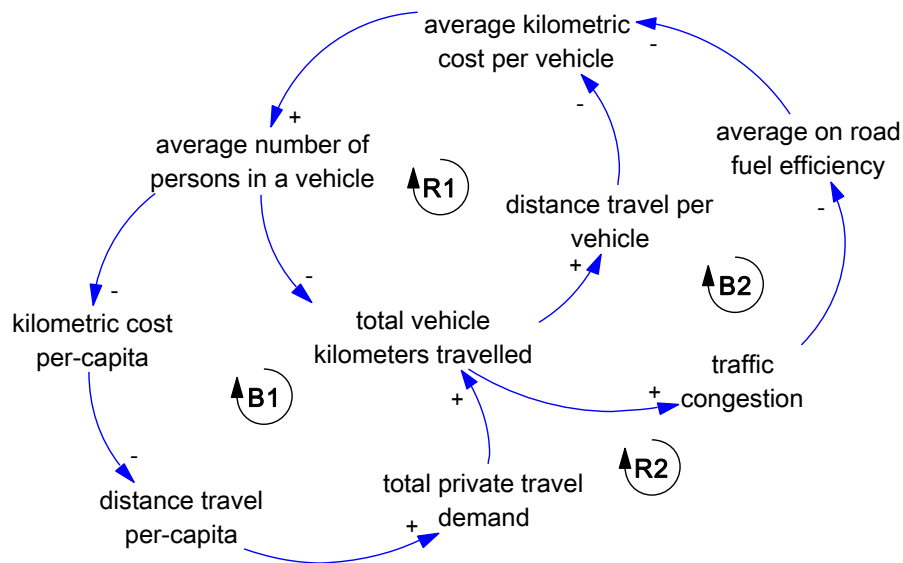
Figure 3: Feedback loops

Reading the causal loop diagram in Figure 3 is quite simple: as the "total private travel demand" grows, the "total vehicle kilometres travelled" grows too, thus increasing the "distance travelled per vehicle", which in turn positively affects the "traffic congestion" factor. The latter, negatively influences the "average on road fuel efficiency", whose eventual improvement may bring to a decrease in the "average kilometric cost per vehicle" and consequently the "kilometric cost per-capita". The latter, in turn negatively influences the " distance travelled per-capita", whose eventual increase may lead back to an increase in the "total private travel demand", thus closing this balancing loop.

However, the quantitative modelling phase usually further clears the overall picture concerning the existing relationships among the various parts of the system, eventually requesting to go back to the qualitative phase if some new considerations arise after the first simulation runs. This situation is particularly evident with reference to exogenous variables: the unavailability of fundamental data may even imply bringing deep modifications to the causal map itself, and thus the relationships among the variables of the system, thus evidencing sometimes also different dynamic structures.

As an example, with reference to the causal loop depicted in Figure 3, the "road congestion" variable represents a very important factor into that loop since it generates dynamics related to its behaviour over time. We can thus suppose that such a factor may be described by a mathematical function. In the reality, the road congestion concept sums up a whole bunch of articulated considerations that may not be summarized by just a mathematical or analytic expression; rather, it alone might be described by another model, thus including other variables, levels, flows, etc.

This issue is quite important since it helps understand how the maybe excessive but necessary simplification in the definition of some elements may generate dynamical behaviours responsible for undesired distortions, independently of the conceived model and its goal. For this reason, we decided to focus our attention on how to represent a substitute element rather than inserting a simplified one, which may generate too much

evident mistakes in describing the system's behaviour. We decided to represent the "road congestion" as a qualitative indicator (condensed in a slight decrease of fuel efficiency related to congestion increase) rather than a quantitative one.

Stock & Flow Model

Fuels Prices

The following Figure 4 shows a sub-model describing how the fuel-pump prices are determined (the LPG is not considered anymore in this part of the model), starting from the Brent price and, step by step, translating it into a final pump price for diesel and gasoline (in Euro).
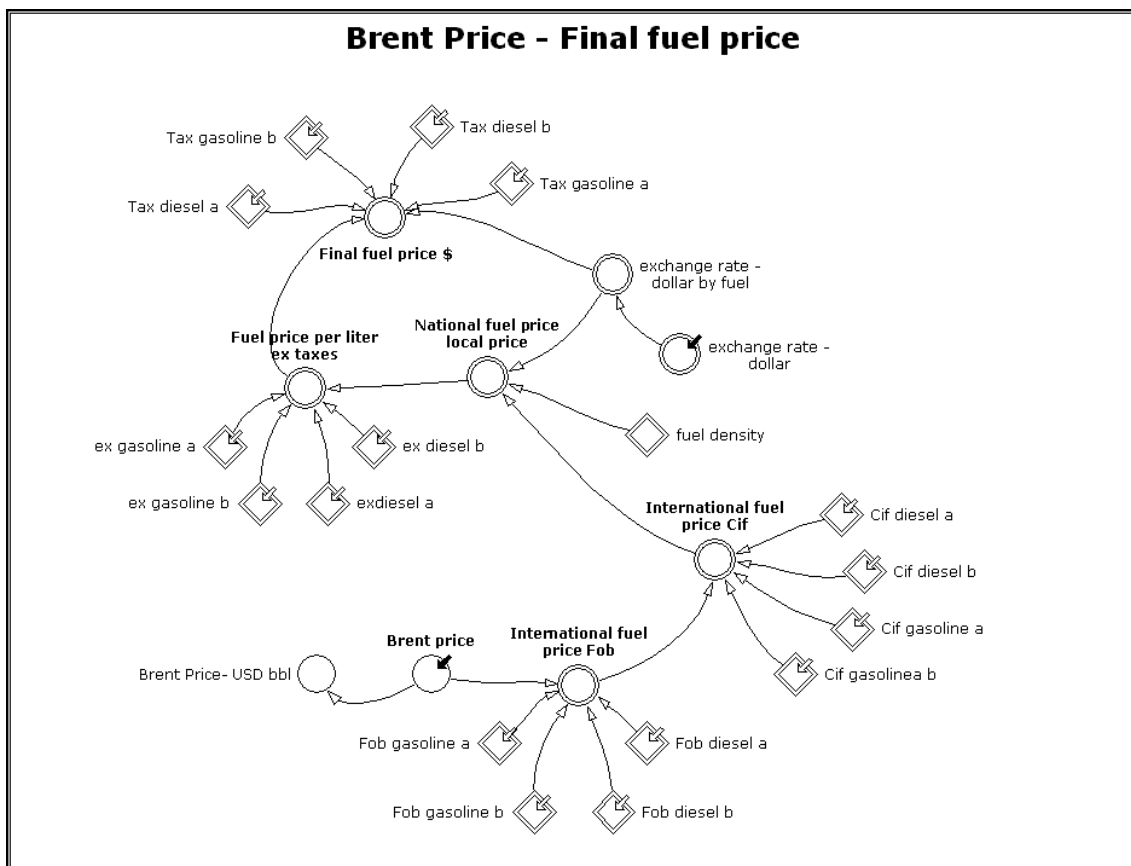
Figure 4: Final fuel price model

A time series on the quarterly Brent price (in dollars), from January 1995 to January 2031 is included in the model by uploading an excel file containing the estimates provided by the "StuEcEn" Center of Economic and Energy Studies and updated in coherence with the latest official scenario. We won't delve into this variable's estimation process, even though, nowadays, it constitutes one of the most interesting aspects on international markets. Moreover, the complexity of such a system requires a

dedicated model, besides the global evolution of energy, political-economic and social considerations.

The main equation is represented by the following logistic function:

$$y = exp\,(a + b \ln x)$$

whose a and b parameters are uploaded in the model at the start of the simulation run by means of excel files. The behavior of the fuel-pump diesel and gasoline prices is however dependant also on the characteristics of related laws in each country. All the simulation runs, performed in order to build scenarios on fuel consumption, do also take into account taxation laws and are based on the correlation of historical data with the price, before taxes, of a liter of fuel in each country. In Figures 5 and 6 we show the fuel-pump petrol and diesel prices for the five most representative countries in EU-OCSE.
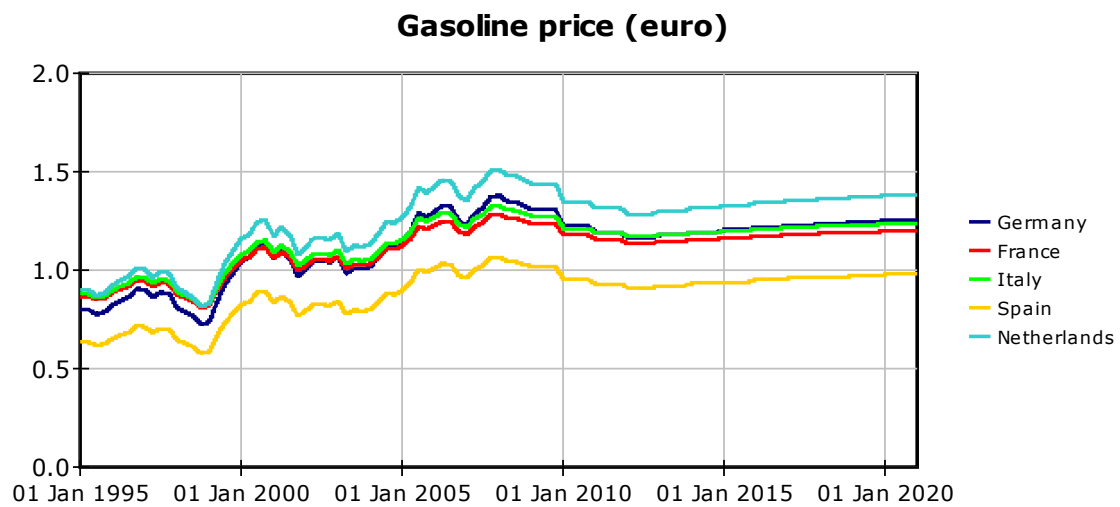
Figure 5: Gasoline pump-price behaviour for the some important country
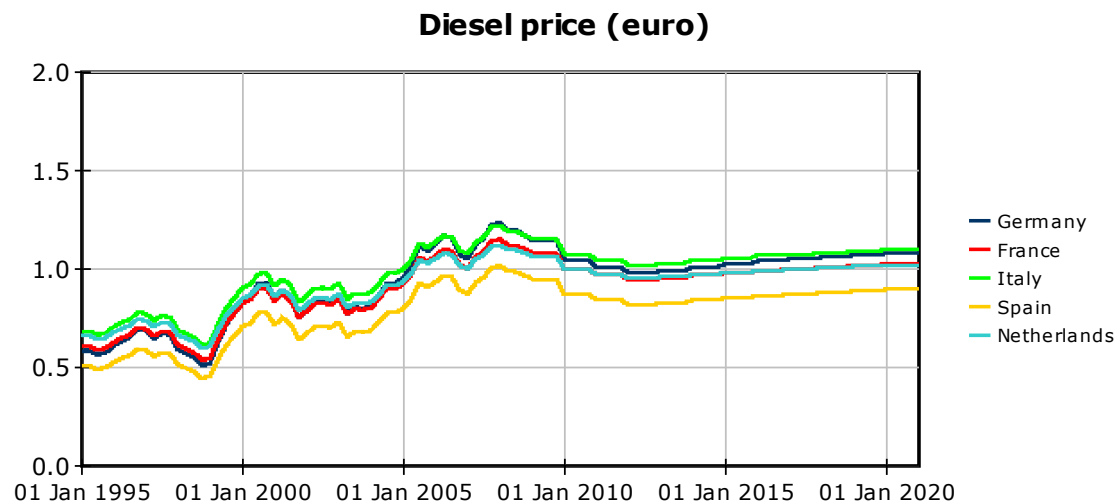

Figure 6: Diesel pump-price behaviour for the important country

Technology-improvement Scenario

This scenario takes into account also the market potential of hybrid engine and electric vehicles, as well as of fossil gaseous fuels (LPG, CNG) on a medium-to-long term basis. The competitiveness of electric vehicles compared to traditional internal combustion engines is likely to depend in the future on the cost and autonomy of battery packs, as well as on the availability of some metals used in building electric engines and battery packs themselves, as also on the price of electricity. Such uncertainties make it particularly difficult to choose among the exogenous variables to include in the model.

Vehicle fleet's dynamics

The level concerning the total amount of vehicles (or Total Fleet) is a time dependant matrix based on three components: age class of the fleet, country, fuel type. Thanks to a sufficiently detailed database, it was possible to initialize this level with the starting date of our simulation runs. It was thus possible to obtain a detailed description of the fleet development behaviour. It is interesting to point out that cars are not simply treated as belonging to a same class, rather they are subdivided according to 25 classes of age, the last of which identifies cars with more than 24 years. Thus the model accounts for the obviously different average efficiency and consumption that each class displays.

The flows affecting such a state of the system do always refer to car scrappings and exports (outflows) and new cars registrations (inflow).

The Scrappings flow rate is a regulating variable that has been defined by taking into account both a sensitivity to car prices, and the association of a car scraping probability to its related age class[1]. Such equation:

$$Scrapping(a,t) = \gamma \left[1 + exp\left(B_0 + B_1 \left(\frac{P(O,t)}{init\ P(O,t)} K^a \right) \right) \right]^{-1}$$

with

$P(O,t)$ = new cars price index at year *t*

K = depreciation rate (0,8 in this case)

a = Age of the car (years)

$[1 + exp(B_0)]^{-1}$ = scrapping rate of the cars with zero residual value

B_1 = parameter for the car price elasticity

expresses the probability that a vehicle in class "a" (thus with age "a") gets scraped during year "t".

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[1] D.L. Greene, 'Aderived demand model of regional highway diesel fuel use' Transportation Research, vol 18B, N°1, 1984,

As long as vehicles' aging is concerned, we modeled an aging chain by considering a yearly shift of all vehicles belonging to a certain age class to the next one. As long as the inflow rate to the aging chain *New cars coming into age* 0 is concerned, while car registrations historical data[2] is derived during the simulation thanks to an excel file imported in the initialization phase, at the start of year 2005 we have set two stocks&flows sub-models so to regulate such an inflow variable as a logistic-growth curve (S-shaped), thus depicting the behavior in each EU country of newly registered vehicles (first submodel) as well as the ratio of the rate of penetration of diesel-engine vehicles to the amount of vehicles in the overall fleet (second submodel).

As far as the total of car registrations is concerned, the relative first sub-model aims to match the historical reference-mode concerning the number of vehicles in the overall fleet, over the years and in each country, as an S-shaped curve having an asymptote (carrying capacity) defined as follows:

$$\lim_{t\to\infty} \frac{total\ car\ fleet(t)}{population(t)} = 1$$

which assumes that, while $t \to \infty$, the ratio of the total of vehicles in a country to its population tends to one: this is notably quite a strong assumption. Thus, such a structure poses a meaningful limit to the growth of overall vehicles over time. In the following Figure 7, we report for some EU countries the behavior of such a ratio, cars to persons, from 1995 to 2021.
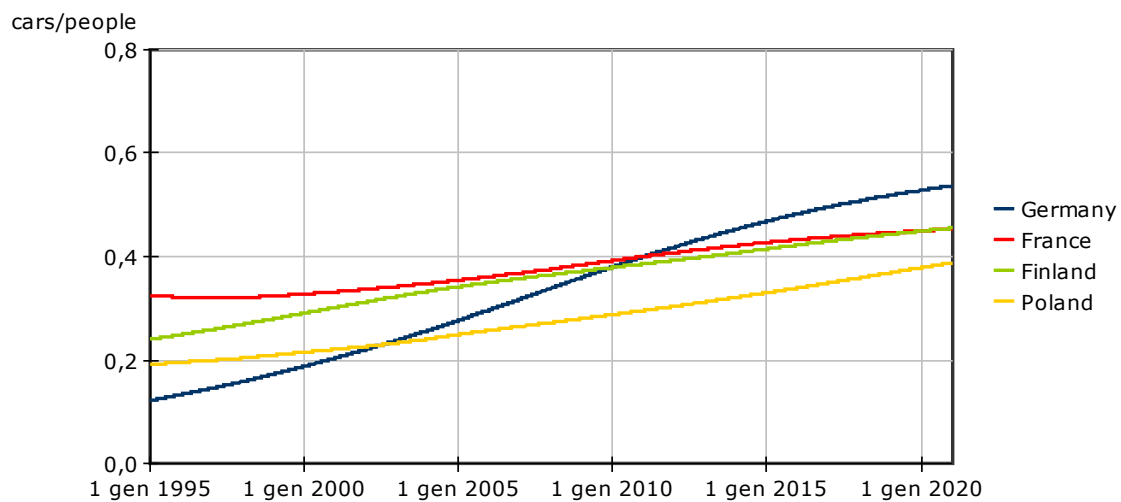

Figure 7: "Total car fleet" to "population" ratio behaviour

In Figure 8 we show the structure of such sub-model, where it is possible to note a level representing a "virtual car stock" whose inflow is determined by the above described ratio and by the growth of pro-capita consumption, and whose outflow is given by the average age of fleet vehicles.
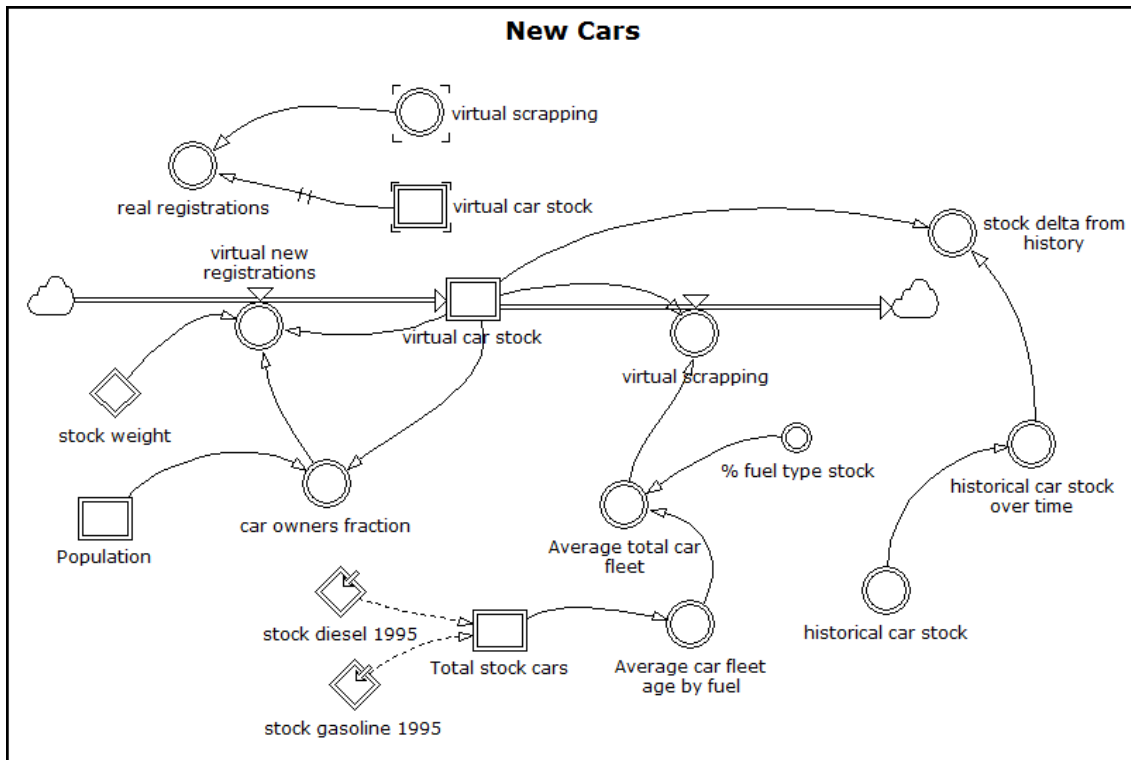
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[2] Fonte Odyssee Enerdata.

Figure 8: New cars generation

The second important submodel (see Figure 10) represents the penetration of diesel engine vehicles in the fleet. The approach to this model is essentially the same as the previous one, but this time the asymptote/carrying capacity has been defined as the ratio of total registered diesel engine vehicles to the total of registered vehicles (the latter value, independent of the engine or fuel type).

$$\lim_{t \to \infty} diesel\ quota\ on\ new\ registration(t) = K$$

where K has been chosen as having a limit percentage value of 70% but can also be defined by a curve or be given another value.

Also in this case, we tried to define a behavior able to match historical data up to year 2005 and then evolving according to an S-shaped growth curve up to the end of the simulation.

It is interesting to note that this second sub-model is capable to infer, based on the historical behavior, what kind of behaviour the system will have in the future: in other words, it may be said that it forecasts the system behavior over time in the future. As an example, by observing the behaviours in Figure 9, we note that the diesel related registration quota in Poland during year 2005 is not yet in a mature phase (it is in the part of the S-shaped curve where the growth rate is still increasing – before the inflection point). On the other hand, for the other reported countries (Germany, Italy, Spain), the growth is instead slowing down. Another interesting aspect is the speed of

achievement of the potential: in Italy, for example, the curve goes from below 10% in 1995 to above the historical value of 60% after 2005 (figure 9).
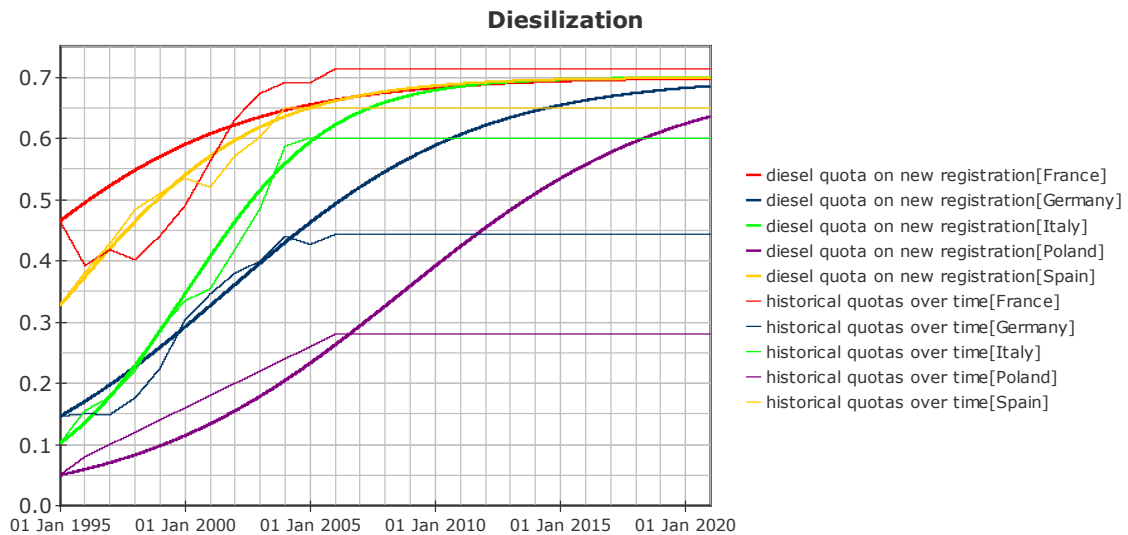
Diesilization

Figure 9: "New diesel registrations" to "total new registrations" ratio

The value of K is chosen on the basis of several considerations, specific to the scenario. For the scenario analyzed in this paper, an aggressive hypothesis on the penetration of diesel engines was made. However, it is clear that certain policies like fuel taxations, higher efficiency in petrol-powered vehicles and restrictive norms on CO_2 emissions may influence such behaviors in the course of the years, so that the initial hypothesis may have to be consequently modified.

In the diagram in Figure 10, which represents the above described second sub-model, we can again easily note the presence of a limits-to-the-growth archetype, which, as known, is made up by two interacting feedback loops having opposite polarities: at first, the positive feedback loops prevails due to a higher gain which starts the exponential growth, while at a certain point, the negative loop takes the lead due to a slowing-down effect given by the proximity to a certain imposed limit on the system's carrying capacity.
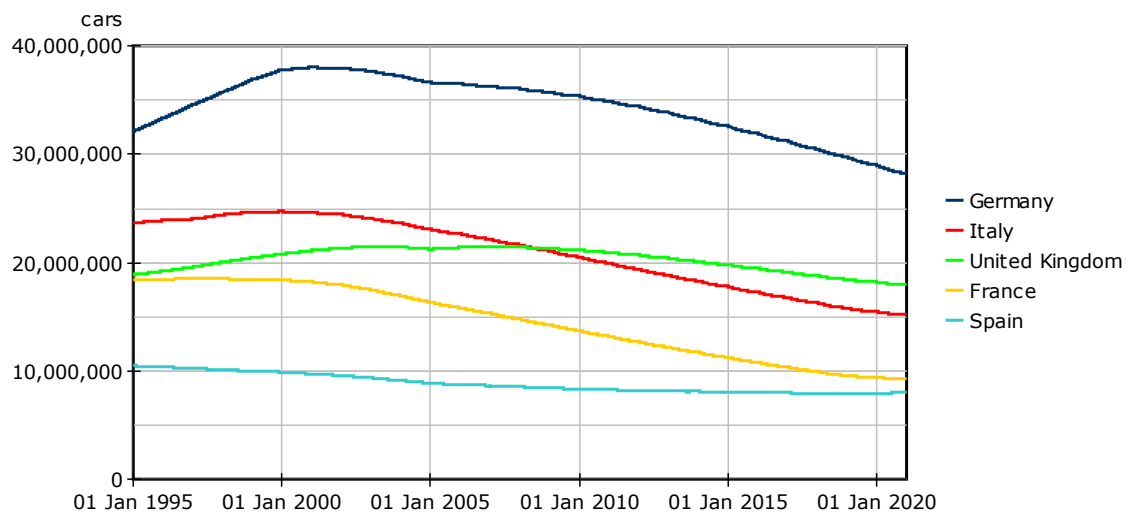
Figure 10: Diesel vehicles penetration within new cars

The results of the "dieselization" trend on the evolution of the total car fleet is shows in the two graphs (Figure 11 and 12) below for some country (*the big five*).

Figure 11: Diesel stock trend (France, Germany, Italy, Spain, UK)

Figure 12: Gasoline stock trend (France, Germany, Italy, Spain, UK)

Structure of the Transportation Model and Costs per kilometer Model

The *Structure of the Transportation Diagram and Costs per kilometer Diagram* represent the central part of our model. As in other parts of the model, exogenous variables upload their relative data either at the initialization phase or during the course of the simulation from some excel files. In particular, they are:

- Initialization of the costants:, $import\ population\ 1995$, $import\ GDP\ 1995$, $total\ passenger\ demand\ 1995$, $import\ car\ efficiency\ 1995$, $import\ roadnetwork\ 1995$, , $annual\ distance\ travel\ parameter$

- Variable behavior over time: $newcarspriceindex$, $populationrateofgrowth$, $GDPrate$.

The focus here is on fuel consumption, which is given by the relation between the "fleet overall travelled distance" and the "average vehicle efficiency". The latter variable is also represented as a level in the model, since it describes the behaviour of such an average property of the fleet with reference to the same fleet variations over time. In particular, the variation of the average efficiency is set according to the instant values of the registrations and scrapping flows values. Also important is to evidence (as it is obvious) that the average efficiency is divided according to fuel types: this means that diesel and gasoline efficiencies are different and are treated separately.

Also in line with such a differentiation per kind of fuel is the variable describing the "fleet overall travelled distance" that, by using a quota partitioning method, associates specific values (per time-unit) to both overall diesel engine vehicles and overall petrol engine vehicles.

This method, based on the analysis of historical data on fuel consumption, on average efficiency and on stock quotes of diesel and petrol engine vehicles, avails itself of a mathematical expression whose solution brings to a partition of travelled distances per

vehicle-power type. Thus, a specific variable "distance travelled quotas per fuel" determines a variable partition percentage which is also function of the evolutions in the overall fleet.

From a structural point of view, a fundamental element has to be recognized in the dynamics of the "car transportation demand". Its variation has been defined as a function of the "pro-capita car transportation demand" and "population". The former is related by a logistic function to the behaviour of the "private pro-capita consumption" and of the "pro-capita cost per kilometer". This way it was possible to represent both an income and a transportation cost elasticity, by means of a specific variable defined as follows:

$$Y = \cfrac{\cfrac{Private\ consumption\ per-capita}{Private\ consumption\ per-capita\,(1995)}}{\cfrac{Per-capita\ cost\ per\ kilometer}{Per-capita\ cost\ per\ kilometer\,(1995)}}$$

This variable will serve the purpose to dampen the growth of each country's "pro-capita car transportation demand", thus as a matter of fact constraining it, on average terms, to the welfare growth. In order to monitor and contain the behaviour of the "transportation demand", we developed a control panel through which it is possible to fix a maximum limit to the development of "pro-capita car transportation demand". Such a panel leans on an underlying submodel which presents again the recurring archetypical structure of the limits to the growth, so to take into account both the development of public transportation policies rather than other policies aiming at reducing the "private per-capita travelled distance" (i.e.: by means of urban planning, congestion charge, etc.). The following Figure 13 shows this sub-model.
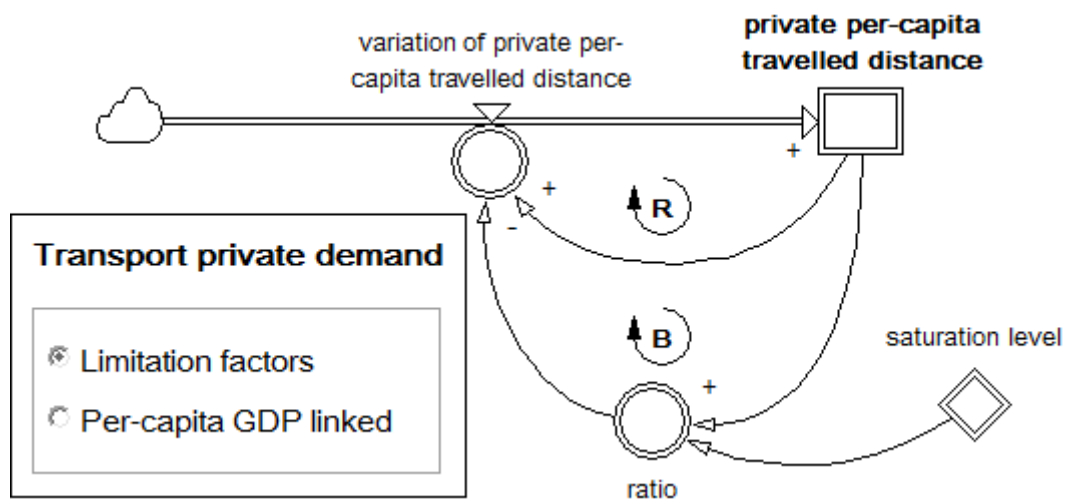

Figure 13: Per-capita car transportation demand limits

A switch panel allows choosing, during each simulation run, whether to intervene on demand by limiting it (according to slider controls which are not shown in the figure) or to leave it in a free evolution according to the equations ruling its dynamics.

4. SIMULATION RESULTS

Simulations were performed by using the Powersim Studio 2005 software. The simulation time window goes from January 1995 to January 2021 and the chosen integration method was the first-order Eulerian.

The model was validated on available historical data. For instance, the next picture (Figure 14) shows simulation results in terms of private per-capita transportation demand for all the considered European countries while the following picture (Figure 15) compares the big fives related data to "Odyssee" time-series from 1995 to 2005.
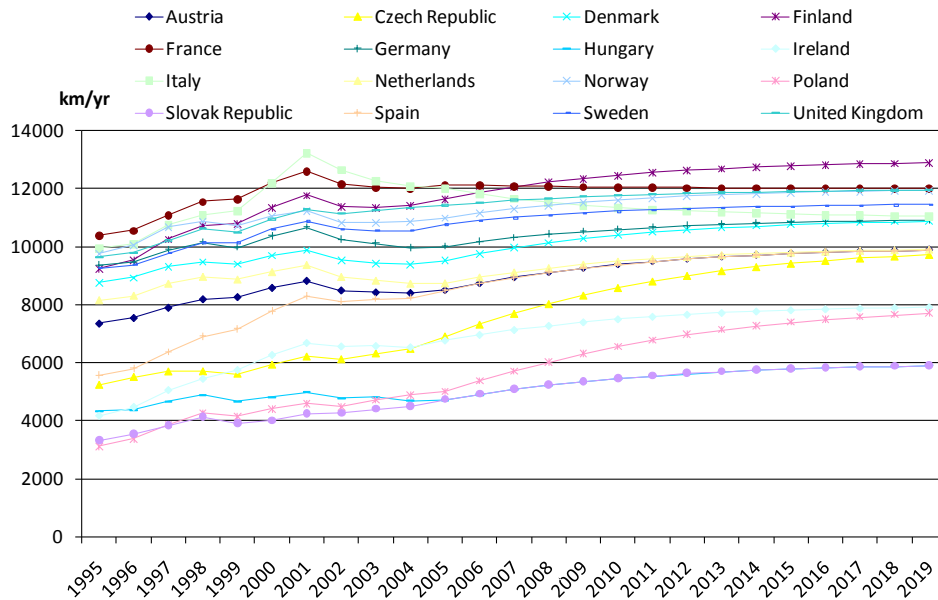
Figure 14: Per-capita demand - EMAT model
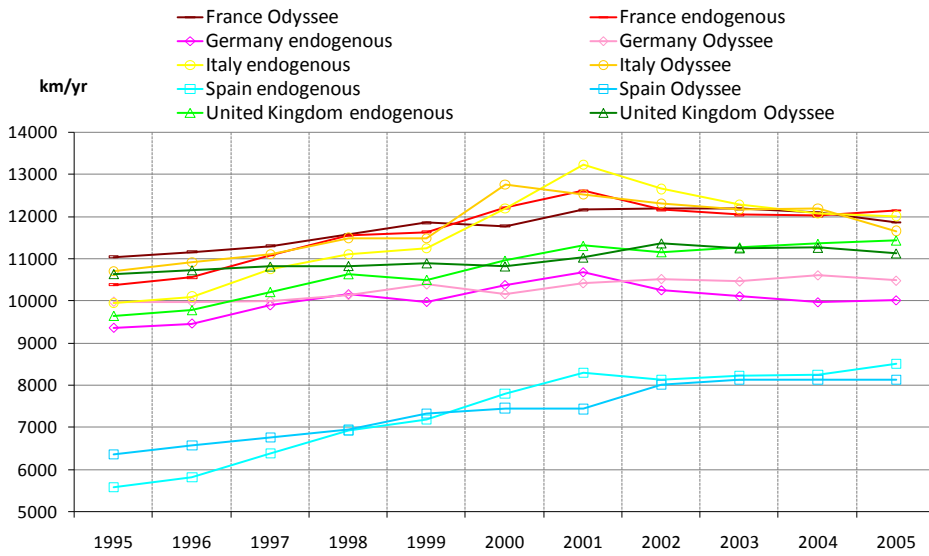
Figure 15: Comparison per-capita demand EMAT model with the Odyssee statistics for the big five (France, Germany, Italy, Spain, UK)

Model results, in terms of diesel and gasoline consumption and CO2 emissions, are reported in the following Figures.
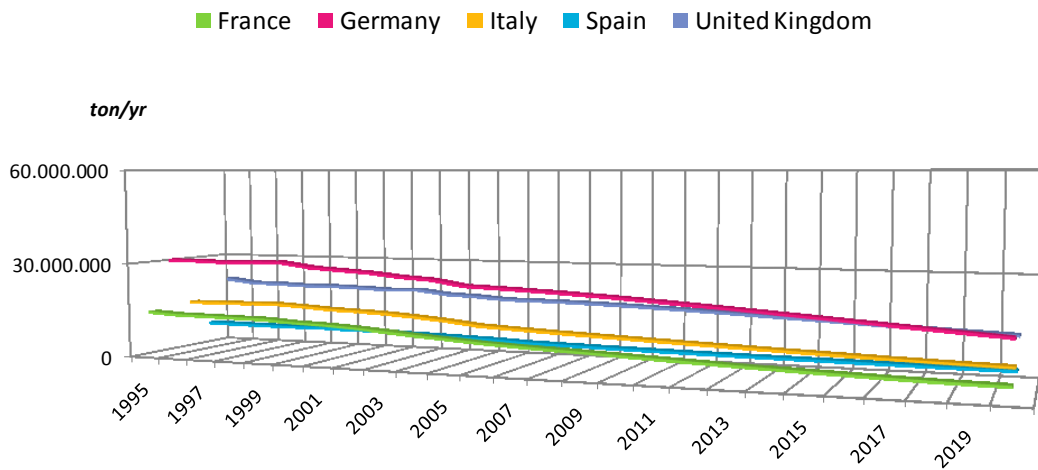
Gasoline consumption

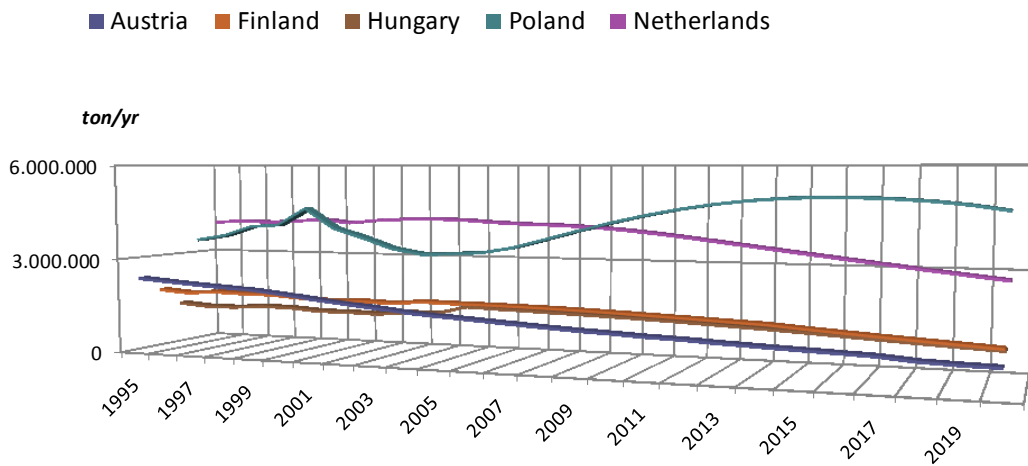**Figure 16: Gasoline consumption of the big five**

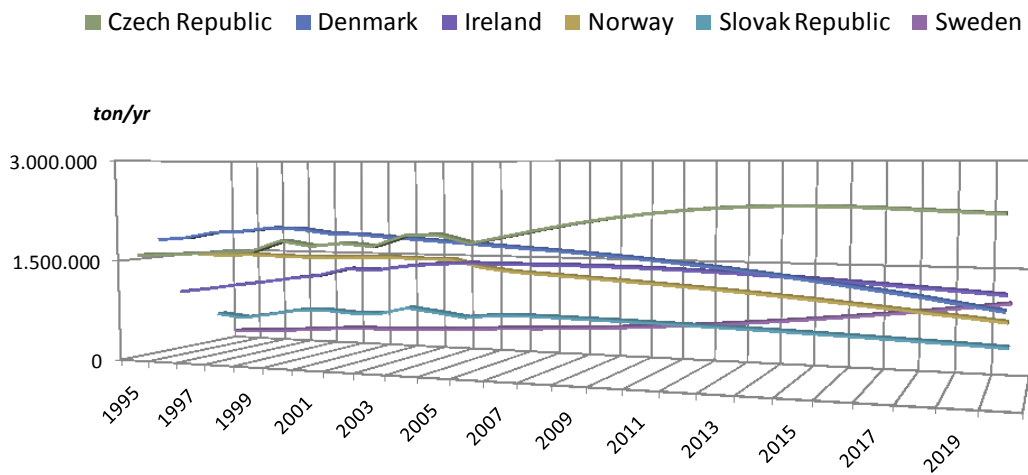**Figure 17: Gasoline consumption of other EU countries**

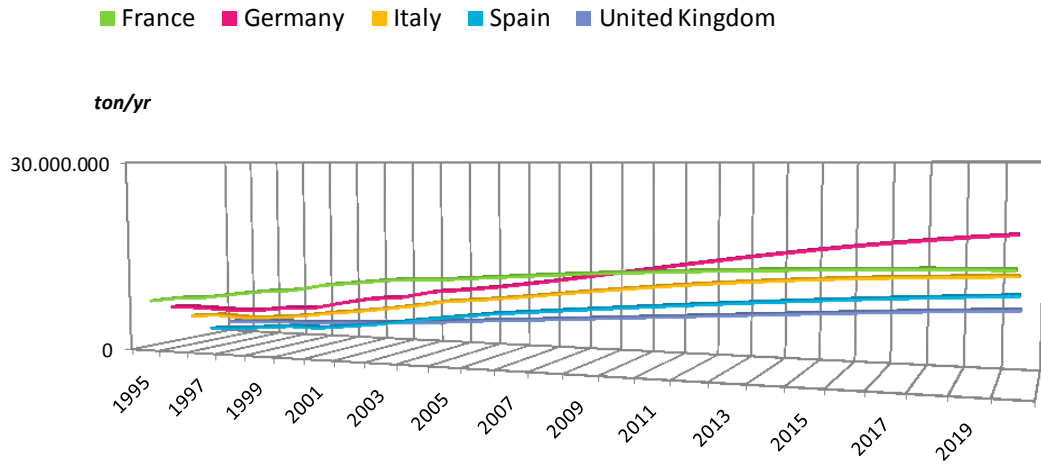**Figure 18: Gasoline consumption of other EU countries**

Diesel consumption
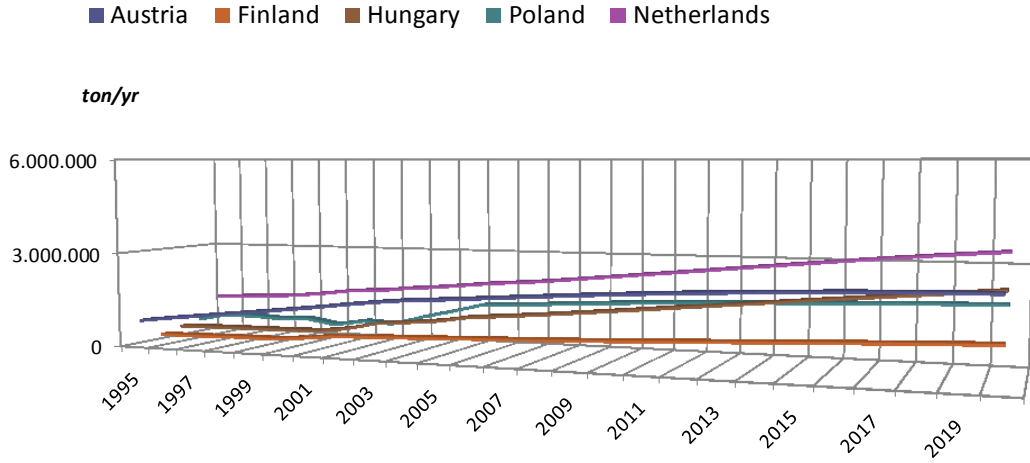

Figure 19: Gasoline consumption of the big five

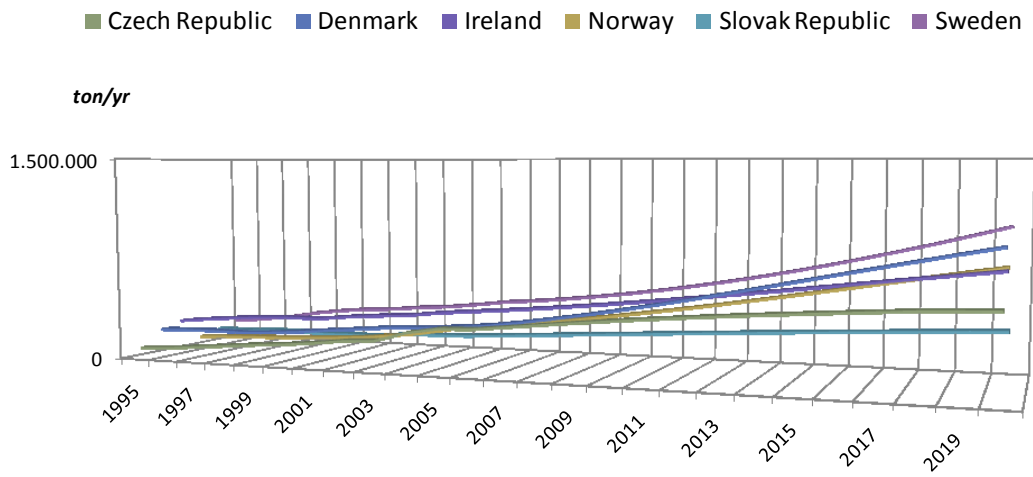**Figure 20: Diesel consumption of other EU countries**

ton/yr

Figure 21: Diesel consumption of other EU countries
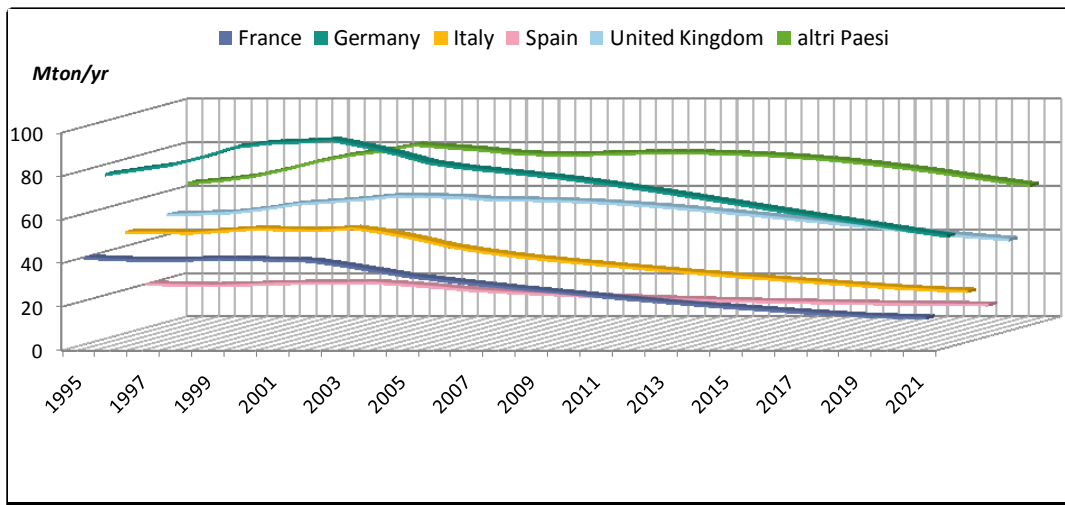
CO₂ emissions

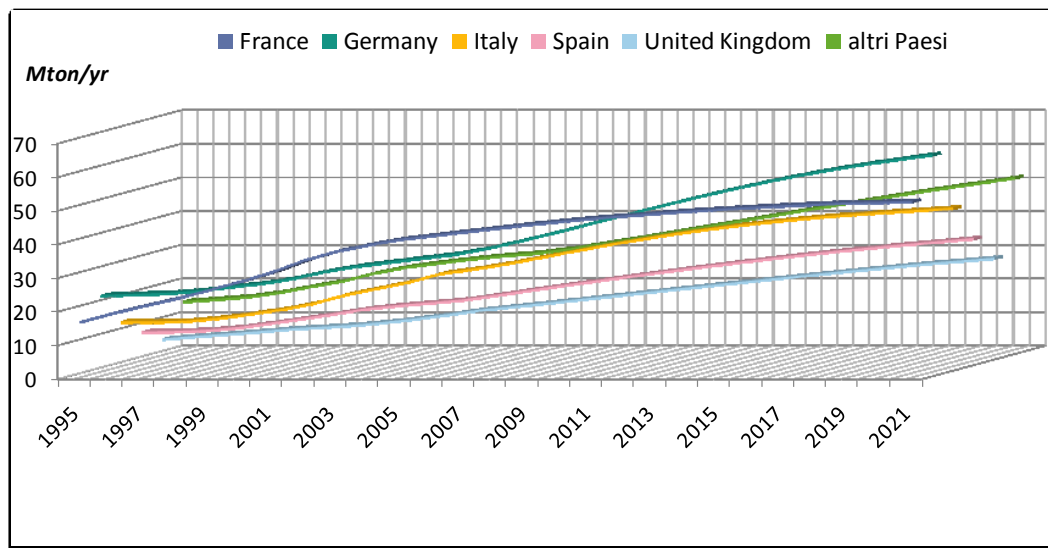**Figure 22: CO2 emissions, gasoline car fleet consumption**

Figure 23: CO2 emissions, diesel car fleet consumption

Simulation results show that the cumulated CO2 emissions from the eleven non-big five countries are substantially equivalent to the production of only one country among the big five. Emissions due to diesel consumption strongly grow while, at the same time, emissions due to gasoline consumption fall.

Simulations confirm relevant differences between the big five and non-big five countries. For instance, the analyzed Eastern Europe countries (Poland, Hungary, Czech Republic and Slovakia) are characterized by a greater increase of private transportation demand and a lower increase in diesel consumption, due to the important development phase they find themselves in.

CO2 emissions results were validated by means of historical data by Enerdata [3]. The comparison is showed in the following pictures.

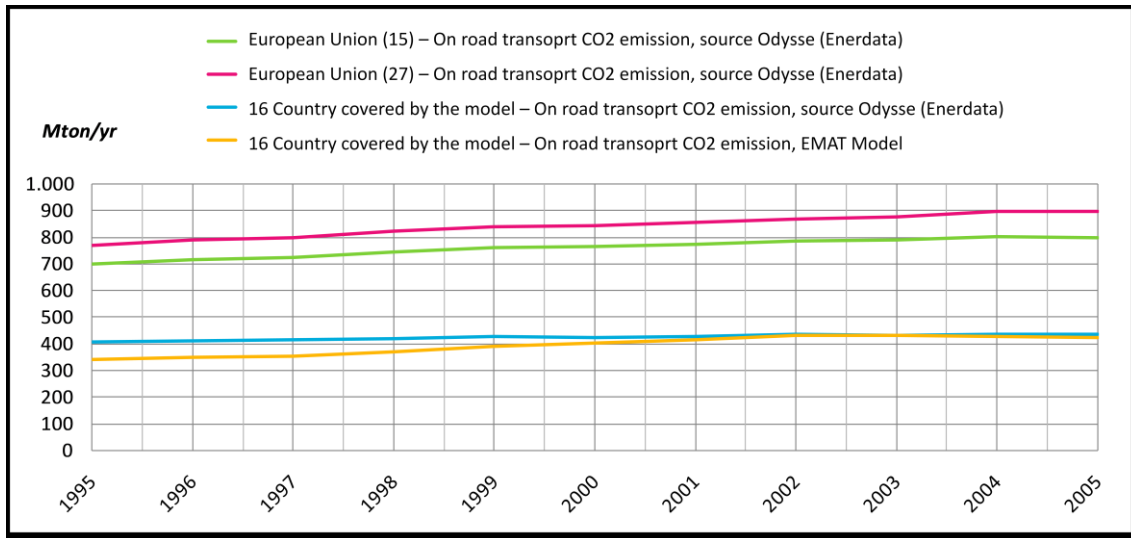- [3] GLOBAL ENERGY INTELLIGENCE, http://www.enerdata.fr/

Figure 24: Comparison CO2 emissions EMAT model with Enerdata statistics (1995-2005)

It is interesting to see how the endogenous results are very close, at the beginning of the simulation time, and get closer, until stabilizing on the reference mode after the first 5 years. This shows how the model is endogenously producing a vehicle stock consistent with the real figures.

5. CONCLUSIONS

Our comments in the previous paragraph concerning the analysis of simulation results allow to consider our model as a valuable tool in order to forecast EU fuels consumption, thus making it a valid alternative to the most known and used forecasting techniques (mostly based on stochastic-econometric models) in the context of energy-economics.

The value added of a dynamic car stock, able to evolve in efficiency and fuel structure with a definition of one year, positions the EMAT model as a unique instrument for the analysis of transitions, like the ones the automotive sector is currently undergoing. Increasingly stringent environmental regulations, strong policy push for aggressive energy efficiency and GHG emission reductions targets, extreme volatility in fuel prices, new entrants in the automotive sector, decline of the mature markets, new power-train designs that can possibly be deployed in the near future: these and more challenges need to be understood and evaluated with an instrument able to represent the scale and dynamic of the transitions lying ahead.

Moreover, the simplicity with which simulations can be carried out, also thanks to the actual processing capability of modern computers, allows testing a great multitude of alternative policies in a short time.

The user can interact with the model using a simple, clear interface, while the results are represented graphically and can be easily exported for comparison: this way, the

relevance and impact of different policies can be compared. Moreover, unlike most of the classical spreadsheet or econometric models, the synergies among different policies are accounted by the feedback structure of the model, making possible the evaluation of sets of policies (i.e. subsidies, standards, different biofuels mandates, etc.) rather than evaluating only one at a time.

EMAT is the demonstration of how system dynamics models can make a difference when the object of the analysis is a sector that is undergoing major transitions and different challenges. The comparison with the results from well-established econometrical models shows how the system dynamics methodology has a competitive advantage in describing a world where nothing is linear and feedbacks are at work.

EMAT is able to provide insights on the scale of the threats oil companies and car manufacturers are facing today. At the same time, it can guide policy makers in the difficult task of coping with global challenges, using an advanced and yet simple tool to prevent the arising of unintended consequences from the interactions of the many different policies they are called to put in place.

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