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SUSTAINABLE TRANSPORT IN FRANCE: IS A 75% REDUCTION IN CO₂ EMISSIONS ATTAINABLE?

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Abstract

Today, numerous works conclude that transport seems to be completely coupled to economic and export/import growth. Therefore, as a direct consequence of economic development transport sits today as one of the major final energy consumers and one of the most important sources of carbon dioxide emissions. Consequently, this situation of continuous increase in transport clearly poses an environmental problem. In this paper we propose to assess a certain number of possible solutions through scenario building in a backcasting manner using the TILT (Transport Issues in the Long Term) model. In particular, we evaluate three different scenarios that address how technology and different public policies can contribute towards a sharp reduction in CO₂ emissions. Furthermore, we propose an estimation of infrastructure investment needs as well as insight on how transport budgets (time and monetary) could evolve in each of the three scenarios presented:

- Pegasus - promoting strict technology standards
- Chronos - promoting green multimodality
- Hestia - promoting transport-GDP growth decoupling.

Each scenario allows a quick comprehension of the types of results that can be obtained through different policy mixes. In sum, realistic technological hypothesis show that a 50% reduction in emissions, from the 2000 level, is a clear possibility, and that the remaining 25 % reduction in emissions is possible through different types of policy mixes.

Keywords:

Greenhouse gas, long-term, scenario, transport, sustainable development.

1. Introduction

Today, numerous works conclude that transport seems to be completely coupled to economic growth. Therefore, as a direct consequence of economic development, transport sits today as one of the major final energy consumers and one of the most important sources of carbon dioxide emissions. Furthermore, in the absence of major technological change, this unsustainable situation will most undoubtedly get worse in the future. Consequently, this situation of continuous increase in freight and passenger mobility clearly poses an environmental problem in a world that is trying to attain sustainability.

It is in part from this preoccupation that spawned the Kyoto Protocol, ratified by the European Union member countries, which came into effect on February 16 2005 and which was a first vital step towards further global emission reductions.

In 2005, the Kyoto protocol signees committed to an average reduction of 2.8% of greenhouse gas emissions by 2008–2012 (from the 1990 level). This goal would require concentrations of CO₂ well below 550 parts per million (ppm) CO₂-equivalent.

In order to have a reasonable chance of keeping concentrations well below 550 ppm CO₂-equivalent, analyses for the EU Environment Council show that global emissions should be limited to an increase of 35 % above the 1990 level by 2020 and then decrease to 15 % below the 1990 level by 2050. However, to reduce the risk of overshooting the 2°C target, recent scientific insight has shown that it is possible that a 50% reduction in global emissions will be necessary for 2050.

This has pushed the EU Environment Council to adopt the conclusion that, in order to achieve stabilization, developed countries should reduce emissions by about 15% to 30 % by 2020 and 60% to 80 % by 2050, below the base year levels (1990).

In this state of affairs, and in view of the uncertainty concerning the ultimate goal, French authorities have fixed themselves a 75% reduction objective from the 2000 level to be attained by 2050. This objective will serve as the work basis for our scenarios which will only focus on transport activities. In France, transport is at the origin of 25% of energy consumption and is responsible for at least, 30% of carbon dioxide emissions (80% of these emissions come from road transport).

Even though we have seen the birth of new technologies in the transport sector and that we have witnessed a growing “social and entrepreneurial conscience”, these environmentally friendly products and/or services have observed a very slow implementation. As A. SCHEAFER (1) et al or D. SPERLING & N. LUTSEY (2) clearly underline in their work, technological progress cannot be effective if it is not accompanied by a deep change in organization and behavior, especially if we are aiming at a very important reduction of CO₂ like the 75% reduction target that French authorities have set.

Following this line of reasoning, the reduction of CO₂ emissions implies not only the need for new technologies and their widespread use but also an increased match in current technology supply and consumer demand through the use of incentive economic instruments. Thus, this reduction objective implies the need to set up a certain number of public policies ranging from inciting technological progress, to tolls, to intermodality/comodality development or even rationing (tradable emission permits).

In consequence, since we deemed necessary to explore the different options available, three sustainable transport scenarios (for both freight and passengers) were developed with the LET-ENERDATA group in 2008 (3).

This paper has two aims: Firstly, to present the main results for the French scenarios developed in 2008, which show that organizational policies can be mixed with technological advances and used to attain significant carbon reductions in the future. Secondly, to present new quantitative insight for each of the scenarios concerning public investment needs in infrastructure; public policy impact and the implications on transport monetary budgets (4).

As it will be presented, the TILT (Transport Issues in the Long Term) model was used to build three representative scenarios that depict viable (though strong) public action options that will sharply reduce CO₂ emissions. This same model was also used to quantify the effects of climate oriented policies on the transport system and the economy. The inherent logic in building these technico-organizational scenarios is linked to the idea of growing constraints –ranging from promoting new motor technologies to public policies aiming at decoupling transport activities and GDP. This underlying principle enables us to present three different scenarios that allow a quick comprehension of what can be obtained through policy mixes. These scenarios are: Pegasus, Chronos and Hestia, and are fully described in Section 3.2.

These three scenarios will be analyzed in order to come up with an assessment pertaining to the impact of four basic policy packages (that are then divided into ten different public policies) inspired by the work done in the VIBAT project (5):

- behavior oriented policies
- market oriented policies
- regulation oriented policies
- spatial and infrastructure planning policies.

2. The TILT Model (Transport Issues in the Long-Term)

In light of the environmental situation, it is, more than ever, necessary to shed some light on the important role played by transport activities in greenhouse gas emissions. It is equally important to develop environmental policies for reducing CO₂ emissions and to be able to model them correctly whilst assessing the effects of the different technological, institutional, regulatory and economic options available. The

TILT model is a flexible tool that does just that. Furthermore, because sustainable development is a highly complex problem area (6 & 7) -which will probably call for major changes of industrialized societies and long-term strategic planning- the choice of method in order to partake our analytical study was very important. This is why, once the specific needs of the research project had been taken into consideration, a backcasting model for scenario building seemed to be the most appropriate way of proceeding.

Backcasting scenario building typically aims at providing policy makers (and an interested general public) with images of the future as a background for opinion-forming and decision-making (8). Consequently, the results offer a new concrete and applied vision of the policies to partake, in order to attain an environmentally sustainable transport system.

Moreover, in the field of future-oriented studies, the traditional forecasting approach is still dominant, but scenarios have come widely into use during past decades (9) because they allow a broader analysis when compared with a formalized prognosis methodology.

The basis of the TILT approach lies on the fact that it is based on a twofold structure composed of a macro- and a microeconomic part (see figure 1). This structure serves as the core transport model that will provide input to three additional modules: These modules are designed to give insight concerning: total energy use, CO₂ emissions, public policy sensitivity and economic impact for any specified scenario.

The core transport model is composed by a macroeconomic determination and a microeconomic optimization that need to be at equilibrium in order to obtain a coherent modal split as a result. Thus, scenario building using a backcasting methodology with the TILT model requires first, the specification of the desired future and second, a “back and forth” movement where there is an interaction between the macro- and the microeconomic modules in order to identify the different equilibriums possible that allow the attainment of the specified future. From these possible equilibriums, the LET-ENERDATA group chose three that best depict the range of solutions available. These three scenarios are:

- Pegasus - promoting strict technology standards
- Chronos - promoting green multimodality
- Hestia - promoting the decoupling of transport activities and economic growth (GDP).

2.1 The macroeconomic determination of the TILT model

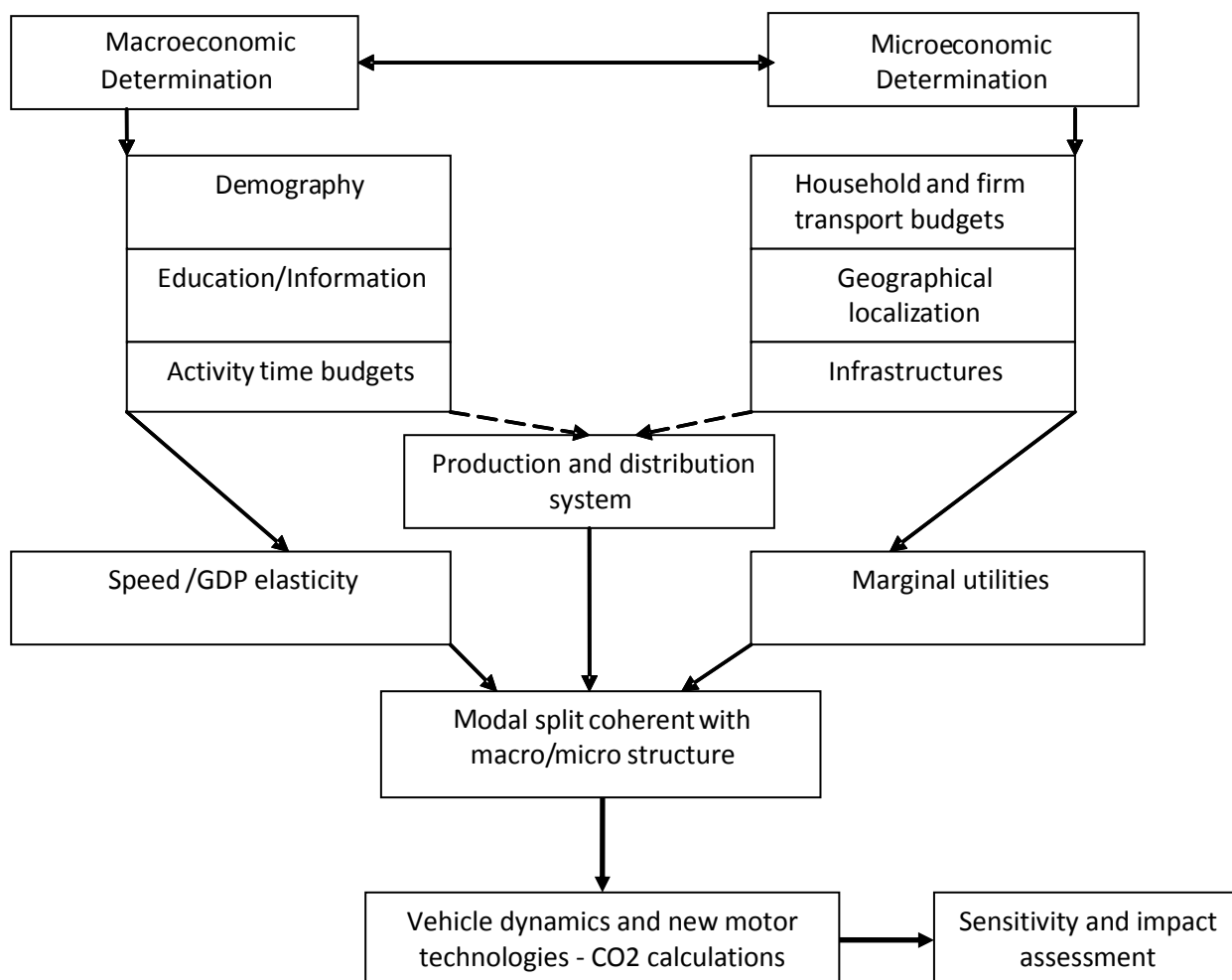
The macroeconomic component of the TILT (3) model is based on the VLEEM model (Very Long term Environment Energy Model), developed in the framework of a European project in 2002 (10). The VLEEM model is based on a re-foundation of the energy-environment modeling structures in order to properly assess very long-term

modifications of demographics as well as social and cultural preferences in relation to transport needs.

The macroeconomic component of the TILT model relies on a structure where population growth (determined by exogenous birth/death rates) and the evolution of population education levels (user determined) influence productivity in the different defined age classes. These changes in productivity, joined to demographic evolution, determine GDP growth as well as consumption levels and time use (work, sleep, self accomplishment, leisure and transport).

From the determination of time used in transport activities, the macroeconomic mobility determination is established through the use of average modal speeds that evolve based on a speed/GDP elasticity (which, in the case of France, has proven to be fairly stable over time(3)). This implies different modal split possibilities, given that the "need for speed" is sensitive to the affluence and freight value (11). Consequently, transport modal saturation rhythms can be varied -in the macroeconomic model- through public policies affecting speed/GDP elasticities.

FIGURE 1 TILT Model Structure



In order to have a more precise view of the effects of public policies on each scenario, a microeconomic component was developed within the TILT framework (4). This component allows further analysis of demand determinants behind each scenario's modal split.

2.2 The microeconomic optimization of the TILT model

The microeconomic component of the TILT model is based on a representative agent's optimization of decisions based on the opportunities inherent to household/firm locations (on an aggregated level), transport costs (ventilated into different categories referring to household/firm transport monetary budgets) and infrastructure availability (based on a lateness index) (12).

The microeconomic component is largely inspired by developments done on ant algorithms (4 & 13) and relies on the idea of a representative agent that optimizes his/her transport choices by taking into account opportunity and cost in respect to a certain level of service on infrastructure. Thus, the results stemming from the macroeconomic determination will influence the representative agent's choices. In turn, these choices must be coherent with the overall transport structure in order to be validated and represented in the decision table where the value assigned to each choice ($a_{ij}(t)$) is calculated using the following equation:

$$a_{ij}(t) = \frac{[\tau_{ij}(t)]^\alpha [\eta_{ij}]^\beta}{\sum_{l \in N_i} [\tau_{il}(t)]^\alpha [\eta_{il}]^\beta} \quad \forall j \in N_i \quad \text{EQUATION 1}$$

Where:

$$\eta_{ij} = \frac{\text{opportunity}}{\text{cost}} \quad \text{EQUATION 2}$$

and

$$\tau_{ij}(t) = \text{Lateness index}(t) \quad \text{EQUATION 3}$$

The TILT model considers opportunities as the sum of the consumption in goods and services in a certain period of time (S. LINDER, (14)) and that the lateness index is defined by the difference existing between normal transit time and the real transit time. This last indicator is useful in factoring in speed, distance and time into the calculation and has the convenience of being comparable between modes.

In this way, TILT has been designed to be a very long-term equilibrium model by combining a macroeconomic and microeconomic structure in a backcasting approach.

2.3 The insight modules of the TILT model

Three additional modules enable the model to take into account new motor technologies and to facilitate sensitivity and impact assessments in three geographical scales: urban, regional and interregional.

The three modules are the:

- **vehicle fleet dynamic and technology evolution module** that analyzes technological impact based on market penetration probabilities and vehicles' survival rates for different motor technologies and different transport services (road, rail, sea, air, inland waterways) (3).
- **public policy module** that joins a sensitivity analysis (for policy categories) and multicriteria analysis (for specific public policies) in order to offer a detailed impact assessment of actions on CO₂ emissions (4).
- **impact assessment module** (*based on an input-output equilibrium analysis*) that details impacts on employment and production by economic sector (4).

In short, the TILT model's structure enables the user to calculate energy consumption and pollutants emitted by transport activity (freight and passengers) on different geographical scales.

The TILT model has three important functions:

- modeling passenger-kilometers and ton-kilometers coherent with a micro/macroeconomic equilibrium structure according to motor technology used for journeys and area of service
- modeling the vehicle fleet according to: age, motor technology, and year of production (for freight and passengers)
- modeling and assessing public policy impacts on CO₂ emissions, infrastructure investment needs as well as overall impact on the economy.

By joining these three functions and the different TILT modules in a micro/macroeconomic equilibrium structure, it is possible to build scenarios based on different values for the exogenous variables (see table 1, *N.B.* GDP is endogenous). These scenarios portray a desired future that is determined beforehand (backcasting) and enable us to:

- quantify the consequences of transport on the environment whilst detailing the systems' structure according to behavior and organizational changes, technology used, vehicle fleet dynamics, nature of a journey and vehicle age
- give a precise view of traffic by motor technology, gas consumption and emission levels for each type of transport according to service distances, type of vehicle and transport cost
- build policy pathways that have different impacts in each scenario configuration and on the economy.

3. The 2050 Scenarios

In order to start analyzing policies and technological effects on the transport system, a business as usual reference scenario (Pegasus) was needed. Since TILT is not a forecasting model we opted to use the same mobility levels as the central scenario presented in the 2006 forecast of the Conseil General des Ponts et Chaussées (CGPC) (15). The CGPC's "World Governance and Environmental Industry" served as our reference base from which two other scenarios (Chronos and Hestia) were built in order to test different types of policies.

On an economic level, all scenarios have roughly the same hypothesis. The differences between each scenario are linked to the transport structure where: speed/GDP elasticities, modal speeds and transport times differ. The basic characteristics of each scenario are presented in table 1.

TABLE 1 Scenario Characteristics

Scenario Characteristics		2000	Pegasus 2050	Chronos 2050	Hestia 2050		
URBAN	Freight						
		<i>Km/h</i>					
		-Road urban	50	60	52	52	
	Passengers		<i>Km/h</i>				
		- Private car urban	23	30	25	25	
	- Public transport urban	20	24	20	22		
REGIONAL	Freight						
		<i>Km/h</i>					
		- Road regional	50	60	52	52	
	Passengers		<i>Km/h</i>				
		- Private car regional	58	67	58	55	
	- Public transport regional	58	68	57	54		
INTERREGIONAL	Freight						
		<i>Km/h</i>					
		- Rail+ Plane national	40	63	45	45	
		- Rail+ Plane international	-	70	70	70	
	Passengers		<i>Km/h</i>				
			- Private car interregional	110	115	90	90
			- Public transport interregional	80	90	80	80
			- High speed rail interregional	250	250	250	250
	- Plane	500	500	500	500		
TOTAL	Freight (nat/inter)						
		<i>Km/h</i>	43	54/52	43/52	43/52	
	Passengers	<i>Km/h</i>	45	50	37	37	
Elasticities							
Speed/GDP		-	0,33	0	0		
T.Km/GDP		-	0,6	0,6	0,3		
T.Km/International trade		-	1,6	1,6	0,25		
Macroeconomics							
Population		64	67	67	67		
Average Yearly GDP Growth			1,5	1,5	1,5		
Child per household		2,19	2,15	2,15	2,15		
Productivity rate		100	225	225	225		
Transport Time Budget		1	1	1,2	1		

Note: - means not applicable

H.G. LOPEZ-RUIZ 2009

The hypothesis made for the emissions calculations for each of the scenarios take into account the current state-of-affairs in France. The most important points are that:

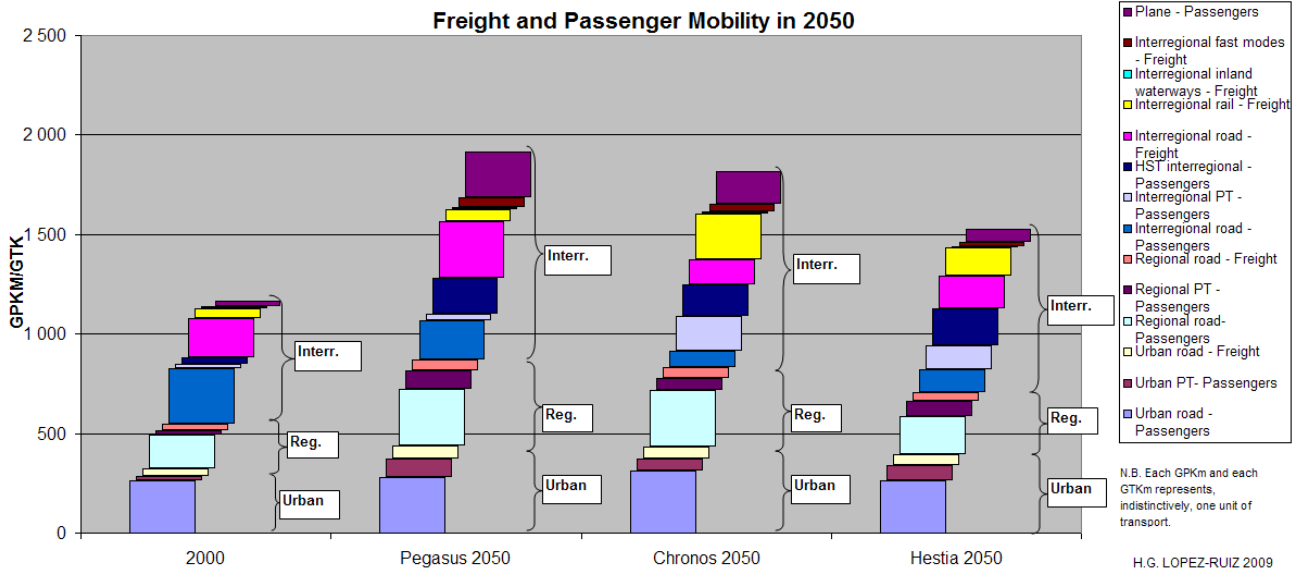
- emission calculations are “well-to-wheel”
- plug-in hybrid vehicles hit the market by 2010 and electric vehicles by 2020 (first at the urban and regional scale, and then at the interregional scale)
- second generation bio-fuels represent 35% of fuel sales by 2050 and are consistent with cropland use for food
- all trains are supposed electric by 2050 and electricity production is supposed to be 100% from nuclear origin (compared to 80% in 2007)
- airplanes emit –in average- 35% less by 2050.

Before going into the details of each scenario, we will present the main results (figures 2 & 3 and table 2) stemming from the calculations based on the aforementioned hypotheses. This will enable the reader to discover the specifics of each scenario afterwards, being already aware of the main results.

3.1 Main Results

The first graph shows France's baseline mobility level (year 2000), as well as the levels calculated for the three scenarios: Pegasus, Chronos and Hestia. As we can see, the mobility levels practically double between 2000 and 2050 for the first two scenarios (Pegasus and Chronos) whereas for the third scenario (Hestia), the mobility level grew at a slower rhythm.

FIGURE 2 Freight and Passenger Mobility in 2050



These mobility levels are associated to specific infrastructural needs and to CO₂ emission levels. The investment needed to meet the infrastructural needs are show in table 2 and are based on a per "kilometer-of-construction" cost of 5 millions euros for highways; 1 million euros for local streets; 12 million euros for railroad lines (mixed average for high speed and normal lines) and 30 million euros for public transport on dedicated lanes (mixed average for buses, subway, tramways and intercity rail). Furthermore, investment needs are totaled in actual (2000) Euros and were calculated considering an average cost per "kilometer-of-construction". The operating costs are not considered (16 & 17). For all three scenarios, we suppose that public transport infrastructure will experience an increase of 15% in overall productivity (as considered by FAIVRE D'ARCIER's study (18)) during the 50-year period. The values obtained for the infrastructural investments needed for each scenario are comparable to those calculated by the WAELBROECK-ROCHA/BIPE report about the financing of the French transportation system to 2030 (19).

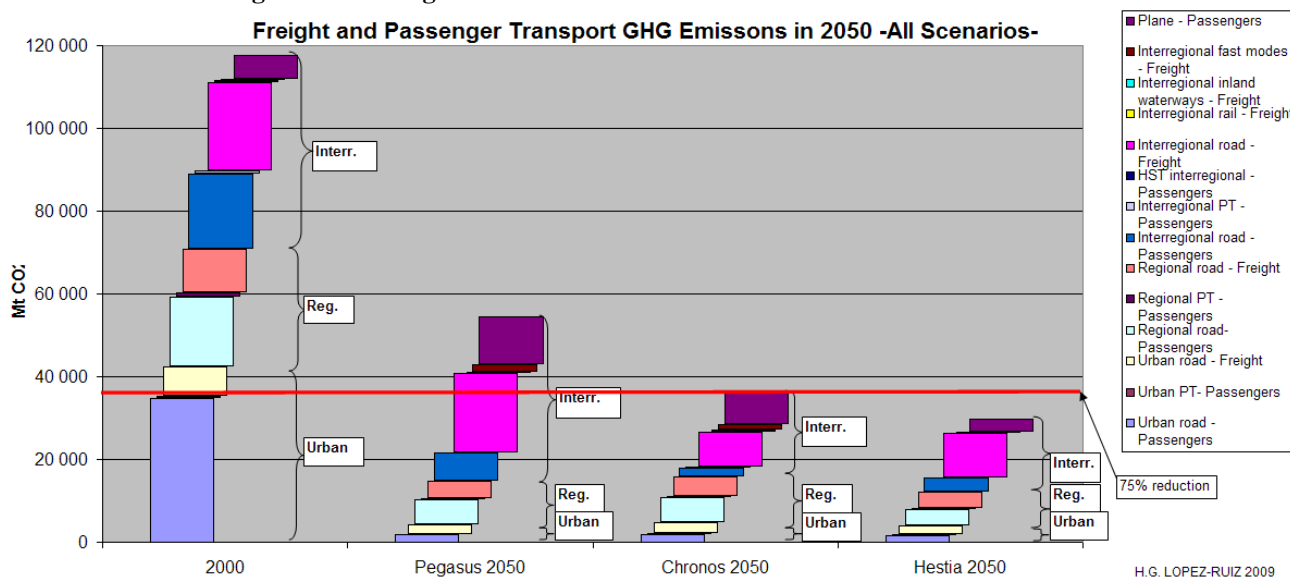
TABLE 2 Investment needs for infrastructures

Billions of €	Mode	2050 Pegasus	Per annum	% of GDP	2050 Chronos	Per annum	% of GDP	2050 Hestia	Per annum	Year 2007	% of GDP
Investments	Road	1043	21	0,7%	384	8	0,3%	140	3	12	0,9%
	Rail	747	15	0,5%	1529	31	1,1%	992	20	2	0,2%
	Public Trn.	137	3	0,1%	74	1	0,1%	77	2	2	0,2%
	Others	-	-	-	-	-	-	-	-	1	-
	Total	1927	39	1,4%	1987	40	1,4%	1209	24	18	1,4%

H.G. LOPEZ-RUIZ 2009
 Note: - means not applicable / values are in 2000€

In figure 3, we can see that the three scenarios show different results concerning CO₂ emissions. The first scenario (Pegasus) represents a 48% reduction in emissions whereas the other two scenarios (Chronos and Hestia) present a reduction of, at least, 75%.

FIGURE 3 Freight and Passenger GHG Emissions in 2050



3.2 The three scenarios

In order to better understand what these results imply, it is necessary to clearly explain what is at play in each of the options. Thus, we will now present the reader with the specifics for each of the three scenarios.

3.2.1 *Pegasus - Promoting strict technology standards*

Pegasus is a BAU (Business As Usual) scenario where the speed/GDP elasticity of 0.33 for passengers and 0.6 for freight are maintained for the 2000-2050 period and where transport times are stable (1 hour per person per day). Pegasus lets us appreciate:

- transport traffic in a situation where there is no major public policy affecting behavior and/or the system's regular performance (continued infrastructure investments and optimization),
- the effects of new motorization technologies on total CO₂ emissions.

In this manner Pegasus lets us evaluate the contribution of strict and realistic technology standards that –according to our calculations- would lead to half of the reductions of the CO₂ emissions target. Moreover, if we suppose that it is absolutely necessary to get to the desired reduction target (-75% CO₂ emission with respect to the year 2000 baseline) solely based on new motor technologies, Pegasus shows that “zero emission vehicles” (well-to-wheel) would be required to hit the market between 2020 and 2030. Furthermore, roughly 80% of the total vehicle fleet should be “zero emission” (well-to-wheel) by 2050. This would require a paradigm shift in technology that is seemingly unrealistic (nevertheless, it could happen, as rapid technology shifts have been observed before). Furthermore, prudence dictates that one should not rely solely on new motor technologies to reach the desired emissions reduction target. This pushes us to consider other scenarios.

3.2.2 *Chronos - Promoting green multimodality*

In this scenario, market oriented policies constrain the use of fast high carbon footprint modes leading to an increase in slower and cleaner transport modes (see figure 2). In Chronos the 75% reduction objective is nearly attained (see figure 3) through an action favoring greener modes by increasing transport costs accordingly to speed and emissions (per mode). As a result, the macroeconomic model shows sharp changes in the mobility determination that, in turn, has strong implications on behavior patterns. Thus we observe:

- a trade-off between the system's need for speed (coupled to growth)
- an increase in transport times in order to be able to take full advantage of all modes.

In this situation, Chronos implies a speed/GDP elasticity equal to zero, which translates into an increase in transport times (roughly 1 hour and 20 minutes per person

per day) because transport distances are still supposed as being coupled to growth. Since Chronos is a scenario based on market oriented public policies in an infrastructure intensive situation (because transport distances and public transport traffic keep increasing), public action in this scenario sums up to an increase in transport cost.

In Chronos, the microeconomic optimization is carried out in a carbon constrained economy, where the limits of new motor technologies push towards a differentiated modal evolution in order to further reduce emissions. This implies that transport costs go up whilst opportunities are constant.

$$\eta_{ij} = \frac{\text{opportunity}}{\uparrow \text{cost}}$$

In this manner, Chronos lets us appreciate that a mix of technology and strong policy can get us to the wished reduction target. Nevertheless, Chronos also shows that the limits of a continuous increase in transport distances are linked to financial constraints on the infrastructure investments required to ensure a steady growth in transport distances. Although investments represent the same percentage of GDP as today, we can question the viability (at least in matters of public acceptance) of large infrastructure investments (see table 2) in a situation where transport times and costs rise sharply.

3.2.3 Hestia - Promoting decoupling

The main issue in this scenario is a trade-off between an elevated transport cost and transport distances. Indeed, transport costs (both in time and in money) are higher than in Chronos and this translates into economic agents choosing to modify their locations and concentrate on proximity strategies (see figure 2).

In this manner, Hestia leads the way to the 75% (see figure 3) reduction objective through public policies which entail new trade-offs between location and transport distances. Thus, Hestia implies a speed/GDP elasticity equal to zero but since transport distances increase less rapidly –than in Pegasus and Chronos- transport times are reestablished around one hour per person per day. Furthermore, this new equilibrium based on proximity also gives a better opportunity for « low range 0 emissions technologies » to develop faster and better.

Higher prices and a growing degree of saturation push towards a differentiated spatial and modal evolution spawning from public action acting on opportunity and cost.

$$\eta_{ij} = \frac{\uparrow \text{opportunity}}{\uparrow \text{cost}}$$

In this manner, Hestia lets us appreciate a situation where mobility increases from the 2000 level but where infrastructure needs are not as overwhelming as in the other scenarios. Furthermore, Hestia depicts a situation where although transport cost goes up, opportunities keep on increasing and transport times are lowered. What is more, this

scenario boasts reduced investments needs. In that sense, we could suppose that this scenario might enjoy higher public acceptability. Nevertheless, very high constraints on air travel might overturn its attractiveness.

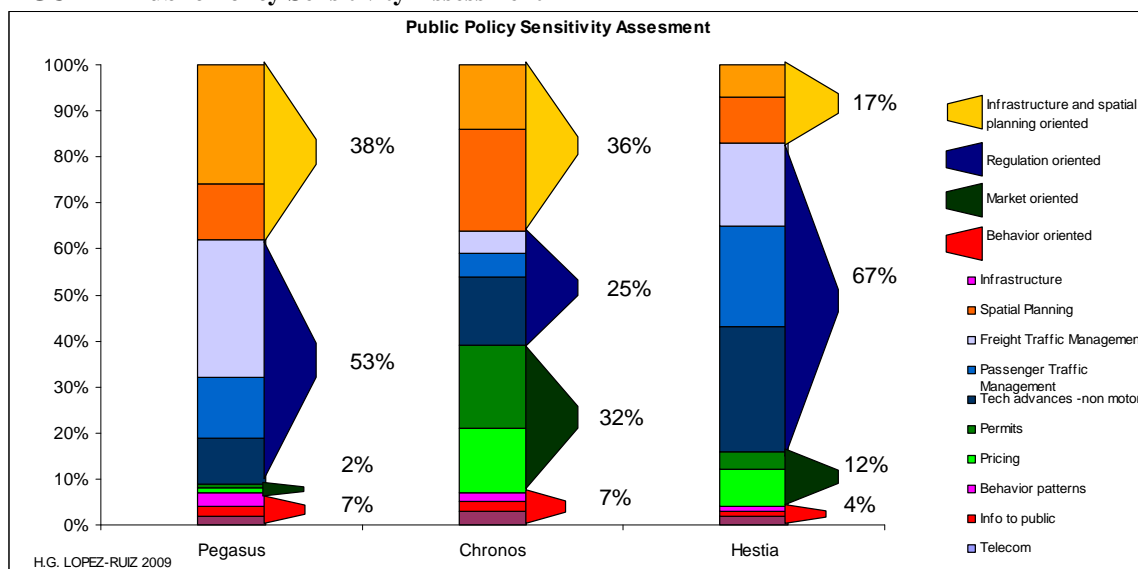
4. Assessing Public Policies and its Effects.

As we showed in the last section, the three scenarios presented imply different strategies concerning public policies. This entails big differences concerning choices in economic agents but also in the needed public investment for infrastructure and in transport spending. In order to have a better idea of what this means, a sensitivity analysis (SA) was performed on all three scenarios and results were obtained on two levels:

- contribution of the different policy categories to reductions
- implications on transport monetary budgets (for firms and households).

Thus, the SA of the three scenarios is calculated on the basis of effective CO₂ reductions (*i.e.* those that are not due to new motor technologies, which account for 48% of the reductions). The results obtained are as follows:

FIGURE 4 Public Policy Sensitivity Assessment



Concerning the implication of public policies on transport monetary budgets, our analysis is carried out by keeping transport demand determinants constant in time, in order to see what new traffic and transport costs imply on this structure. We are aware that this assumption on the determinants is quite unrealistic, nevertheless it is only used to asses the implications of public policies.

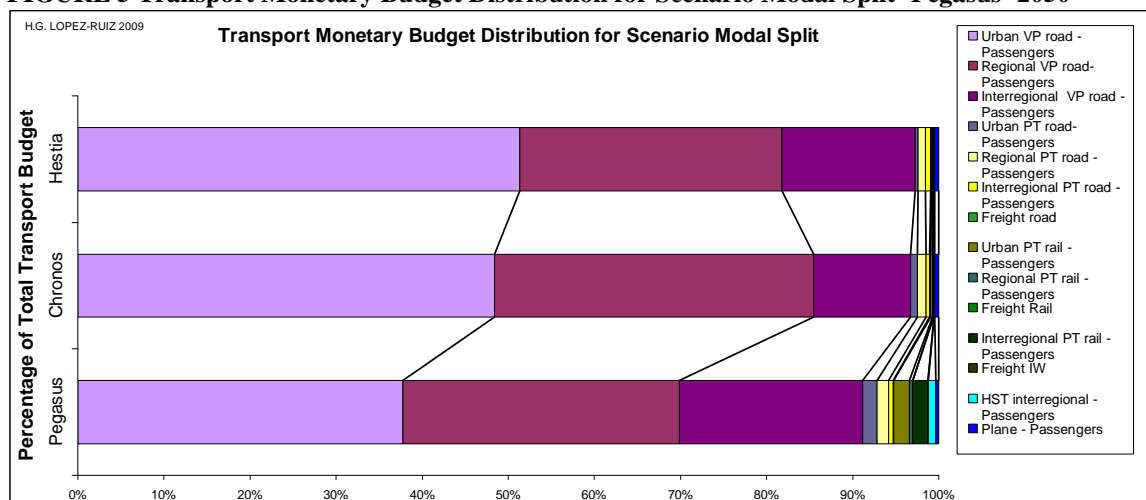
The Pegasus scenario is based on an inelastic market structure largely dependent on private vehicles. In the scenario, the modal split is explained by the fact that a rise in

oil prices translates into behavior changes that are determined by a sharp increase in private vehicle cost (figure 5) accompanied by a comparatively more interesting offer from public transport. Even though private vehicle costs go up, transport in Pegasus is very dependent on road transport and, thus, dependent on road infrastructures.

In Pegasus, the need for rail infrastructures is very important. Firstly, the mild increase of the cost linked to personal vehicle use incites the use of public transport (of which rail is a big part) on an urban and regional scale. Secondly, long distance travel in Pegasus is largely based on low air fares and a growing high speed train sector. Indeed, since Pegasus is based on a business as usual evolution -established on growing distances with stable transport times- high speeds on interregional transport are a big part of the scenario's equilibrium.

As we have already stated, in this scenario, the 75% reduction is not attained. The reductions in CO₂ emissions are solely obtained through the introduction of new hybrid motor technologies. In this manner, public policies appear merely as accompanying policies in an ongoing trend of the system with no real impact on GHE emissions. This explains why the scenario is mostly linked to regulation oriented policies as well as infrastructure and spatial development policies that accompany the BAU development.

FIGURE 5 Transport Monetary Budget Distribution for Scenario Modal Split -Pegasus- 2050



In the Chronos scenario, constraints on speed and emissions come into play as a signal aiming at changing behavior patterns. In consequence we observe an increase in road transport costs (figure 5) that are coherent with the CO₂ values that are actually being proposed by public authorities (A 32€ tax per ton of CO₂ is supposed to bring in over 8 billion Euros in tax revenues by 2010. This tax is supposed to go up to 350€ by 2050).

This rise in road transport cost translates into a sharp increase in the use of rail and public transport for personal and freight mobility. This in turn implies that average speed in the system goes down and transport times go up. This means that, if we suppose that

the market structure and its inherent elasticities do not change in time, household and firm transport budgets would invariably go up in a very sharp way (more or less depending on car use elasticity).

In Chronos, the monetary budgets for road transport go up so much that they are over 15% of total household and firm budgets (which are known to be fairly stable in time) (11). Therefore, in order for Chronos to be viable, we should accept a very sharp increase in public transport and rail subsidies (as a return of tax revenues into the system that would ease monetary budgets); accept that transport monetary budgets will go over the 15% mark which supposes that demand determinants and market structure would strongly change (especially concerning personal vehicle elasticity).

The system's adaptation in Chronos should be accompanied by very big investments in rail infrastructures that will offer over 30% of total trips. This entails a very big need in investment needs but also a very big need in subsidies for public transport.

Hestia is a scenario that is very influenced by proximity services, the public policies in play are largely related to spatial planning and infrastructure investment. This is also explained by the fact that Hestia is a scenario where market oriented policies are in place.

In the Hestia logic, the main trade-off at play is directly linked to location strategies and production organization aimed at decoupling transport distances. This entails a densification of main cities and production sites which would in turn translate into a sharp increase in the use of urban and regional road networks. In this manner road investments needed are less important than in other scenarios but they are totally concentrated on urban and regional infrastructure.

Even though road transport is important on an urban and regional level, investments in public transport represent over 30% of total mobility, especially on an interregional scale. This is automatically translated in very big needs in infrastructure investment on rail.

Unlike Chronos, this scenario's characteristics point towards a more stable monetary budget (around 15%), although current mobility determinants would imply a very big increase in road transport costs followed by a very sharp decrease in rail and public transport costs.

In this manner, the fact that public policies at play in the Hestia scenario aim at reducing CO₂ emissions through the decoupling of transport distances translates into investment needs that are largely inferior to Pegasus and Chronos.

Lastly, although specific results were not presented for the economic impact of each scenario, the analysis carried out on this matter shows that no negative impact on the economy is to come from any of the scenarios if -and only if- tax revenue stemming from

carbon taxing is correctly reinvested in transport services (infrastructure, regional transport aid, etc.) This joins the opinions of the recent CO₂ tax workgroup formed by French public authorities that even a positive impact on the economy could be expected if funds coming from tax revenues are correctly allocated.

5. Conclusions

On the basis of the three LET-ENERDATA scenarios that depict three different ways of attaining planned CO₂ reductions, we have presented new insight concerning public policies, investment needs and microeconomic trade-offs linked to sustainable transport development. What is more, this analysis was carried out with a methodology and a model that use widely available national statistics and that are applicable to other countries.

In sum, realistic technological hypothesis show that a 50% reduction in emissions is a clear possibility and that going further -solely based on new technologies- would require very big advances in zero emission vehicles.

Nevertheless, in the absence of these new technologies, the remaining reductions in emissions are possible through different types of policy mixes that come down to:

- encouraging important modal shifts that would translate into a decrease in total average speed which would in turn make transport times go up
- encouraging modal shift accompanied by a decoupling of transport distances, consecutively, this would help to maintain stable transport times.

This implies public action based on the optimization of cost and opportunities (subject to carbon constraint) aiming at a differentiation in modal and spatial evolution on the basis of the carbon footprint.

No real way of implementing these policies was proposed because the focus of this paper was not to offer a ready-made policy-mix. However, we offer a complete view of current studies concerning organizational solutions that could lead to a reduction in oil consumption and emissions through important changes in the transport structure and behavior patterns.

Although it is safe to say that organizational changes will most certainly be a part of the future of transport, the real challenge for a sustainable future will be linked to the analytical basis and decision-making tools used to plan policies for a sustainable environment.

In this manner, a shift from “truth seeking” methodologies referring to the maximization of opportunities based on quantity and variety towards “path seeking”

methodologies referring to a differentiation of choices based on optimizing cost and opportunities is necessary.

Moreover, the efficiency of environmental policies in transport will lie on the ability of international deciders and planners to convince almost every country in the world of the necessity for action in tackling CO₂ emissions while not forgetting equity issues between countries and populations.

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