

# Transportation infrastructures in a low carbon world : an evaluation of investment needs and their determinants - Supplementary Material

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# 1 Details on scenario alternatives

## 1.1 Transport activity

The aim of this parameters set is to represent two alternatives contrasted: (i) continuation of urban sprawl and the lock-in phenomena associated with high freight use in the economy and (ii) a decrease of mobility needs and freight use in order to represent activities relocation, supply-chains organization and teleworking. In the model, freight content is represented by the input-output coefficient of freight sector intermediate consumption by productive sectors. To represent the decrease of transport use for passenger, we supposed a shift of budget allocation from transportation to other sectors.

Parameter	Assumption 1	Assumption 2
Household budget share allocated to transportation	Constant	0.5% decrease each year
Input-output coefficients for freight use	Constant in all sectors	1% decrease each year

Table 1: Alternatives on transport activity determinants

## 1.2 Transport structure

For the baseline case, the car occupancy value was supposed to converge to the OECD countries values by 2100 in the 12 regions. In a second case, it was assumed that the car occupancy factor will converge to higher value in order to represent emerging new mobility phenomena as car sharing. In each region, the motorization rates increase with per capita income through variable income-elasticity: (a) low for poor households whose access to mobility relies on non-motorized and public modes; (b) high for households with a

medium per capita income (c) low again, because of saturation effects, for per capita income level comparable to that of the OECD. For developing countries, high and low values of income growth multiplier for the motorization rate were studied. About infrastructures policies, we created two alternatives on the evolution of road capacity in the model. In one case the road capacity increases with automobile stock and in another case, this capacity converges to a value corresponding to a threshold per capita. The latter assumption can create congestion in the model causing lower profitability of road car mode.

Parameter	Assumption 1	Assumption 2
Car occupancy	Convergence to 1.53 by 2100	Convergence to 1.89 by 2100
Income growth multiplier for motorization rate in emerging countries	1 (OECD value)	0.6
Road capacity for car	Increase with automobile stock	Convergence to a value corresponding to 7000 pkm per capita

Table 2: Alternatives on transport structure determinants

### 1.3 Transport intensity

High and low values for the learning rate value of the different car technologies (liquid fuel, hybrid, electric) were studied. This parameter has an impact on the investments costs and hence influences the evolution of the vehicle fleet. About the other terrestrial transports (trucks, train and public transports), two values of price elasticity of the sector energy intensity were studied.

Parameter	Assumption 1	Assumption 2
Learning rate for car technologies	0.1	0.2
Price elasticity of the energy sector intensity for other transports	-0.2	-0.4

Table 3: Alternatives on determinants of transports energy intensity

#### 1.4 Transport Fuels

In our numerical exercises with the Imaclim-r modelling framework, biofuels (first and second generation) and Coal-to Liquid fuels represent the main alternatives to refined oil over the 21st century. In our first assumption, we represented a relatively high availability of coal-to- liquids and a relatively low availability of biofuels, whereas it was the contrary in our second assumption, such that we considered one alternative (assumption 1) where alternative fuels were carbon intensive and one alternative (assumption 2) where alternative fuels had a lower carbon content.

Parameters subset	Parameter	Assumption 1	Assumption 2
Biofuels	Inertia factor on production	0.75	0.65
	Supply multiplying factor	1	1.2
Coal to liquids	Time scale of reactive anticipation for production	6	20

Table 4: Alternatives on transport fuel determinants

## 1.5 Natural growth drivers

The natural growth rate of the economy defines the growth rate that the economy would follow if it produced a composite good at full employment, like in standard neoclassical models developed after (Solow, 1956). In the IMACLIM-R model, it is given by exogenous assumptions on active population and labor productivity growth. We considered three alternatives corresponding to the Shared Socioeconomic Pathways (SSP)1, SSP2 and SSP3 values (Marangoni *et al.*, 2017).

Parameters subset	Parameter	Assumption 1	Assumption 2	Assumption 3
Productivity	Growth of the leader from 2001 to 2100	from 2.5% to 1.5%	from 2% to 1%	from 1.4% to 0.4%
	Convergence speed of the "laggards" in years	Low income : 400 Medium income : 200 High income : 150	Li: 500 Mi : 300 Hi : 200	Li : 800 Mi : 300 Hi : 200
Population	Growth rate of population	SSP1 OECD projection	SSP2 OECD projection	SSP3 OECD projection

Table 5: Alternatives on growth factors

## 1.6 Mitigation challenges determinants

Parameters subset	Parameter	Assumption 1	Assumption 2
End-use energy efficiency	Exogenous energy efficiency rate of the leader at fixed energy prices	0.5%	1%
	Other countries' speed of convergence (% of the initial gap after 100 years)	95 %	70%
	Asymptotic level of catch-up targeted by the laggards (% of the leader's energy efficiency)	30 %	85%
	Maximum rate of annual induced energy efficiency	3% for OECD countries 4% for others	3% for OECD countries 5.85% for others
	Maximum rate of autonomous energy efficiency	1% for OECD countries 1.13% for other countries	1% for OECD countries 2% for other countries

Availability of fossil fuels	Oil	Amount of ultimately re-coverable	3.6 Tb	3.6 Tb
	Gas	Indexation of gas price on oil price	Until 80\$/bl	Always indexed
		Price growth elasticity to production decrease	1	1
		Price growth elasticity to production decrease	3.5	2.5
	Coal	Price growth elasticity to production decrease	1	1
		Price growth elasticity to production increase	0.8	3
Development patterns		Asymptote to surface per capita	80-100	60-80
		Households industrial goods consumption saturation level	1.5-3	1.2-2
Availability of LC technologies for electricity	Nuclear	Maximum market shares	20%	No new nuclear
	Renew.	Maximum market shares	50%	80%
		Learning rates	5%	15%

Table 6: Alternatives on mitigation challenges determinants

## 2 Description of the data used in the module investments evaluation

Region	Passenger bus	Passenger rail	Passenger BRT/bus	Passenger high speed rail	Freight road	Freight rail
ASIA	73.4	23.2	0.1	3.5	71.4	28.6
CIS	57.5	42.5	0	0	12	88
MAF	94.4	5.6	0.13	0	88.2	11.8
LAM	98	2	0.9	0	78	22
OECD	55.7	35.5	0.7	8.8	64.7	35.3

Table 7: Mode split (%) of land transport activity (public transport and freight transport) for the past trend scenario, calibrated from different databases<sup>1</sup>

Mode	Unit	ASIA	CIS	MAF	LAM	OECD90
Road	lane.km/km2	3	1	1	1	4
Rail and HSR	track.km/km2	0.05	0.05	0.05	0.05	0.1

Table 8: Applied infrastructures density limits for the different regions in the model

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<sup>1</sup>World Bank (2017), Schafer (1998), Singh (2006), OECD (2017), UIC (2017) for ASIA; OECD (2017), ESCAP (2017) for CIS; World Bank (2017), Schafer (1998), UIC (2016), ITF (2017) for MAF; ITF (2017), Schipper *et al.* (2011) for LAM; UIC (2017), UIC (2016), OECD (2017), European Commission (2016) for OCDE. The overall volume of BRT activity taken from Dulac (2013) has been distributed among the different regions based on the shares of BRT infrastructure in each region (data from EMBARQ (2017)).



### 3 Past trends of investments on transport infrastructures

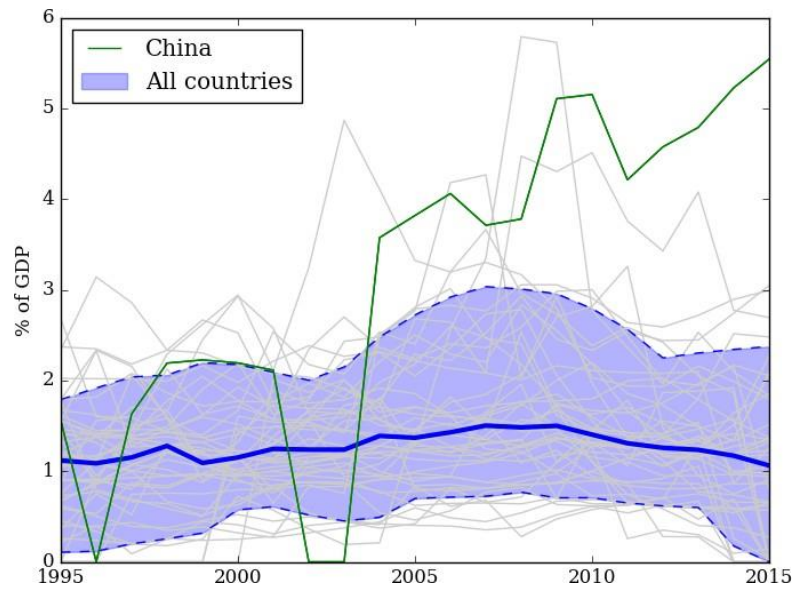


Figure 1: Historical annual investments on transport infrastructures (rail, road and airports) - median(solid line) and 10th and 90th percentile (dashed lines) - Data aggregated by the authors from OECD (2017) and World Bank (2017)

## 4 Evolution of mode shares over time for the five regions studied

		2015	2050			2080		
			Baseline	LMA	HMA	Baseline	LMA	HMA
<b>ASIA</b>	Personal Vehicle	24%	37%	34%	30%	41%	35%	30%
	Air	1%	3%	3%	3%	5%	4%	3%
	Public transport	40%	49%	50%	51%	44%	45%	41%
	Non Motorized	35%	11%	13%	17%	10%	16%	26%
<b>CIS</b>	Personal Vehicle	64%	68%	66%	61%	67%	47%	44%
	Air	2%	8%	8%	8%	14%	12%	9%
	Public transport	23%	20%	22%	24%	16%	26%	27%
	Non Motorized	11%	4%	4%	7%	3%	15%	20%
<b>MAF</b>	Personal Vehicle	31%	43%	41%	38%	50%	32%	27%
	Air	2%	5%	3%	3%	7%	2%	1%
	Public transport	42%	40%	42%	40%	30%	25%	21%
	Non Motorized	25%	12%	13%	19%	14%	41%	50%
<b>LAM</b>	Personal Vehicle	49%	52%	51%	52%	55%	57%	58%
	Air	5%	10%	10%	9%	12%	8%	6%
	Public transport	38%	36%	36%	37%	30%	31%	30%
	Non Motorized	8%	2%	3%	2%	3%	4%	6%
<b>OCDE</b>	Personal Vehicle	81%	69%	69%	70%	62%	66%	67%
	Air	6%	14%	14%	13%	19%	15%	13%
	Public transport	12%	16%	16%	16%	19%	19%	19%
	Non Motorized	1%	1%	1%	1%	0%	0%	1%

Table 9: Transportation mode shares in the different regions in Baselines, low mitigation ambi- tions (LMA) scenarios and high mitigation ambitions (HMA) scenarios (average values across scenarios sets)

# 5 Analysis of cumulative investments needs by including correlation between modal shift and climate policy implementation

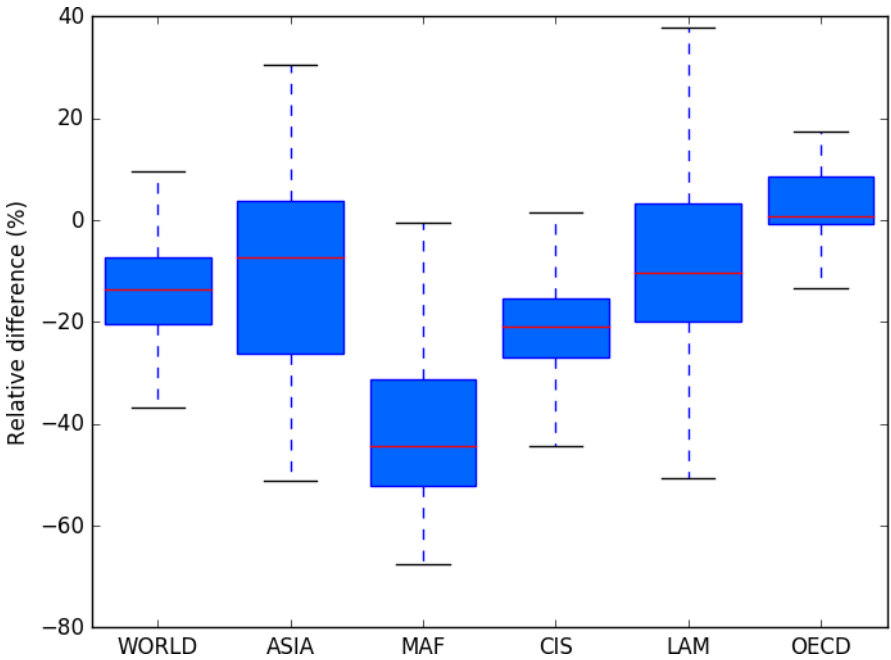


Figure 2: Relative difference in cumulative investment needs between mitigation scenarios with modal shift (from road to rail for public transportation and freight) and baseline scenarios without modal shift

## 6 Sensitivity analysis with cumulative investments needs as output

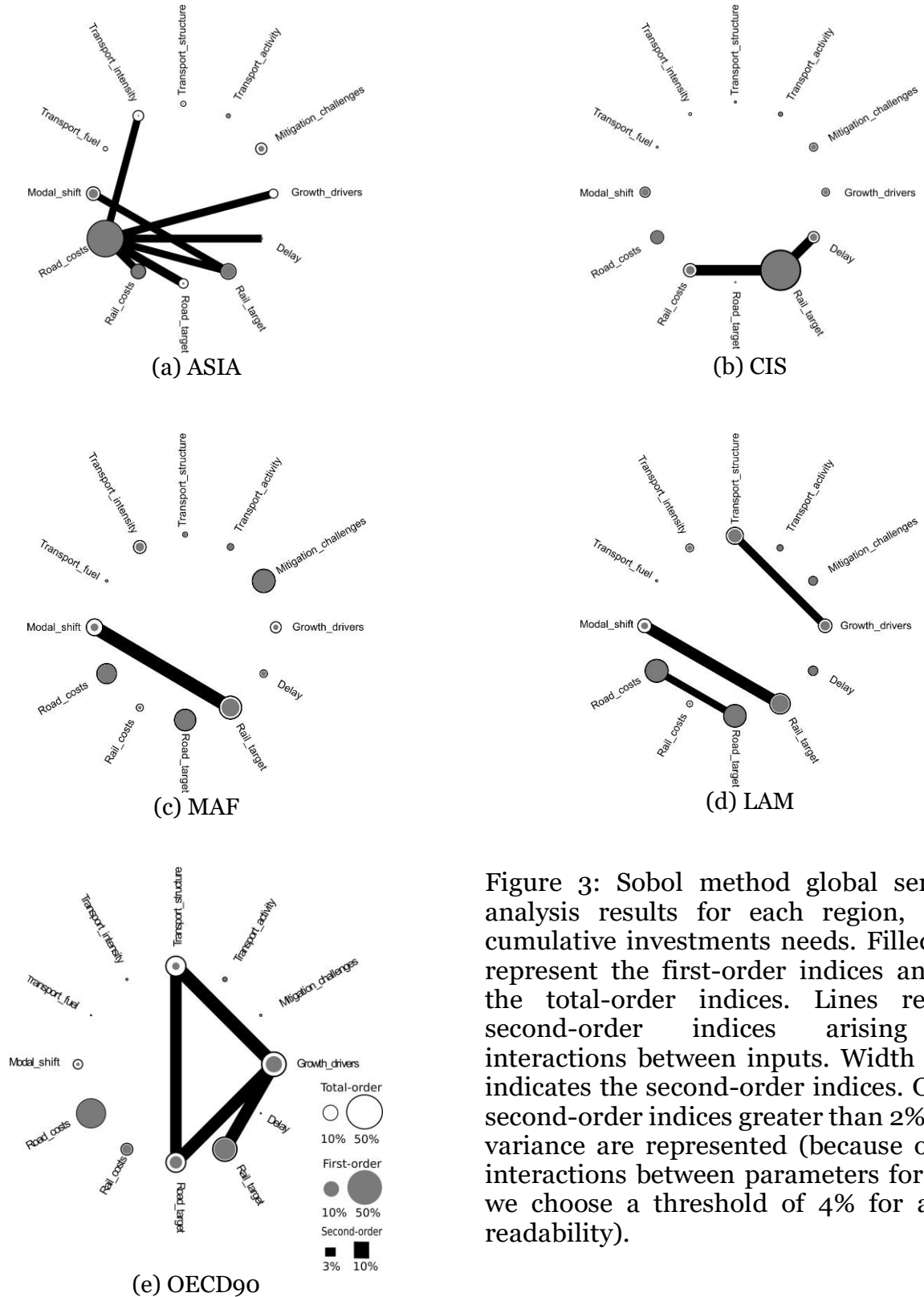


Figure 3: Sobol method global sensitivity analysis results for each region, for the cumulative investments needs. Filled nodes represent the first-order indices and rings the total-order indices. Lines represent second-order indices arising from interactions between inputs. Width of lines indicates the second-order indices. Only the second-order indices greater than 2% of total variance are represented (because of many interactions between parameters for OECD, we choose a threshold of 4% for a better readability).

## 7 Investment cost for passenger transportation by mode and region

We calculated the marginal investment cost of passenger-kilometer for the mode  $i$  in average for the period 2015-2050 using the next formula:

$$Marginal\_inv_i = \frac{(Cum\_inv_{i,2015-2050} - Constant\_maint\_inv)}{(pkm_{i,t=2050} - pkm_{i,t=2015})} \quad \text{with}$$

$Cum\_inv_{i,2015-2050}$  the cumulative investments (new built and maintenance) from 2015 to 2050;  $Constant\_maint\_inv$  the cumulative investments of maintenance if no new builds is added from 2015 to 2050 (constant activity);  $pkm_{i,t}$  the passenger activity for the mode  $i$  at the year  $t$ . Data of activity for the different infrastructures types (road and rail) have been converted in passenger-kilometers equivalent for the three modes using vehicle occupancy factors applied in the model.

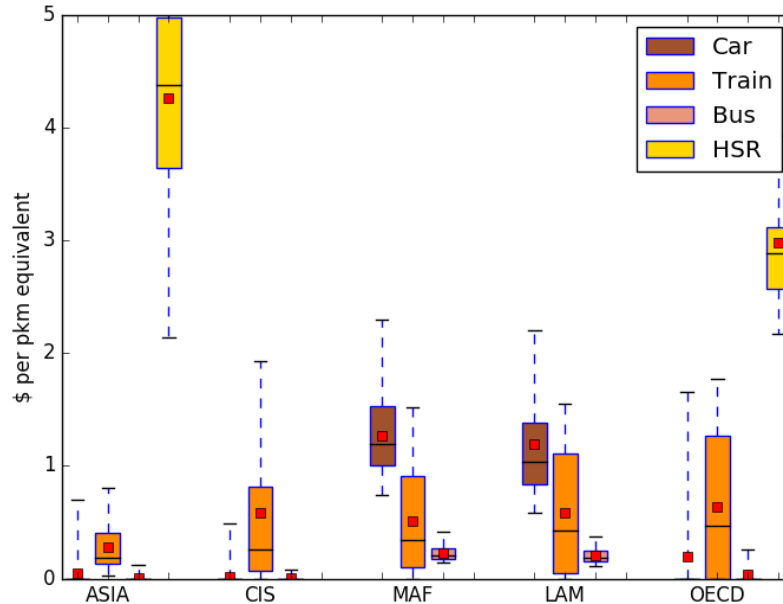


Figure 4: Distribution of marginal investment cost of one passenger-kilometer from 2015 to 2050 for the different regions and modes for passenger activity. Red squares represent the average of the distribution for all scenarios.

## 8 Contribution of ASIF factors to investments reduction under low carbon pathways

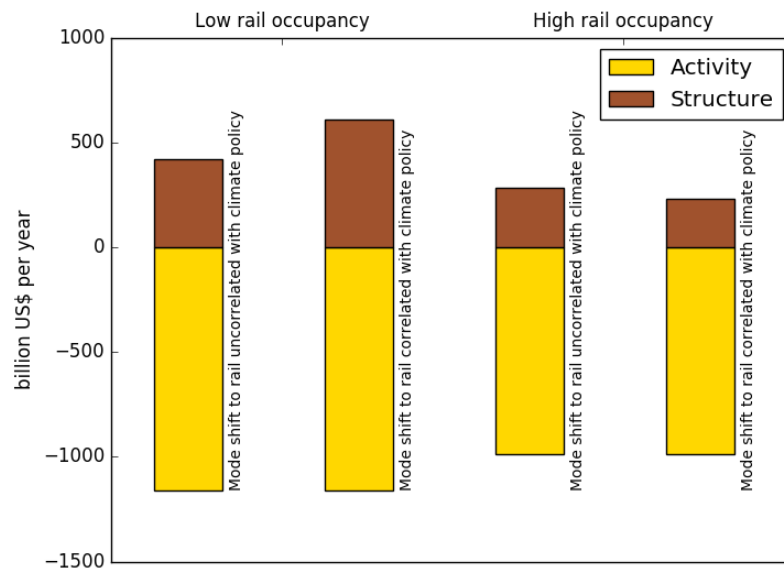


Figure 5: Decomposition of transport activity and structures effects on global investments needs per year for one scenario. Two rail occupancy rates have been tested. Red edges represent the cases where modal shift to rail is correlated to low carbon policy implementation. Fuel and Intensity factors are not on this figures because we did not consider in this study additional investments related to energy efficiency or infrastructures for the use of alternative fuels

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