Investment needs of transport infrastructures along low carbon pathways

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 suppose 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 is supposed to converge to the OECD countries values by 2100 in the 12 regions. In a second case, it is 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 are studied. About infrastructures policies, we create 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) are 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 are 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 represent a relatively high availability of coal-to-liquids and a relatively low availability of biofuels, whereas it is the contrary in our second assumption, such that we consider one alternative (assumption 1) where alternative fuels are carbon intensive and one alternative (assumption 2) where alternative fuels have 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 consider 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 2001	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

Table 5: Alternatives on growth factors

1.6 Mitigation challenges determinants

Parameters subset		Parameters	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 other countries	3% for OECD countries 5.85% for other countries
		Maximum rate of autonomous induced 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 recoverable	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 increase	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
	Renewables	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/Passenger 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 (except car) for the past trend scenario, calibrated from different databases[1]

Mode	Unit of stocks	ASIA	CIS	MAF	LAM	OECD
Road	thousand lane.km	16172	3108	2290	1489	24000
BRT	thousand trunk.km	1.24	0	0.309	1.8	2.05
Rail	thousand track.km	187	159	57.1	84.5	663.7
High speed rail	thousand track.km	36.43	0	0	0	24.77

Table 8: Calibration of infrastructures stock for the year 2015 from different databases[2]

Cost category	Mode	Unit	ASIA	CIS	MAF	LAM	OECD
New built	road	thousand usd/lane.km	1100	1000	1100	1200	1200
	brt	thousand usd/trunk.km	7000	7000	7000	7000	15000
	hsr	thousand usd/track.km	24000	24000	24000	24000	24000
	rail	thousand usd/track.km	4500	4000	4500	5000	5000
	air	usd/pkm	0.25	0.25	0.25	0.25	0.25
Upgrade/Reconstruction	road	share of new build cost	0.008	0.0075	0.009	0.008	0.009
	brt	share of new build cost	0.025	0.025	0.025	0.025	0.025
Operation and maintenance	road	share of new build cost	0.0075	0.0075	0.0075	0.0075	0.0075
	brt	share of new build cost	0.01	0.01	0.01	0.01	0.01
	hsr	share of new build cost	0.004	0.004	0.004	0.004	0.004
	airports	share of new build cost	0.01	0.01	0.01	0.01	0.01

Table 9: Costs of infrastructures- Sources : Broin & Guivarch (2016), Dulac (2013)

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 10: Applied infrastructures density limits for the different regions in the model

[1] 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.* (2010) for LAM; UIC (2017), UIC (2016), OECD (2017), European Commission (2016) for OCDE

[2] UIC (2016), CIA (2017) and EMBARQ (2017) for ASIA, CIS and MAF; EMBARQ (2017) and BID (2016) for LAM; UIC (2016) and IRF (2017) for OCDE

3 Past trends of investments on transport infrastructures

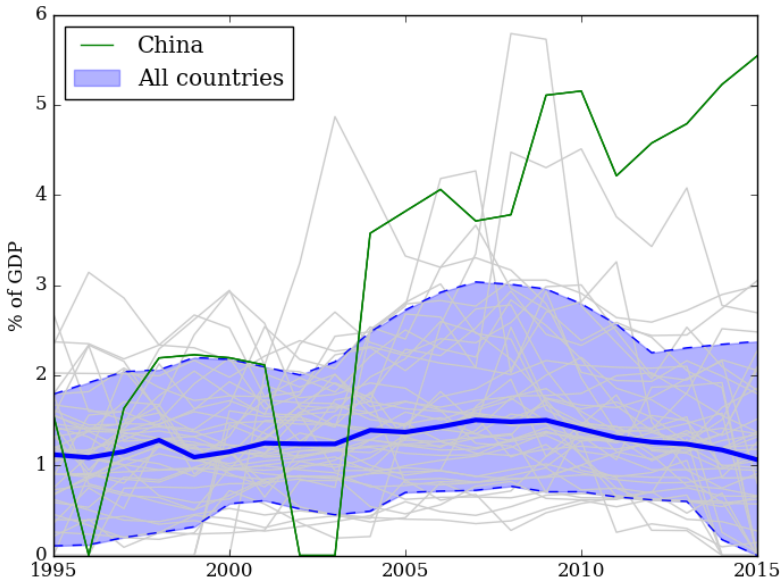


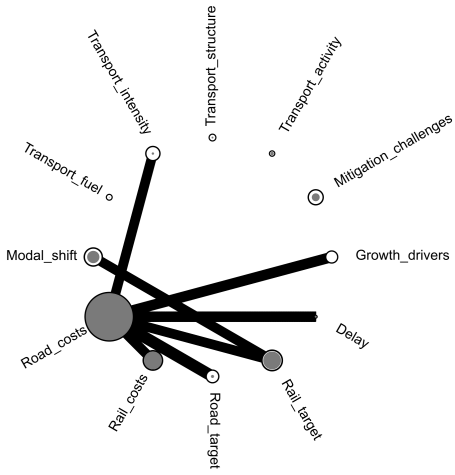
Figure 1: Historical annual investments on transport infrastructures (rail, road and airports) - median(solid line) and 10th and 90th percentile (dashed lines) - Data aggregated by the authors from OECD (2017) and World Bank (2017)

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

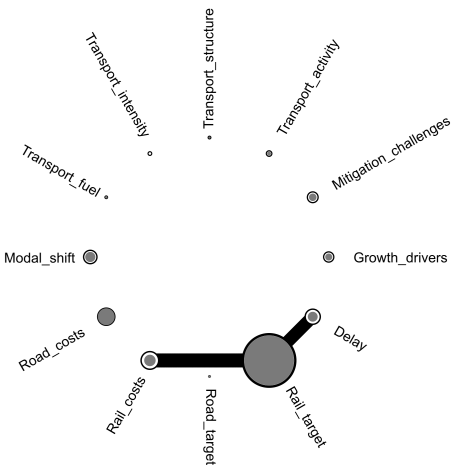
		2015	2050			2080		
			Baseline	LMA	HMA	Baseline	LMA	HMA
ASIA	Personal Vehicle	24%	37%	34%	30%	41%	35%	30%
	Air	1%	3%	3%	3%	5%	4%	3%
	Public transport	40%	49%	50%	51%	44%	45%	41%
	Non Motorized	35%	11%	13%	17%	10%	16%	26%
CIS	Personal Vehicle	64%	68%	66%	61%	67%	47%	44%
	Air	2%	8%	8%	8%	14%	12%	9%
	Public transport	23%	20%	22%	24%	16%	26%	27%
	Non Motorized	11%	4%	4%	7%	3%	15%	20%
MAF	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%
LAM	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%
OCDE	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 11: Transportation mode shares in the different regions in Baselines, low mitigation ambitions (LMA) scenarios and high mitigation ambitions (HMA) scenarios (average values across scenarios sets)

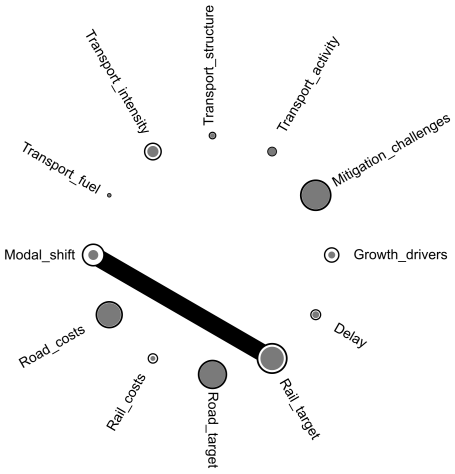
5 Sensitivity analysis with cumulative investments needs as output



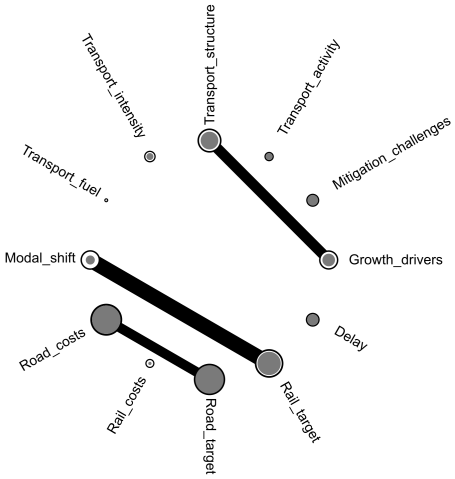
(a) ASIA



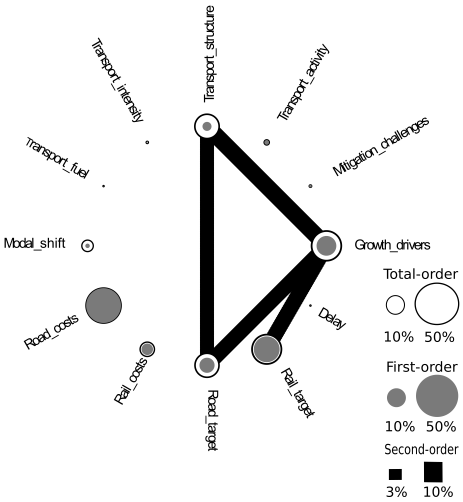
(b) CIS



(c) MAF



(d) LAM



(e) OECD90

Figure 2: 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).

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