C.I.R.E.D. Centre International de Recherche sur l'Environnement et le Développement

Chaire Modélisation prospective au service du développement durable

The transportation sector as a lever for reducing long-term mitigation costs in China

Meriem Hamdi-Cherif
hcmeriem@centre-cired.fr

34th International Energy Workshop

International Renewable Energy Agency (IRENA)
Abu Dhabi, *June 03–05 2015*

Context/Motivation

- **Chinese economic development** goes hand in hand with :
  - (i) A growth of the production
    Accompanied with an increase of the FREIGHT transport
  - (ii) An enriched population and fast-growing urbanization
    that induce increasing demand for passenger transport
    (notably an increase of the motorization rate)

- The Transportation sector is crucial for China
  - High reliance on oil products
  - Increasing energy demand
  - Increasing CO_2 emissions

  → Particularly regarding Energy Security and Climate Change issues

Rationale/Objective

- In its attempts to have a **sustainable development**
  - → The transportation sector is indeed particularly challenging for China
- To avoid important *“lock-ins”* in carbon-intensive pathways …

  … especially given

  - ✓ The high coal availability
  - ✓ The important life span of infrastructures

  → China has to redouble its efforts …

  …with voluntary schemes

Rationale/Objective

- In its attempts to have a **sustainable development**
  - → The transportation sector is indeed particularly challenging for China
- To avoid important *"lock-ins"* in carbon-intensive pathways …
  - … especially given
    - ✓ The high coal availability
    - ✓ The important life span of infrastructures
  - → China has to redouble its efforts …

    …with voluntary schemes

- *The purpose of this paper is to investigate the role of passenger and freight transportation activities in the transition to a low carbon Chinese society*
  - → It is an attempt to quantify the impact of urban voluntary policies on Chinese mitigation costs.
  - → A particular attention is given to specific measures designed to control the growth of mobility.

The role of transport in low-carbon pathways

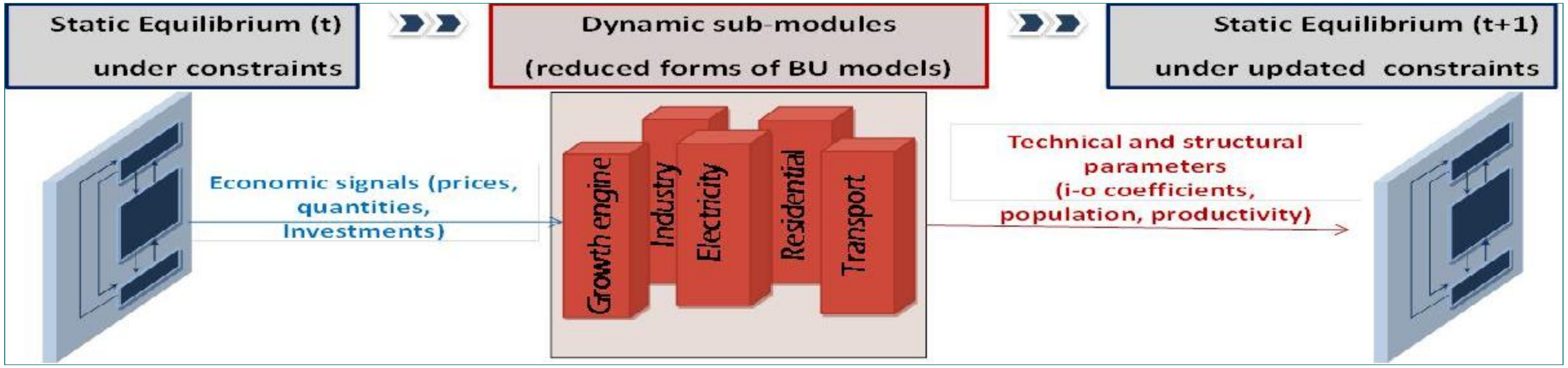
Methodology and Modeling approach

IMACLIM-R → Energy-Economy-Environment (E3) model

→ allows an explicit representation of the interplay between:

Transportation , Energy and Growth patterns

.



- General equilibrium model: Hybrid, multi-region, multi-sector, Dynamic and Recursive
- Represents the "second best " nature of economic interactions, and the inertias on technical systems (that limits the flexibility of adjustments)
- Relies on hybrid matrices ensuring consistency between money flows and physical quantities (Mtoe, passenger.kilometers and ton.kilometrs)
- Embarks a detailed description of passenger and freight transportation

Transportation in the IMACLIM-R model

The standard representation of transport technologies …

… is supplemented by an explicit representation of the **“behavioral” determinants of mobility**

Utility Maximization:

$$\boldsymbol{U_k}\left(\vec{C}_k, \vec{S}_{\boldsymbol{k}}\right) = \prod_{\substack{\text{goods } i \\ \text{services } j}} \left(\mathrm{C}_{\mathrm{k,i}} - bn_{k,i}\right)^{\P_{k,i}} \left(S_{\mathrm{k,j}} - bn_{k,j}\right)^{\P_{k,j}}$$

$$S_{k,mobility} = \left(\left(\frac{pkm_{k,air}}{b_{k,air}}\right)^{\text{¦}_k} + \left(\frac{pkm_{k,public}}{b_{k,public}}\right)^{\text{¦}_k} + \left(\frac{pkm_{k,cars}}{b_{k,cars}}\right)^{\text{¦}_k} + \left(\frac{pkm_{k,nonmotorized}}{b_{k,nonmotorized}}\right)^{\text{¦}_k} \right)^{-\text{¦}_k}$$

Twofold contraint:

A standard income budget constraint

$$ptc_k \cdot Income_k = \sum_i pArmC_{k,i} \cdot C_{k,i} + \sum_{\text{Energies } Ei} pArmC_{k,Ei} \cdot \left(S_k^{cars} \cdot \sim_{k,Ei}^{cars} + S_k^{m^2} \cdot \sim_{k,Ei}^{m^2}\right)$$

$$Tdisp_k = \sum_{\text{means of transport } \mathrm{T_j}} \int_0^{pkm_{k,T_j}} 2_j(u)\,du$$

A travel time budget constraint

Capacity=function (infrastructures, equipment)

Transportation in the IMACLIM-R model

This representation…

+

The dialogue between the *top-down* structure and the *bottom-up* modules allows to represent:

- The rebound effect of energy efficiency improvements on mobility
- Endogenous mode choices in relation with infrastructure availability
- The impact of investments in infrastructure capacity on the amount of travel
- The constraints imposed on mobility needs by firms' and households' location (urban form)

To assess the effects of mobility control measures on the Chinese economy
Three worlds are considered

- Reference: Business-As-Usual (**BAU**)

- A stringent climate objective ($3.4 W/m^2$ in 2100)/ Satisfied by a "carbon price only" policy (**S1**)

- Complementarily to carbon pricing ...

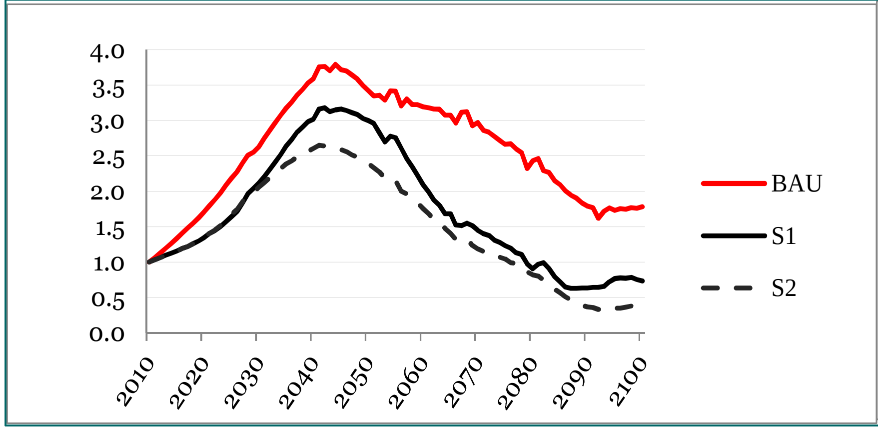
… we consider urban organization policies that aim at controlling the 'behavioral' determinants of the mobility demand (**S2**):

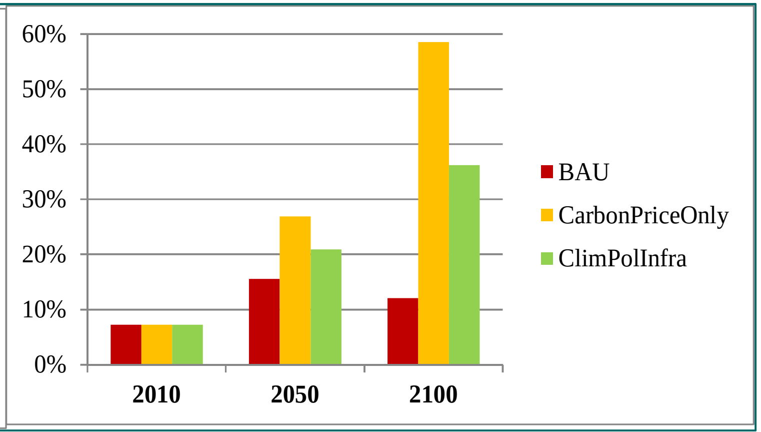
(i) Urban reorganization lowering the constrained mobility (i.e. mobility for commuting and shopping)

(ii) Reallocation of infrastructure investments in favor of public transportation modes

(iii) Adjustments of the logistics organization to decrease the transport intensity of production/distribution processes.

The transportation sector in the Chinese low carbon transitions





CO_2 emissions from transportation sector (as an index of 2010 level)

Share of emissions from Transport in the total Chinese CO_2 emissions

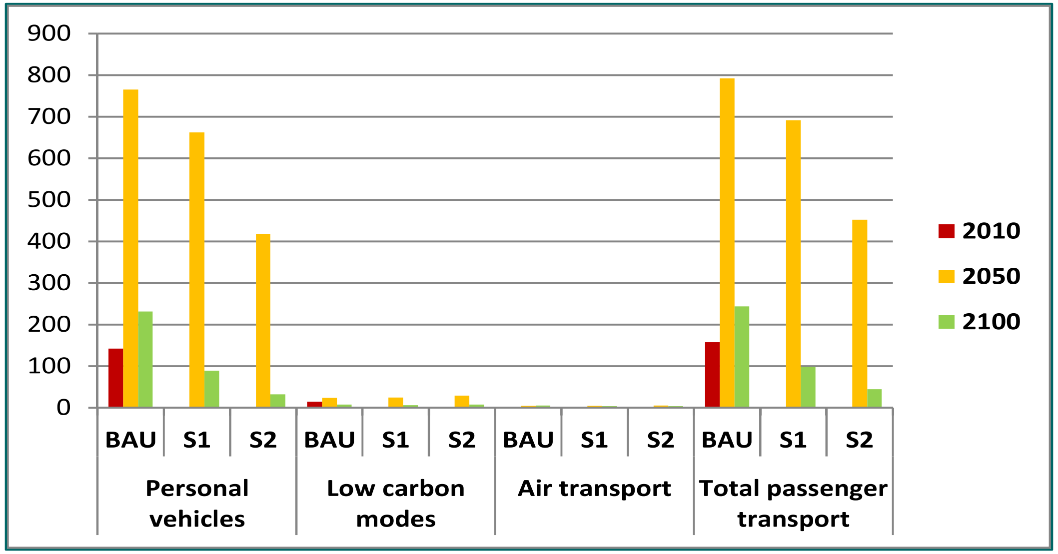
- Emissions decrease in the second half of the century … *population* …

- Despite this decrease …

  … Emissions from transport represent a significant part of remaining emissions (60% in S1 et 37% in S2)

- Effects of the mobility control measures: Emissions in S2 are lower during the whole century.

Dynamics of passenger transport



Chinese CO2 emissions from passengers transport (MtCO2)

Low carbon modes (public transport + non-motorized)

- Whatever the scenario, whatever the transportation mode…

  Emissions increase significantly during the first half of the 21st century

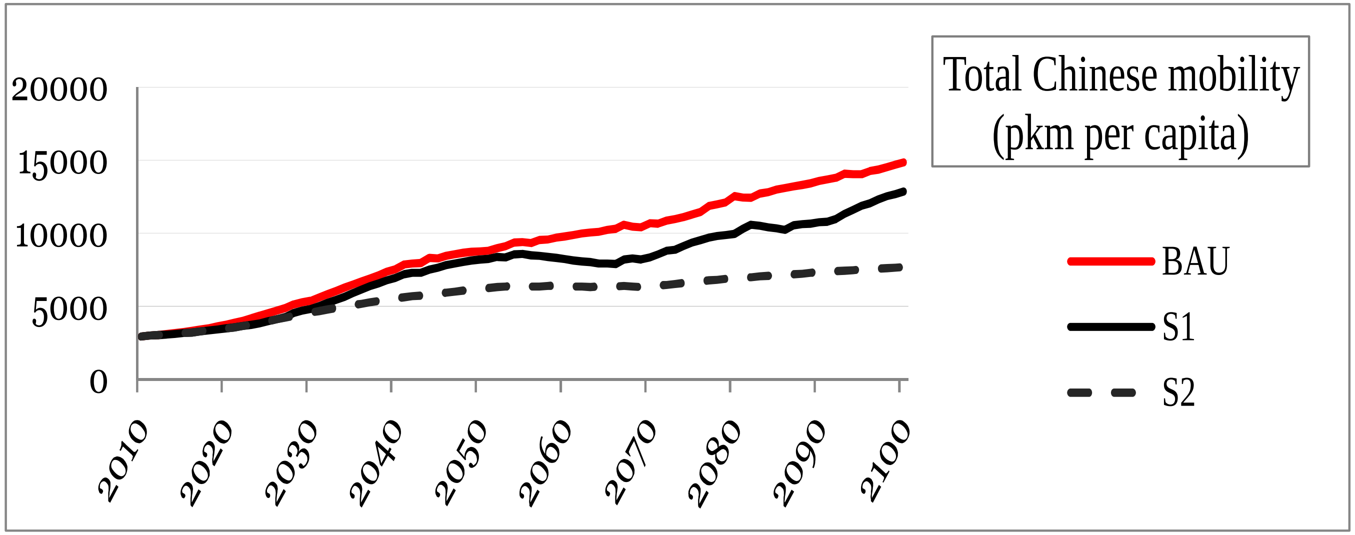
- While they remain above their 2010 level in the BAU scenario …

  they become significantly lower in the stabilization scenarios

  Particularly in S2! (-37% in S1 *vs*. -72% in S2)

- Mechanisms at play ?
  - The evolution of the total passenger mobility per capita
  - Modal structure evolution
  - Efficiency improvements and/or electrification of the vehicle fleet

Passenger Transport evolution



- The rapid increase of mobility in the baseline scenario …

  … is only moderately affected by the mitigation policy when the carbon price is the sole used instrument (-7% in 2050 and -13% in 2100)

  → Limitation in the increase of fuel costs

  (lower oil and coal demand induced by the climate policy)

  → Strong inertia of urban organizations (long-lived organization)

  (The constrained mobility can't be changed overnight!)

- The mobility in S2 is significantly lower. (-29% in 2050 and -48% in 2100)

  → measures favoring urban sprawl moderation

Passenger Transport
Modal breakdown

	2010	2050			2100		
		BAU	S1	S2	BAU	S1	S2
Pesonal vehicles	28%	78%	74%	60%	92%	88%	67%
Low carbon modes	72%	22%	25%	39%	7%	11%	31%
Air transport	0.2%	0.3%	0.4%	0.6%	0.6%	0.7%	1.5%

Modal distribution of the Chinese passenger mobility

- S1 and BAU are similar!
  - → The lowering of international oil and coal prices, due to the carbon price
    Partially offset the increase of fuel costs
    Motorized modes more accessible
  - → Investments in road infrastructures
    Decreases road congestion
    Favors the attractiveness of private cars at the expense of other transportation modes

Passenger Transport
Modal breakdown

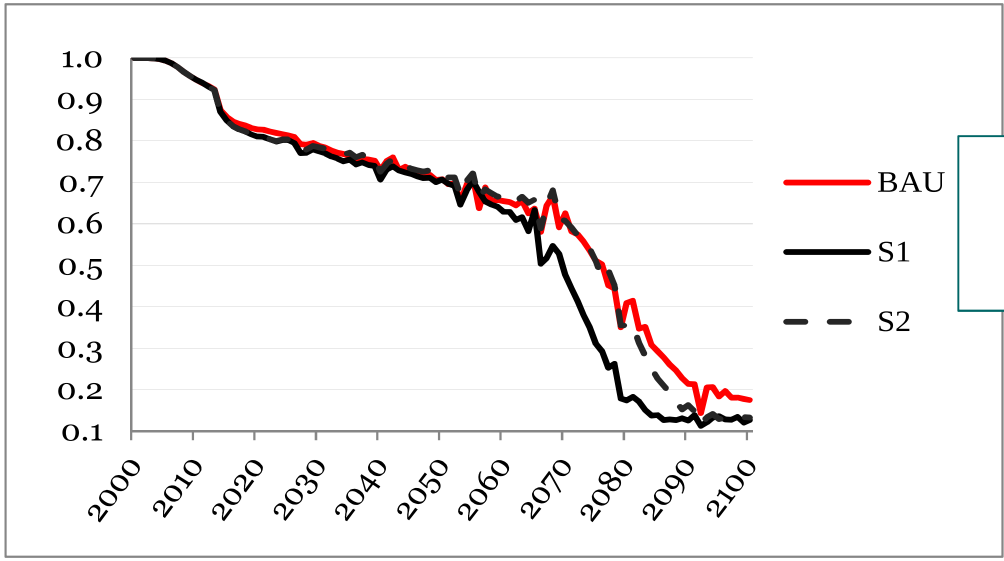
	2010	2050			2100		
		BAU	S1	S2	BAU	S1	S2
Pesonal vehicles	28%	78%	74%	60%	92%	88%	67%
Low carbon modes	72%	22%	25%	39%	7%	11%	31%
Air transport	0.2%	0.3%	0.4%	0.6%	0.6%	0.7%	1.5%

Modal distribution of the Chinese passenger mobility

- With specific measures triggering a redirection of investments in favor of low-carbon transportation infrastructures:

  → Significant shift from personal vehicles to public and non-motorized modes

Passenger Transport
Vehicles' Efficiency



Liquid fuel consumption of the Chinese personal vehicle fleet per pkm (Index of 2000 level)

- → To capture
  - → The efficiency improvements of internal combustion engines (ICE)
  - → The electrification of the fleet through the diffusion of hybrid and electric vehicles

- ➢ In the S1 scenario, the carbon price allows for significant vehicles efficiency improvements/BAU
- ➢ Lesser effect in S2, due to
  - → Lower carbon prices
  - → Slower fleet turn-over, due to lower vehicle use!

Passenger Transport
Determinants of emissions reductions

→ Very different according to the implemented policies

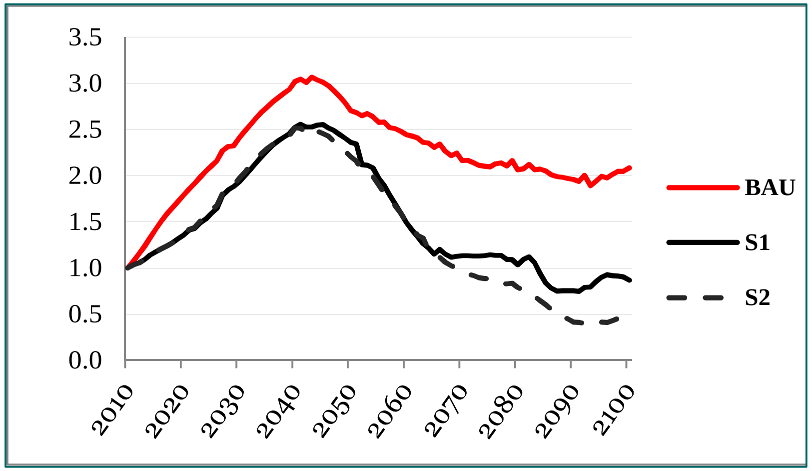
- If the carbon price is the only instrument …

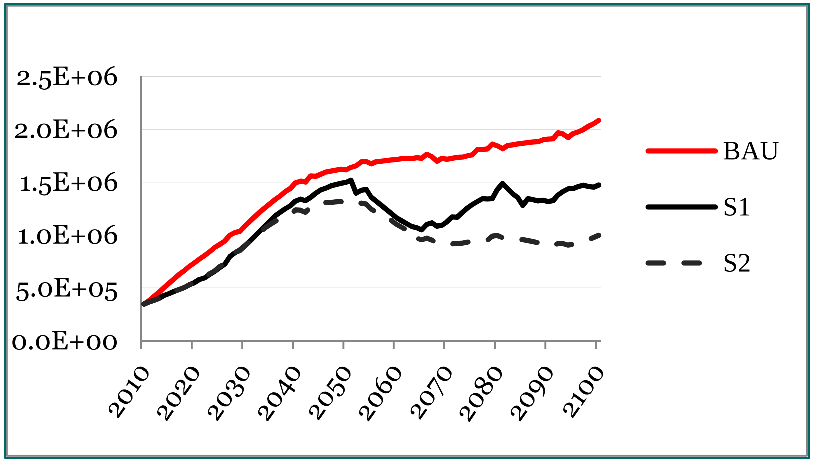
  the major effect comes from the diffusion of energy efficiency in vehicles

- When complementary policies are implemented …

  modal shifts towards low-carbon modes coupled with mobility reduction measures play a dominant role

Freight Transport





Chinese CO2 emissions from freight transportation

Chinese freight transportation activity (tkm)

- *Similar results … but lack of time …!*

Mitigation efforts in the Chinese economy

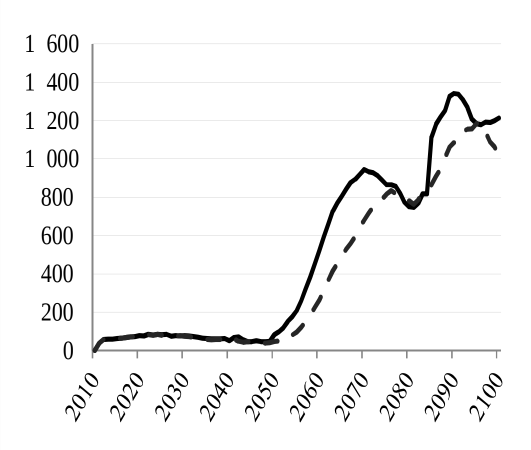
		2010-2050	2050-2100
Transports	S1	2.2%	-2.8%
	S2	1.8%	-3.4%
Electricity	S1	-2.7%	-3.0%
	S2	-2.3%	-2.3%
Industry	S1	-0.3%	-6.5%
	S2	-0.1%	-6.2%

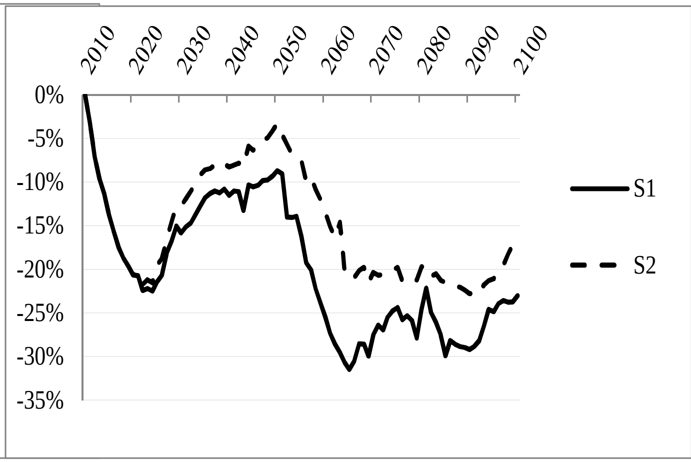
Mean annual emissions variations
By period – Three main emitting sectors

- Without specific measures aimed at reducing mobility, decarbonization efforts are mainly based on electricity and industry

- The "transportation policies"
  - ✓ increase the contribution of the transportation sector to mitigation efforts
  - ✓ allow the other main emitting sectors to slow their decarbonization efforts

Macroeconomic effects





CO2 price (left)

GDP variations / BAU (right)

- Very weak sensitivity of the transportation sector to price signals
  - → Need for very high CO_2 prices during the second half of the century to reach the climate target
  - → Significant macroeconomic costs if the CO_2 price is the only instrument
  - → The implementation of mobility growth control measures offers mitigation potentials independent of carbon prices
  - → These measures allow for important reductions in the level of carbon prices (on average 25% lower over 2050-2100)
  - → Significant reductions of the macroeconomic mitigation costs

    (costs are reduced by 5 points in 2050 and by 10 points in 2100)

Conclusion

- This study allows to highlight the role of transportation in the mitigation process

- Given a climate objective, …

  … the implementation of measures fostering a modal shift towards low-carbon modes + a decoupling of mobility needs from economic activity prove to:

  → Modify the sectoral distribution of mitigation efforts

  → Contribute to avoid the risk of 'lock-ins' in carbon-intensive pathways

  → Significantly reduce the mitigation macro-economic costs relatively to a "carbon price only" policy

→ **Early** and **voluntary infrastructure policies** have a key role to play…

… as a **hedge against the risk of very high costs** of the climate stabilization that China seems to undertake …

Centre International de Recherche sur l'Environnement et le Développement

C.I.R.E.D.

Chaire Modélisation prospective au service du développement durable

Thank you for your attention !!

Meriem Hamdi-Cherif
hcmeriem@centre-cired.fr

http://www.imaclim.centre-cired.fr/

34th International Energy Workshop

International Renewable Energy Agency (IRENA)
Abu Dhabi, June 03–05 2015

Transport de passagers
Répartition modale

	2010	2050			2100		
		BAU	S1	S2	BAU	S1	S2
Pesonal vehicles	28%	78%	74%	60%	92%	88%	67%
Low carbon modes	72%	22%	25%	39%	7%	11%	31%
Air transport	0.2%	0.3%	0.4%	0.6%	0.6%	0.7%	1.5%

Modal distribution of the Chinese passenger mobility

- Although very small (1.5% in 2100), the share of the air transport is significantly higher in S2:

  mobility needs are decreased due the urban reorganization, and can be satisfied by low-carbon modes, which releases time and budget to … travel by plane.

Salient features of the IMACLIM-R framework (1)

Improving the realism of the description of consumption patterns

- Energy consumption does not provide satisfaction by itself but through the **services** (light, heating, devices) it delivers.
- Transport consumption shows specific patterns: **Zahavi's law** (constant time-budget), rebound effect, congestion, modal choice.
- Energy consumption and transportation are driven and constrained by the **ownership of durables**, cars and square meters of housing (themselves driven by their prices)

Static equilibrium under short-run constraints: demand

Utility maximization:

$$\boldsymbol{U_k}\left(\vec{C}_k,\vec{S}_{\boldsymbol{k}}\right)=\prod_{\substack{\text{goods } i\\ \text{services } j}}\left(\mathrm{C}_{\mathrm{k,i}}-bn_{k,i}\right)^{\P_{k,i}}\left(S_{\mathrm{k,j}}-bn_{k,j}\right)^{\P_{k,j}}$$

$$S_{k,mobility}=\left(\left(\frac{pkm_{k,air}}{b_{k,air}}\right)^{\text{¦}_k}+\left(\frac{pkm_{k,public}}{b_{k,public}}\right)^{\text{¦}_k}+\left(\frac{pkm_{k,cars}}{b_{k,cars}}\right)^{\text{¦}_k}+\left(\frac{pkm_{k,nonmotorized}}{b_{k,nonmotorized}}\right)^{\text{¦}_k}\right)^{-\text{¦}_k}$$

Under two constraints:

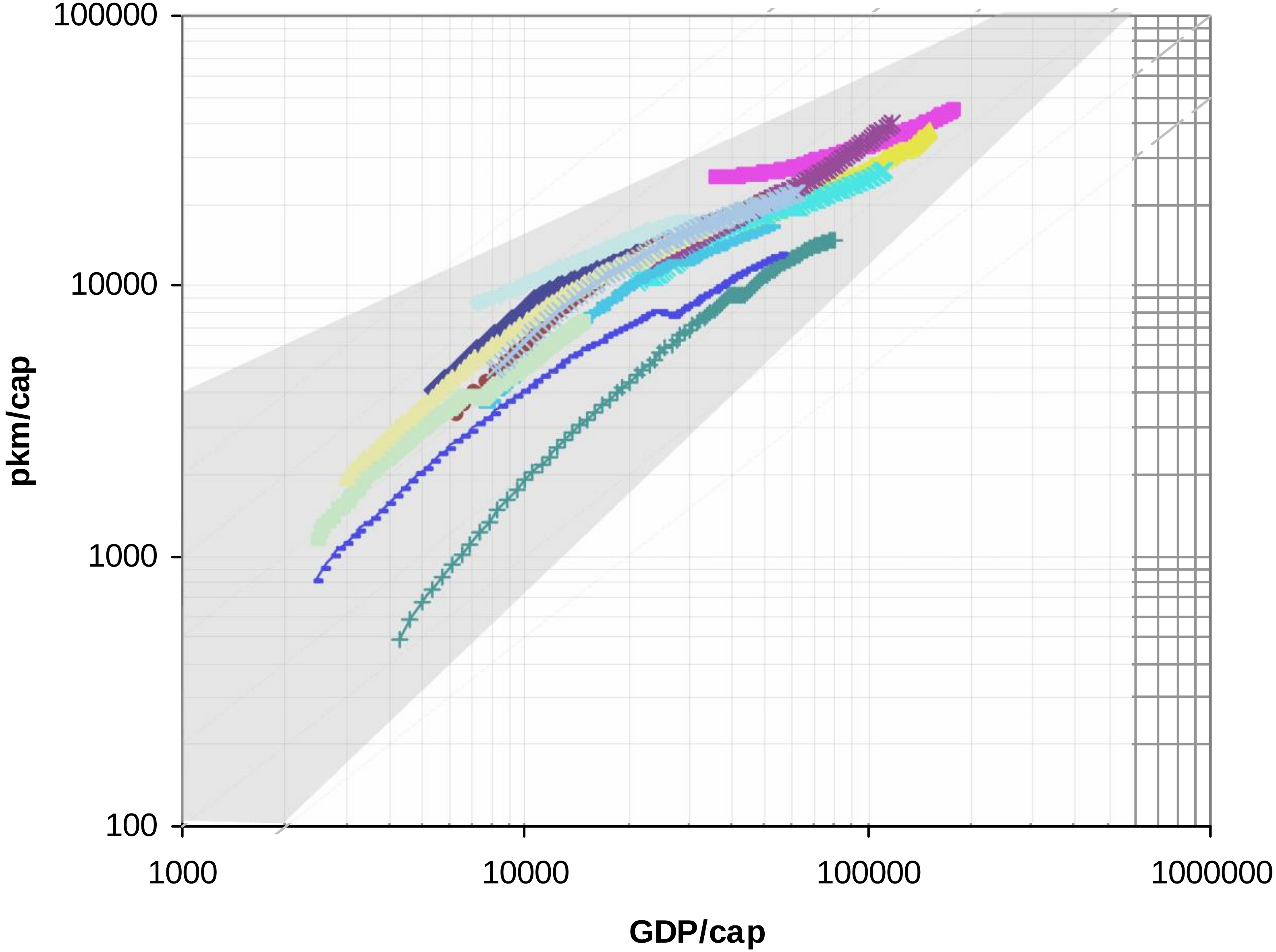
$$ptc_k\cdot Income_k=\sum_i pArmC_{k,i}\cdot C_{k,i}+\sum_{\text{Energies } Ei} pArmC_{k,Ei}\cdot\left(S_k^{cars}\cdot\sim_{k,Ei}^{cars}+S_k^{m^2}\cdot\sim_{k,Ei}^{m^2}\right)$$

$$Tdisp_k=\sum_{\text{means of transport } \mathrm{T_j}}\int_0^{pkm_{k,T_j}}2_j(u)\,du$$

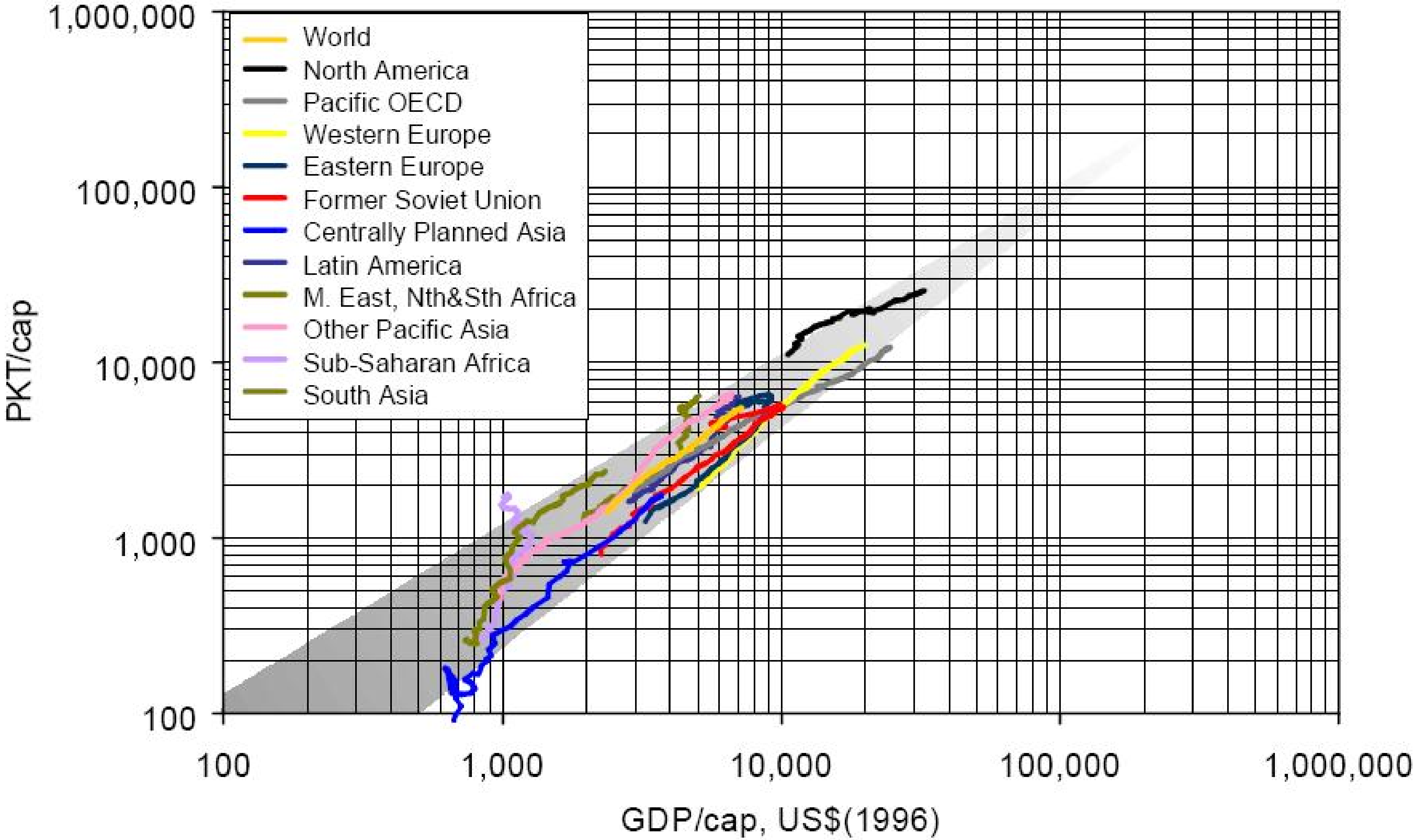
Capacity=function (infrastructures, equipments)

Illustrative results
at the global level

Evolution of mobility per region (model results)

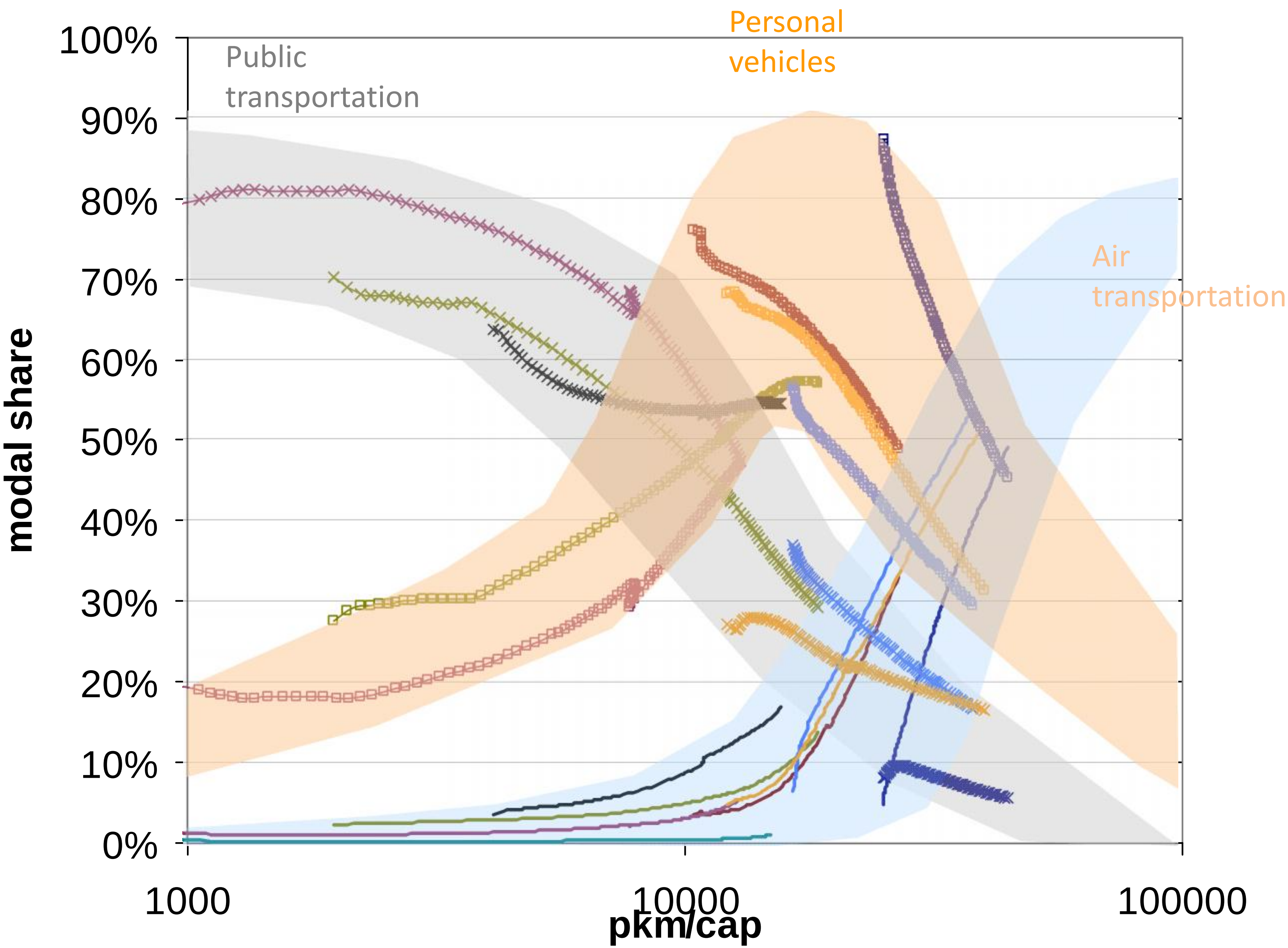


Evolution of mobility per region (historical data)

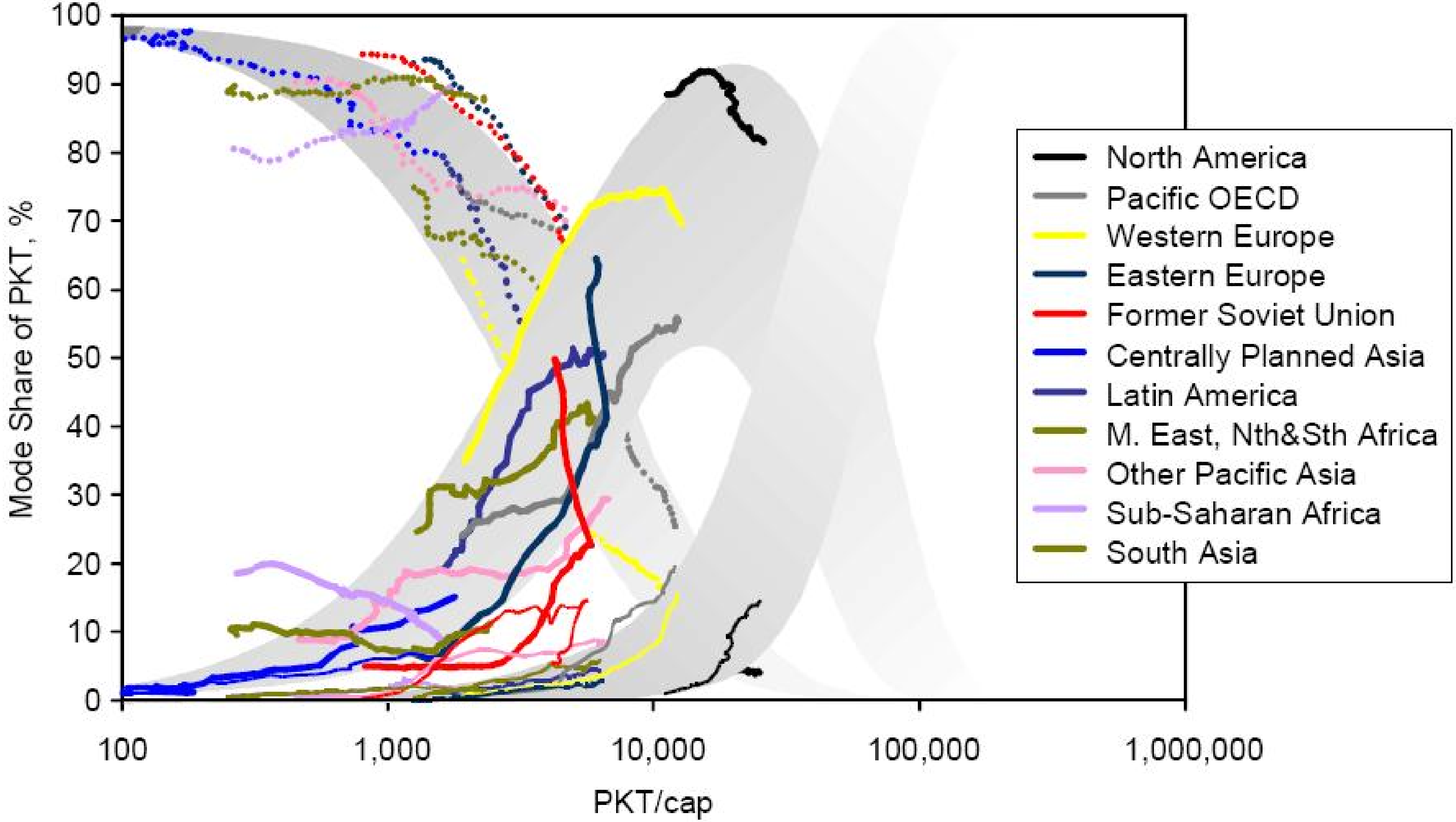


Source: Schäfer, 2007. Long-term trends in global passenger mobility.

Evolution of modal shares per region (model results)



Evolution of modal shares per region (historical data)



Source: Schäfer, 2007. Long-term trends in global passenger mobility.