HAL
open science

Climate policies : what if emerging country baseline were not so optimistic? - a case study related to India

Sandrine Mathy, Céline Guivarch

To cite this version:

Sandrine Mathy, Céline Guivarch. Climate policies : what if emerging country baseline were not so optimistic? - a case study related to India. 2009. halshs-00366276

HAL Id: halshs-00366276

https://shs.hal.science/halshs-00366276v1

Preprint submitted on 6 Mar 2009

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Climate policies : what if emerging country baseline were not so optimistic? – a case study related to India

Sandrine Mathy[a,*], Céline Guivarch[a]
a Centre International de Recherche sur l'Environnement et le Développement, Nogent-sur-Marne, France
* Corresponding author at: CIRED, 45bis, Av. de la Belle Gabrielle, F-94736 Nogent-sur-Marne, France.
Tel.: +33 1 43 94 73 96; fax: +33 1 43 94 73 70.
E-mail address: mathy@centre-cired.fr (S. Mathy)

Keywords

India, domestic policies and measures, climate policies, long term scenarios, international negotiations, power sector, climate regime, policies and measures, energy efficiency, realistic baselines, peak-oil

Abstract

One of the current main objective of international negotiations on climate change aims at enlarging the coordination regime to developing countries (DCs), and particularly to emerging countries. The international coordination system built at the Kyoto Conference relies on a coordination system based on a purely climate centric approach which shows irreconcilable contradictions between climate and development issues. This article aims at evaluating possible pathways implementing synergies between climate policies and development policies in order to create an incentive towards DCs to take part in climate mitigation. We focus on an illustrative example on India.

When most reference scenarios postulate rapid energy decoupling of the GDP and rapid decarbonisation of DCs economies in the future, this article elaborates, with the IMACLIM-R model, a baseline taking into account weaknesses and current disequilibria of the Indian technico-economic system such as the high dependency on imported energy, or the structural shortage in electricity. We show why a purely climate centric approach (quota allocation), adopted to commit with a world objective of stabilization to 550ppm, induce very high transition costs in spite of significant financial transfers. On the contrary, a strategy based on the research of synergies between the reduction of these disequilibria, and the mitigation of GHG emissions is investigated in the power sector, which presents the biggest potential of no-regret measures. This permits to drop down transition costs applied to the Indian economy by improving the overall energy efficiency. An economic and environmental evaluation of this alternative scenario is lead.

Introduction

Existing reference scenarios forecast optimistic views on the spontaneous decarbonisation of economies (Pielke et al. 2008) leading to a possible underestimation of the challenge posed by climate change and to biased recommendations in term of climate policies necessary to respond to climate mitigation.

One reason for that is that economic models often consider the world as a first best world in which economic signals and particularly relative prices signal function drive technological change and in which there is no no-regret potential, i.e. there is no measure that can lead at the same time to a reduction of GHG emission and to economic gains, i.e. there is no possible synergies between climate mitigation and development. With this assumption, to reach decarbonisation, to give a price to carbon will be enough. This is one of the reasons why international negotiations have considered climate policies only as a carbon price (via the emission permit price in a quota scheme).

This is without considering that real world doesn't behave according to economic theories assumptions. This is of primary importance since, optimal tools in a first best world may deteriorate the situation if applied in a second best world. This is the reason why to evaluate the economic impact and possible decarbonisation induced by climate policies, it is necessary to disentangle the mechanisms driving decarbonisation in an economy and the constraints that may stall this process, in order to identify the conditions and the measures which can lead to decarbonisation.

Our goal in this paper is to conduct such an analysis. Taking India as a case study, we analyse climate policies and their impact, as well as the barriers that may prevent decarbonisation, and that are likely to persist. The global

mitigation objective is to commit to a global 550ppmCO2eq stabilization objective[1] that is to be reached with quota allocation responding to a contraction and convergence[2] rule. We consider particularly existing barriers that prevent decarbonisation and that are likely to persist. To do this, in the first section, we build with the IMACLIM-R model a long term (2050) baseline specifically for India that accounts for deficiencies in the power sector. This has deep implications in terms of climate policies that would be suitable. In the second section, we show that the implementation of quota allocation (that is translated through an international carbon price and financial transfers) implies high transition costs until 2030 that are likely to be unacceptable. We disentangle economic mechanisms at stake. To correct this, we propose in the third section an alternative mitigation scenario for India, focusing on the alleviation of deficiencies in the power sector through specific policies and measures in parallel to the quota allocation system. This leads to a 50% reduction of the transition costs. In conclusion, India could profit from a global climate regime if it would be implemented nationally in a consistent way, but if not it might fear significant economic losses in the transition period. Apart from recommendations regarding modelling methodologies that need to embark the representation of the specific national circumstances, this drives us to recommendations for improving an international agreement related to climate change and for the definition of an enlarged climate regime.

Building a reference scenario accounting for real inefficiencies of the Indian technico-economic system

Do existing scenarios forecast too optimistic energy decoupling?

A large panel of reference scenarios related to India can be found in the literature: successive annual World Energy Outlooks (WEO) from the International Energy Agency (IEA), International Energy Outlooks (IEO) from the Department of Energy of the United States (DOE), declination of SRES scenarios at the Indian level (Shukla, 2006). Most of them are based on exogenous economic assumptions which determine energy demand, induced energy supply needed, and GHG emissions till a medium/long term horizon (2030 or 2050). A comparison of main characteristics of these reference scenarios to past trends are given in table 1.

Table 1: Comparison of GDP, primary energy supply growth rates, of energy decoupling and of GHG emissions of existing reference scenarios (from the IEA, and the DOE) to past tendencies

	Period	Economic annual growth	TPES annual growth	Energy decoupling	CO_2 emissions (2030/2005)
Past tendencies (Enerdata)	1975-1995 1995-2005	5.0% 6.4%	6.0% 4.7%	1.2 0.8	
WEO 2007 Reference scenario	2005-2015 2015-2030	7.2% 5.8%	3.7% 3.6%	0.51 0.60	x 2.9
WEO07 High Growth scenario	2005-2015 2015-2030	8.3% 7.5%	4.1% 4.3%	0.49 0.57	x 3.4
WEO07 Alternative scenario	2005-2015 2015-2030	7.2% 5.8%	3.0% 2.8%	0.42 0.48	x 2.2
IEO 08 (DOE, 2008)	2008-2015 2015-2030	7.1% 4.6%	2.9%	0.5	

Figures related to the energy decoupling provided in these reference scenarios are of particular interest. They mark a real breaking point compared to past trends, as between 1975 and 1995, the elasticity of primary commercial energy to GDP was equal to 1.2, and the elasticity of electricity consumption to GDP was more than 2. Between 1995 and 2005, even if the energy decoupling increased, energy intensive sectors which have lead the economic growth, remained highly inefficient with energy consumption critically high compared to international standards (Graus et al. 2007; Kim and Worrell, 2002). Energy decoupling of the Indian economy remained close to 1, while the consumption of electricity kept on growing faster than GDP.

Such a decoupling as described in WEO and IEO scenarios is not out of reach, but recent observed trends could refute such optimistic decoupling. Raupach *et al.* (2008) have shown that nearly constant or increasing trends in energy intensity have been recently observed in both developed and developing countries particularly in rapidly

[1] With a stabilisation at 550ppmCO2eq, there is only a 30% probability to reach the +2°C target which has become the official objective of European Union in 1996. The IPCC also sets at +2°C the limit of warming in order to avoid dangerous and irreversible climate disruptions.

[2] The contraction and convergence strategy (Meyer 2002) consists of reducing overall emissions of greenhouse gases to a safe level, ('Contraction'), where the global emissions are reduced because every country brings emissions per capita to a level which is equal for all countries, ('Convergence').

developing economies. Pielke *et al.* (2008) also show that the IPCC assumptions for decarbonisation in the short term (2000–2010) are already inconsistent with the recent evolution of the global economy. All SRES scenarios predict decreases in energy intensity during 2000 to 2010. But in recent years, global energy intensity has risen, reversing the trend of previous decades. Following R. Pielke: "One reason for the current increase in global energy and carbon intensities is the economic transformation taking place in the developing world, especially in China and India".

Forecasting such high levels of energy decoupling as the ones forecasted in WEO and IEO scenarios is coherent with the branch of literature (Goldemberg 1998) that argues developing countries should leapfrog to low energy GDP elasticity without passing through the "top of the hill", as they should benefit from transfers of modern and low GHG emitting technologies, but there are reasons why such a transition may be stalled by market and institutional failures of the energy system. They are extensively described in the following sub-section.

Embarking market and institutional failures in a reference scenario

The Indian energy system has long been very inefficient. Successive governmental plans have tried to bridge the gap between a rapid growing demand and a highly constrained development of producing capacities, but until now, attempts have rather failed. Whether these failures are likely to persist or not is decisive for the evaluation of GHG emissions trajectories because 55% of electricity rely on coal (which represents 57% of CO_2 emissions) and because these suboptimalities could induce inertia in the penetration of cleaner technologies.

The power sector remains characterized by a restrained access to energy services for both households and productive sectors:

- Capacity shortage amounts to 10 GW (i.e. 14.8% of peak power) and the gap between supply and demand rose to 66 TWh (9.6% of total demand) in 2007.
- Electrification covers only 60% of Indian households. The energy needs of the 40% of Indian households not connected to the grid rely mainly on biomass or on diesel generators to compensate for the deficiencies in the centralized power supply.
- Productive sectors are also affected by power cuts, which hinder productivity and development, in particular for the industry, and force the use of diesel generators as well.

Power cuts and capacity shortage are caused by structural under-investment in the power sector, rooted between market and institutional failures. The opening of the sector to independent power producers that began in 1991 in order to absorb the shortage and to compensate for the constraints on public funding has failed in improving the situation as the private sector contributes only to 11%, 0.4% and 12% of total generation, transport and distribution respectively. And, overall, during the 10th Plan (2002 – 2007), less than the half of the additional power capacity that had been forecast, has actually been built. This is largely due to too high risks incurred by private investors when investing in India. Administered prices can not guarantee a sufficient level of profitability, as the Indian government keeps on following cross subsidies, which induce important tariff distortions. These subsidies are justified by positive externalities on development, particularly regarding access to cheap energy for irrigation in an effort to promote food production (Tongia and Banerjee, 1998).

In 2006, the average price of electricity sold only covered 77% of the average production cost. According to official data (Government of India, 2008), the total under-recovery of costs – the difference between total costs and total revenues – is estimated to 431 billion rupees in 2008 (i.e. 8.8 US$ billion), and has experienced a nearly 6-fold increase since 1992. The same report estimates that the residential tariff covers 56% of the generation costs and farmers tariff only 12%, while industries and the commercial sector partly compensate by paying respectively 108% and 122% of production costs. Official data demonstrates that subsidies to households trebled to 80.8 billion rupees (i.e. US$ 1.7 billion) over the period 1992-1993 to 1999-2000. Subsidies to agriculture more than tripled to 227 billion rupees (i.e. 4.7 US$ billion) over the same period and between 1992-93 and 1997-98, agriculture has represented one third of electricity sales when incomes from these sales were estimated to 4 or 5% of total incomes only.

These subsidies have two kinds of consequences:

- The very low tariffs for farmers and households induce overconsumption (Dorin and Jullien (2004) estimate that the over consumption of electricity in the agricultural sector amounts to 30% of its consumption as the

combination of critically low prices and of frequent but unpredictable power cuts is a strong incentive to a continuous use of electric pumps for irrigation[3,4]) and so increase the magnitude of capacity shortage.

- Low revenues from electricity sales induce maintenance under financing and increasing inefficiencies in transmission and distribution (T&D) as technical and commercial T&D losses have increased from around 20% in 1993 to more than 30% in 2001 (Thakur et al., 2006).

Beyond this, this situation constrains economic activity and economic growth, as industry is the first sector impacted by electricity shortages, which limits physically production capacities. This constraint on economic development also reduces tax incomes for the government, and capital availability to invest in additional power capacity.

It appears that the deficiencies in the energy Indian system are not generated by simple market inefficiencies that could be corrected within a few year time period: the current high GDP growth could help absorbing capacity shortage (if higher electricity prices and lower risks were boosting investment in capacity and T&D), but the rebound effect of higher incomes on energy demand may also reinforce it. Indeed, if it can be expected that electrification and energy access will be enlarged, the outcome may be a reinforcement of capacity shortage. That is why there are good reasons to think that energy supply deficiencies will persist during a very significant period of time. It seems therefore that the sub-optimalities described above are rooted in a system with a lot of technical inertia and vested by social interests that are expressed by the cross-subsidy pricing system. Reforming this tariff system would mean to change this implicit social contract and would entail high transaction (in term of negotiations, administrative costs, and compensation) and social costs.

A reference scenario characterized by a low energy decoupling

We implement these market and institutional failures in IMACLIM-R in order to build a reference scenario for India on the period 2005-2050. A description of the model is given in the Annex.

Our reference scenario is characterized by an economic growth in line with the WEO07 reference scenario, but the total primary energy supply is much higher. The outcome is lower energy decoupling and higher emissions on the period 2005-2030.

Table 2: Main characteristics of the IMACLIM-R scenario

	Period	Economic annual growth	TPES annual growth	Energy decoupling	CO_2 emissions (2030/2005)
Imaclim-R	2005-2015	7.0%	4.7%	0.67	3.1
	2015-2030	5.9%	4.3%	0.73	
	2030-2050	4.5%	3.6%	0.80	

When looking more precisely at the evolution of the Indian GDP growth rate over the first half of the century in our reference scenario, the graph 2 shows our scenario is nothing like a smooth course pathway. Growth rate declines occur in 2015 and 2031. The reason for this growth profile is due to the interplay between a permanent characteristic of the domestic energy system in India, namely (i) a structural under-capacity of the power sector and (ii) the rising profile of oil prices and particularly the peak oil that is assumed here for about 2025 (see below).

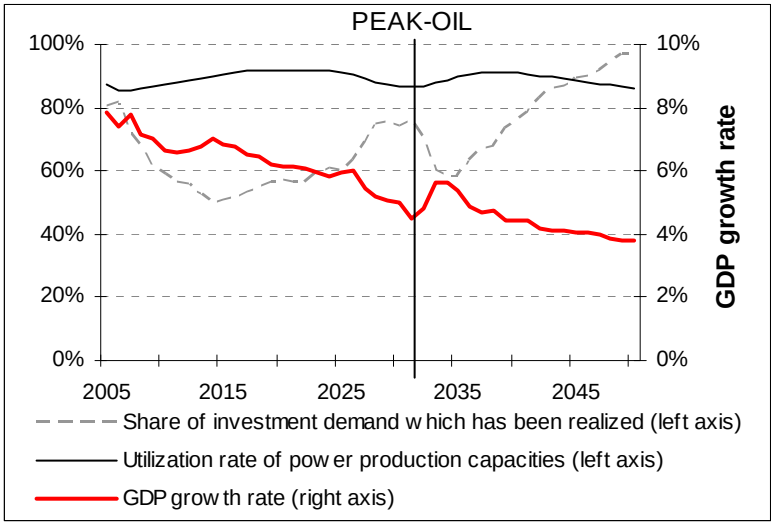
In the model, an utilisation rate of the capacities of the electricity sector superior to 0.8 means that the capacity is overused. On the overall period, it remains around 0.9. This entails extracosts of production due to the existence of static decreasing returns generally due to higher labour costs to pay extra hours with lower productivity, costly night work and more maintenance works[5] (Corrado and Mattey 1997). These extracosts represent, over the simulation period, 1.5% to 15% of the production costs and 25% on average of the estimated needs for investment in the electricity sector.

[3] Farmers do not pay in function of their actual consumption but in function of the engine power of the irrigation pump.

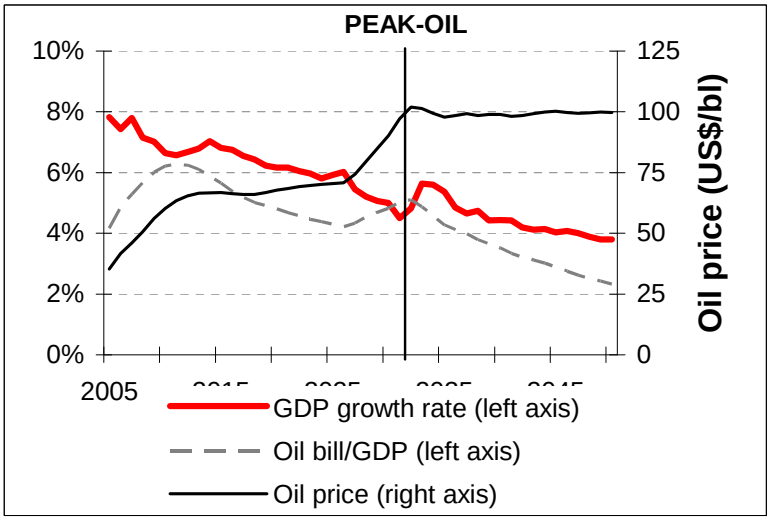
[4] This raises also water resources issues. This is all the more worrying as availability of water resources may become the main constraint for the development of agricultural activities (Aggarwal et al., 2004), which currently contribute to 24% of the Indian GDP and employ 60% of the active population

[5] More generally, mean costs increase because less efficient units are switched on at last at the aggregate level. By default in our model the increasing factor is attached to wages.

Graph 1: The capital shortage in the power sector



Graph 2: Oil dependency of the economic growth



This evolution of the utilisation rate is due to the constraint on investments in the power sector which can be deducted from the continuous gap shown in graph 1 between the estimated need for investments and realised investments. Estimated needs for investments are given by the level of investment in additional plants to satisfy a demand which anticipates the prolonging of current demand growth trends. In 2005, only 2/3 of the estimated needs for investment in the power sector are satisfied with investments equal to 14 billions US$. Producers have no choice but using more the existing capacities, and have recourse to diesel generators (industry consumes more than 30% of the total oil consumed in India until 2040). It is interesting to realise that the additional investment necessary to satisfy the estimated need is inferior to the amount currently spent in tariff subsidies for electricity consumption (9 US$ billion) which drives to commercial losses from electricity sales equal to US$ 6 billion. This share falls down to 60% until 2025. During the peak-oil period, the gap is smaller because of the slow down of economic growth, but increase again when economic activity takes off again.

This demonstrates that structurally there is no capital available to adjust to the "march to the peak-oil" from 2025 till 2033[6] when oil price reach an asymptote[7] at 100$/bl (graph 2). As a result India is deeply affected by its oil

[6] Oil prices in IMACLIM-R result from the endogenous interplay between the strategic behaviour of oil producers, constraints on supply (temporal constraints on capacity development and total reserves available) and demand dynamics.

dependency: until the end of the peak oil period, oil imports remain superior to 4% of GDP. This has an important effect on industrial production costs and on household energy bills dedicated to the residential sector (industries and households compensate for deficiencies of the power sector by relying heavily on oil). To compensate this energy bill, India pulls down the Rupee exchange rate to reinforce its export competitiveness. Industrial goods[8] are then more exported but as their production is energy consuming the utilisation rate in the power sector increase, pulling up production costs

Obviously these findings are strongly assumption dependent. One can indeed argue that in the future, India may become more capital attractive for foreign investors which would alleviate the tension on the funding of the energy system. However the warning emerging from these simulations should be considered seriously for one reason: during the "march to peak-oil", two major world economic regions may experience a drop of their saving capacities due to an aging population namely Europe and China (Aglietta *et al.*, 2006), which is likely to add tensions on the international capital market.

Economic disruptions and impasses of a carbon constraint in India

Leaving from this reference scenario, we investigate different policy scenarios of mitigation in India in a world context corresponding to a GHG concentration stabilisation at 550ppmCO_2 equivalent[9]. A quota allocation corresponding to the contraction and convergence rule[10] is implemented after 2012 in our model as to follow a global emission pathway compatible with this stabilization level. In this scenario, Indian emissions increase from 2008 till 2022 (from 1.52 GtCO_2 to 1.84GtCO_2) and then decrease to 1.46GtCO_2 in 2050 (compared to a final level of 6.54GtCO_2 in the reference scenario) .This stabilisation objective leads to a quasi linear world carbon price from 2010, equal to 75US$(2001)/tC in 2020 and to 426 US$(2001)/tC in 2050. This induces financial transfers between countries and regions which are described in table 3.

In spite of the huge amount of transfers received by India, the economic impact of the carbon constraint is significantly negative between 2012 and 2029, with GDP losses reaching 5% compared to the reference scenario (Graph 3). After 2030, the economic impact is significantly positive and appears to be positively correlated to financial transfers received by India.

In the following we disentangle economic mechanisms at stake which explain the GDP profile.

A temporary alleviation of the "oil bill"

The first mechanical impact of the carbon tax is the decrease of oil demand and, in feedback, of the international oil price (Graph 4). This explains the relative decrease of the Indian "oil bill" compared to the reference scenario. Nevertheless, this relative drop down gets to an end after the peak-oil period, as if the decrease of oil demand has

---

[7] With such an oil price, the coal-to-liquid (CTL) technology combined with carbon capture and storage (CCS) as part of CO_2 emissions becomes competitive and penetrates the market. This technology is considered as the backstop technology. It is important to note that the oil price value which corresponds to the penetration of CTL+CCS is not stable in the future and it is normally dependent upon the coal price and upon the existence of a CO_2 penalty (which would increase the value of the penetration price). Moreover, we have considered the CTL+CCS technology as the backstop technology, with the potential to become more than a niche technology. This is translated in our scenario by a flat oil price equal to the asymptote (100$/bl) when the CTL+CCS technology penetrates. It would have been possible to make the assumption of a limited potential of penetration of the CTL technology (due to environmental constraints such as water availability which is necessary in huge amount for the CTL technology) and thus of a continuous increasing oil price after the CTL competitive price is reached. Nevertheless we made the assumption in our scenario, that oil price stabilizes as soon as the oil price of 100$/bl is reached because a continuous increased price would not have changed fundamentally the results, and underlying mechanisms.

[8] In the version of IMACLIM-R which has been used, exports and imports are represented according to Armington's specification (Armington, 1969). Armington elasticities are chosen to mimic the fact that industrial goods are the most traded goods on world markets (compared to construction, transports or services), and Armington coefficients are calibrated in 2001 when India's exports represented a very small share of total exports (for all sectors, including services). This explains why it is the exports of industrial goods that compensate the higher energy bill. Though, we may argue this result would be, in reality, attenuated by the increase of India's exports of services.

[9] To translate this stabilisation objective, we use global emission trajectories given by IPCC (2008).

[10] This allocation rule is chosen as it is one of the most commonly considered rule that may appear acceptable for India as it allocates quotas on a per capita basis, which will favour countries with large and growing population.

reached a saturation point. This can be further explained by the analysis of the composition and the evolution of energy budgets of households, and by the adjustment of the terms of trade.

Graph 3: Indian GDP losses and gain sequence compared to the reference scenario

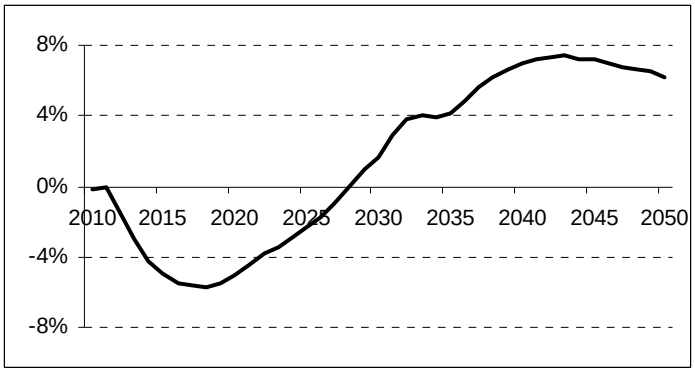
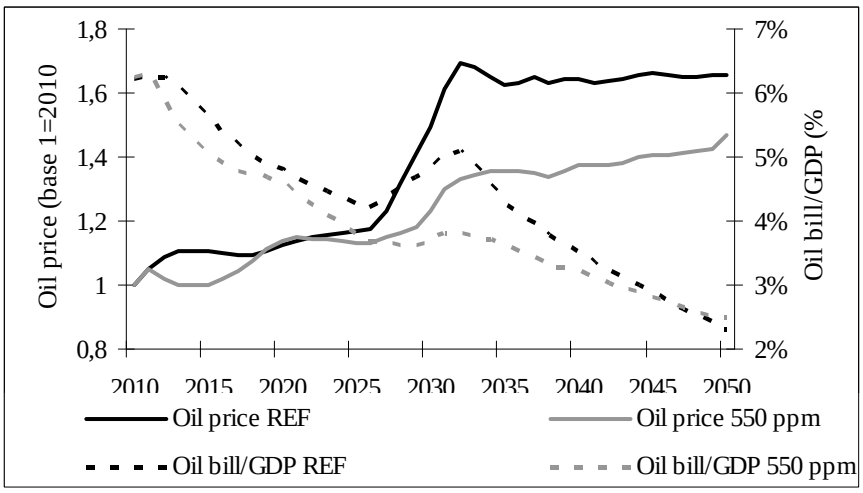


Table 3: Transfer amounts induced by the contraction and convergence rule in billions US$2001 and in percentage of the GDP

	2020		2030		2040		2050	
USA	-33	0%	-126	-1%	-342	-2%	-625	-2%
CAN	-3	0%	-15	-1%	-41	-2%	-75	-4%
EUR	-5	0%	-124	-1%	-354	-2%	-558	-2%
JAN	-16	0%	-77	-1%	-183	-2%	-260	-2%
CEI	-65	-7%	-136	-9%	-186	-9%	-241	-11%
CHN	-167	-3%	-456	-4%	-594	-3%	-486	-2%
IND	**89**	**5%**	**312**	**10%**	**597**	**11%**	**770**	**9%**
BRE	16	1%	33	2%	39	2%	40	1%
MO	-25	-2%	-53	-3%	-77	-3%	-95	-3%
AFR	121	8%	406	18%	767	23%	1 052	22%
RAS	67	3%	193	5%	322	5%	416	4%
RAL	21	1%	42	1%	53	1%	61	1%

Graph 4: Oil price and ratio of oil bill to GDP in both scenarios



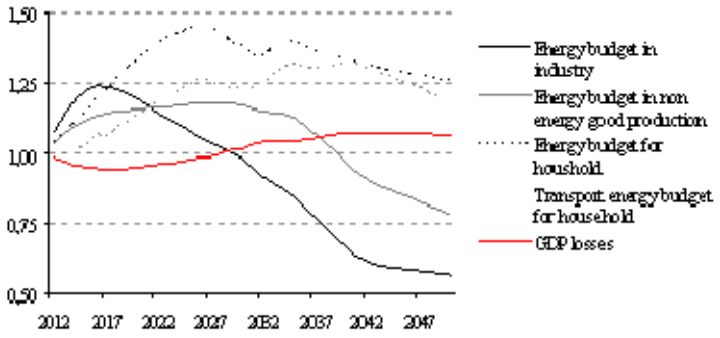
Energy budget for households and industries

In a scenario without climate policies, in developing countries, the evolution of household energy bill (transport + residential) is the balanced outcome, on the one hand, of the global increase of household incomes which induce supplementary consumption toward more energy services (electric devices, mobility) and, on the other hand, of technological change which decreases the energy need per unit of energy services. In the reference scenario, the impact of the income increase is larger than the impact of energy efficiency improvement while the energy price

remains low. When oil price begin to increase significantly, still in a reference scenario, the income effect is counterbalanced by the combined effect of an autonomous energy efficiency improvement and of the tremendous oil price increase during the peak-oil period which pulls up technological change and increases the costs of energy services. The energy budget is stabilized.

The introduction of a carbon constraint[11] in such a coal and oil dependent economy as India modifies this profile (Graph 5). During the first years of the constraint, the inertia of the highly carbon dependent Indian technico-economic system induces a mechanical increase of the energy budget for households. As energy needs are (considered as) basic needs (in the model), the budget dedicated to energy needs mainly determines the level of final demand in non energetic goods and thus of the activity level in these economic sectors. This partly explains the inverse correlation between the increase of household energy budgets and the GDP decrease.

Graph 5: Energy budget for industries and for household compared to the reference scenario (base 1=2010)



After this period, the carbon tax induces a relative decrease of energy expenses due to a more rapid technological change[12] and to a change of behaviour in energy consumption. This phenomenon gets to saturation with the increase of mobility demand induced by the relative recovery of economic activity after the peak-oil.

The role of energy cost in industry production appears as a major determinant controlling GDP, as there is a significant correlation between the increase (decrease) of energy costs in industry and the decrease (increase) of GDP compared to the reference scenario. After the peak oil, the decline of energy budget in industries compared to the reference scenario leads to a gradual reduction of GDP losses compared to the reference scenario, but before the peak-oil period, the energy cost increase is particularly important. Nevertheless at the end of the period considered here, the energy input per unit has decreased by nearly 40%, and a substitution toward electricity drives to a strong decline in the coal share.

The technological change which has been induced by the carbon tax is more important for industries than for households.

To summarise, our analysis shows the temporal dimension of the impact of a carbon price induced by the quota system on the Indian economy is crucial. Indeed, the main impact on economy does not occur when the carbon price is very high, because at this time, the endogenous technological change induced by the high level of carbon tax will decrease fossil fuel dependency and lead to a better economic situation than in a reference scenario without climate policies. The main economic impact will be during a transition period which corresponds to a period of rapid infrastructure development which relies upon energy intensive industries in a highly fossil fuel dependent economy.

The concomitance of a carbon price and of the peak oil in the highly carbon intensive, oil dependent and energy inefficient Indian economy induces a several year long economic slow down which may further lead to social tensions. Actually the significant increase of budgets for energy services which induce a lower budget available for

[11] The introduction of a carbon price in the Indian technico-economic system is not compensated by increased energy subsidies and is translated into net increases of energy prices depending upon their carbon content.

[12] Changes in energy consumption for the composite sectors are related to (i) a general energy efficiency coefficient that affects energy consumption of all vintages (ii) the energy mix embodied in the new vintage of productive capacity. The energy efficiency improvements impacts on total energy intermediate consumption of the composite sector and depends on cumulative investments in the composite good. The shares of energies in new vintages of productive capacity are described by a logit function of the variation of energy prices between the previous and the current year. For a detailed description of technological change within Imaclim-R, please refer to Crassous et al. 2006a, 2006b and to Sassi et al. 2007.

non energetic goods may provoke explosive situations comparable with the hunger riots in Haïti or in Cameroun which occurred during the spring 2008, and reinforce dualism. The GHG emission mitigation entails in this scenario a decrease of economic activity which provokes welfare drop down until 2030, in spite of significant financial transfers (which amount to more than 5% of GDP between 2020 and 2030). Moreover, the economic model that India has developed, i.e. auto-centred and weakly exporter, does not allow a compensation for the increase of overall energy import bill.

To limit the economic impact of the contraction and convergence quota allocation during this transition period in India, it is thus necessary to alleviate the dependency of industries toward fossil energies in the short term. This can be done by improving the global efficiency of the energy system in India, and particularly of the power sector. This is the avenue further explored in the following part in order to implement synergies between climate policies and development.

Looking for synergies between climate policies and development

The concept of an emission trading system with the underlying world carbon market therefore provides countries with a lot of flexibility to overcome any unique obstacle that the carbon price may pose for them individually. Governments are not forced to increase all their domestic energy prices by the level of the international carbon price; they have the leverage to employ other policy parameters in delivering their domestic objectives or constraints. This is the reason why we envisage in this part a strategy of GHG mitigation different from merely implementing a carbon tax in India with the objective to try and reconcile economic development and climate policies. The international objective remains to stabilize world GHG emissions at 550ppmCO_2eq with quota allocation according to the same contraction and convergence rule as in the preceding section.

Elaborating a strategy for reforms in the power sector

The strategy described in this part focuses on energy efficiency improvements of the energy sector through a ‘package of domestic policies and measures’ (PAMs) in order to alleviate transition costs induced by GHG emission mitigation which are particularly high in India until 2030.

Implementing tariffs reflecting costs

We have shown that the Indian power sector remains largely sub-optimal in the reference scenario. Literature on energy issues in India shows the need for a tariff reform so that prices better reflect costs (Filippini et Pachauri, 2004). This tariff reform would lead to the reduction of electricity waste in the agriculture sector, and increase financial incomes for the government. However, such a reform comes up against a strong opposition from the population and politicians because it would induce regressive effects on the poorest households as well as on agriculture. Nevertheless, because of social and political obstacles to the implementation of such a fiscal reform and because of the important potential of improvement of the efficiency of the power system (in term of energy but also in term of financing), it appears relevant to state, as pointed out by Bose et al. (2006)[13] that a tariff reform will be accepted only if it is combined with an ambitious program aimed at improving the quality of power supply. In addition to the incentive toward energy savings, a tariff reform would release financing capacity for the government. Two contrasted strategies are then possible: either financing additional productive capacities or improving of the overall efficiency of the system.

Development of productive capacities *vs.* reduction of inefficiencies of the system

Many studies related to the Indian power sector state that the solution to reduce the gap between demand and offer lies in the investment in additional productive capacities, which would keep almost constant the overall energy efficiency of the system. This is also the strategy lead by the Indian government which postulates that the only constraint to release is capital scarcity. This is the reason why since 1991, the Indian government has opened the sector to independent power producers. Private investors have only partially answered. Actually, attracting more independent power producers and guaranteeing them a minimal rate of return will need further reforms to be implemented. However, the potential of delivering electricity by improvement of the energy efficiency is huge and this could respond to a significant part of the existing gap between offer and demand. To do this, one main option is the reduction of technical and/or commercial losses induced by poor management[14].

[13] Bose et al. (2006) evaluate for different consumer categories their willingness to pay more for a better supply quality (with less shortage) in the Karnataka region.

[14] The level of losses stated by the Indian Planning Commission is 22% when the World Bank (1998) points out that it could actually be twice this official level around 40-50%. Moreover, as there is no metering of the electricity consumption it is very difficult to distinguish technical from commercial losses.

Presentation of the alternative scenario

The alternative scenario 550EE (EE states for Energy Efficiency) is a 550ppm stabilisation scenario based on a contraction and convergence rule. It considers a tariff reform based on a progressive removal of subsidies between 2009 and 2019. The following assumptions are adopted:

- farmers : the budget dedicated to electricity remains constant (on one hand, the subsidies decrease and the unit price increases, but on the other hand, the consumption level decreases in order to reach the objective of cutting by 50% the level of electricity wasting induced by poor management and consumption habits[15]).
- households: subsidies are removed. To evaluate the impact on demand, an elasticity of -0.65 is used referring to a median value regarding different estimates in the literature on Indian electricity demand (Filippini and Pachauri, 2004 ; Bose and Shukla, 2006; Shukla 1998).

In the 550EE scenario, a program for the reduction of technical and commercial losses is implemented. This program would partly be composed of refurbishment of obsolete installations of power distribution all around the country but also of new managerial methods: more control in general and particularly in order to remove illegal plugging on the grid and fiscal evasion. This program can be considered as a national priority program. The cost and the potential for improvement are calibrated on Ruet (2001). The initial level of losses in 2007 is equal to 35%, and this level decreases to 15%[16] in 2031 and remains constant afterwards. The remaining part of the amount of money saved from the removal of subsidies is invested to finance additional capacities if needed or rebated to households as lump-sum transfers.

Economic and environmental evaluation of the alternative scenario

The implementation of the energy efficiency measures in the power sector leads to a decrease in the transition costs due to the mitigation constraint. From a 6% GDP loss in 2018 in the 550CC scenario compared to the reference scenario, the GDP loss in the 550EE scenario is only 3% in 2017. This gain is conserved until the end of the simulation period. In the following we further describe the reasons for this gain compared to the 550CC scenario.

Decrease in energy budget industry production cost

The decrease in T&D losses and the decrease in power wasting in agriculture lead to an early decrease in the total power production compared to the 550CC scenario. This drives to a decrease in the utilisation rate and of the electricity cost of production (Graph 7). This induces an energy substitution in industry from diesel generators toward electricity, and to a decrease in the energy cost in industry which is mechanically transmitted to the industry production cost and so to the price.

This drives to contrasted sectoral GHG emission compared to the only contraction and convergence scenario (Graph 8). The total CO2 emission compared to the 550CC scenario is the combination of

- The energy substitution in industry toward electricity. This induces a substitution of CO2 emission from industry toward power sector after 2020
- The improvement of energy efficiency in the power sector (decrease in CO2 emissions)
- The income effect which induce additional consumption of transport services, particularly additional individual cars.

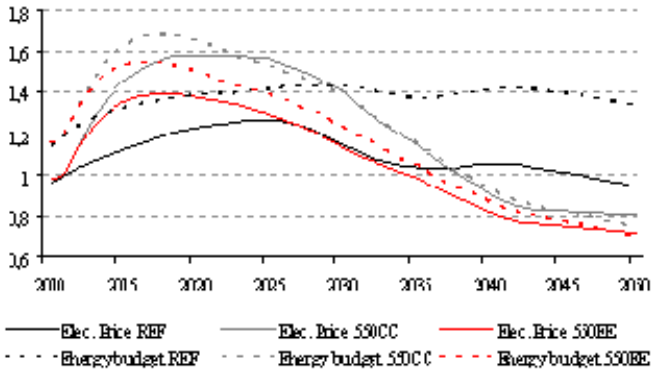
This last point is of particular importance as the income effect that may go with the implementation of synergies between climate policies and economic development may have counterproductive effects on GHG emission trajectories because of a possible rebound effect on transport demand. This shows the importance to consider seriously the opportunity to implement a low carbon transport infrastructure.

[15] 10 years to reduce electricity waste and change consumption habits in such a rigid system may appear a bit optimistic, except if the program is considered by the Indian government as a national priority program with huge human resources in order to heighten public awareness and to change consumer behaviours. Moreover, if the grid quality and the service are improved, the number of unpredictable power cuts will be significantly lower, and farmers will not have to remain their pumps switched on all day long.

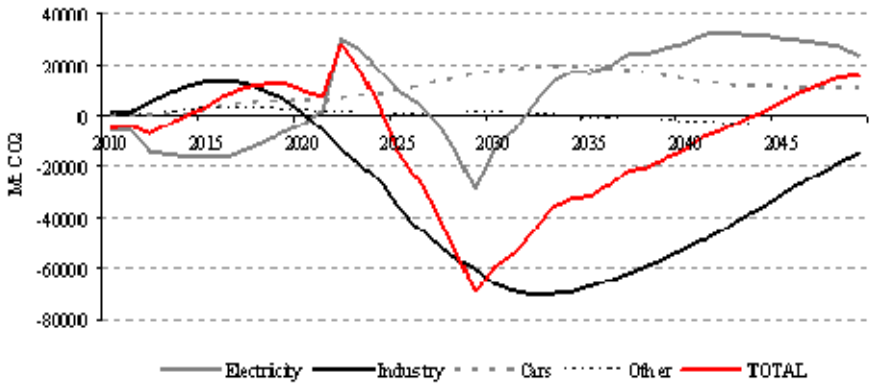
[16] This value is rather conservative as the current technology state of the art is below 5%, the potential of energy efficiency improvement may be thus underestimated.

Graph 6 GDP losses compared to the reference scenario

Graph 7: Electricity price and energy budget in industry production cost in REF, 550CC and 550EE scenarios



Graph 8: Sectoral CO_2 emissions compared of the 550EE scenario compared to the 550CC scenario



Conclusion

The main conclusions which can be drawn from this modelling exercise related to the Indian power sector are of three kinds:

First, from a methodological point of view, the nature and the content of the baseline is a key when evaluating climate and development policies. In line with Raupach et al. (2008) and Pielke et al. (2008), we have thus developed a “realistic” baseline which reveals to be less optimistic on the short term regarding the assumptions related to the autonomous (without policies) decarbonisation of the Indian economies than assumed by the IPCC scenarios. This emphasizes the importance to use modeling methodologies that allow for the representation of the specific national circumstances including sub-optimalities in the projected scenarios, and the coherence between the evolution of the energy system and economic constraints.

Second, from a mitigation point of view, the exercise has shown, once determinants of the vulnerability of the Indian reference scenario have been well understood, the existing potential for implementation of synergies between

climate and development to reduce weaknesses and vulnerability of the baseline especially concerning energy dependency. We are conscious that this exercise is limited because of the focus on the power sector only. Conclusions related the potential for implementing synergies between development and mitigation could be reinforced by considering a larger panel of measures. Other sectoral policies could be explored: the question of urban forms and of infrastructures would be quite relevant to address the sensitive problem of mitigation in the transport sector for instance.

From a political point of view, the article suggests several recommendations for improving an international agreement related to climate change and for the definition of an enlarged climate regime:

- Decarbonisation will depend on a wider range of signals than just the carbon price (Mathy and Hourcade, 2006). Indeed, because the Kyoto Protocol only creates a carbon market among countries, it is up to governments to do the selecting, controlling, and redistributing of emission allowances among sectors, and to apply other policy tools that cannot be exchanged individually on a world carbon market. Governments are not forced to increase all their domestic energy prices by the level of the international carbon price; they have the leverage to employ other policy parameters in delivering their domestic objectives or constraints. The climate regime should therefore support rather than constrain domestic policies.
- The results of this experiment thus show that India as one of the most important developing nations could profit from a global climate regime if it would be implemented nationally in a consistent way, but if not it might fear significant economic losses in the transition period.
- Given this result, it is crucial that the new regime will significantly support proper national implementation of climate and energy policies with subsidies removal and increasing of energy efficiency, including technology transfer as these are key in making climate policy a win-win game for countries like India. Only if these significant issues are met those countries might find themselves in a situation to be able to support the strong climate regime that is needed. This is valid for developing countries, but for industrialised countries as well.

References

Aggarwal P.K., Kalra N., Kumar S., Vasisht A.K. (2004) Exploring land use options for sustainable food production: methodological framework, in Agricultural incentives in India, Past trends and prospective paths towards sustainable development, edited by B. Dorin et T. Jullien. Manohar, New Delhi, 334p.

Aglietta M., Borgy V., Chateau J., Juillard M., le Cacheux J., Le Garrec G. et Touzé V., 2006. World Growth and international capital flows in the XXIst century. Working Paper OFCE 2006-07, Avril. 41pp.

Armington, P. S., 1969. A Theory of demand for products distinguished by place of production. IMF, International Monetary Fund Staff Papers 16, 170-201.

Bose R.K., Shukla M., (1998) Elasticities of electricity demand in India. Energy Policy 27, 137-146.

Bose R.K., Shukla M., Srivastava L., Yaron G. (2006) Cost of unserved power in Karnataka, India. Energy Policy 34, 1434-1447.

Corrado, C. and Mattey, J. (1997). "Capacity Utilization", Journal of Economic Perspectives, Vol. 11, No. 1, pp. 151-167.

Crassous, R., Hourcade, J.-C., Sassi, O., 2006a. Endogenous structural change and climate targets: modeling experiments with Imaclim-R. Energy Journal, Special Issue on the Innovation Modeling Comparison Project.

Crassous, R., Hourcade, J.-C., Sassi, O., Gitz, V., Mathy, S., Hamdi-Cherif, M., 2006b. IMACLIM-R: a modeling framework for sustainable development issues. Background paper for Dancing with Giants: China, India, and the Global Economy. Institute for Policy Studies and the World Bank, Washington, DC. Available at http://siteresources.worldbank.org/INTCHIINDGLOECO/Resources/IMACLIM-R_description.pdf

Dorin B., Jullien T. (2004) Agricultural incentives in India. Past trends and prospective paths towards sustainable development. Manohar, New Delhi, 334p.

Energy Information Administration (EIA) (2008) International Energy Outlook 2008. Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, DC. 260pp.

Filippini M., Pachauri S. (2004) Elasticities of electricity demand in urban households. Energy Policy 32, 429-436.

Goldemberg, J., 1998. Leapfrogging energy technologies. Energy Policy 10, 729–741.

Government of India, 2008. Economic Survey 2007-08. **http://indiabudget.nic.in**

Graus W.H.J., Voogt M., Worell E. (2007) International comparison of energy efficiency of fossil power generation. Energy Policy 35 3936–3951

International Energy Agency (2007) World Energy Outlook. OCDE/IEA. Paris.
Intergovernmental Panel on Climate Change. (2007) Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 851 pp.
Kim Y., Worrell E. (2002) International comparison of CO2 emission trends in the iron and steel industry. Energy Policy 30 827–838
Mathy S., J.-C. Hourcade (2006) Un régime de coordination internationale malgré tout, in Regards sur la terre
Meyer A, (2002) Contraction and convergence, the solution to climate change, Schumacher Briefing N°5, Green Books.
Pielke R., Wigley T., Green C. (2008) Dangerous assumptions. *Nature* 452, 531-532
Planning Commission (2002). India Economic Roadmap: The Next Five Years- 2002-2007: The Essence. Planning Commission, New Delhi
Raupach M. R., Marland G., Ciais P., Le Quéré C., Canadell J.G., Klepper G., Field C. (2008) Global and regional drivers of accelerating CO2 emissions. PNAS June 12, 2007 vol. 104 no. 24 10288-10293
Ruet J. (2001). Investment profitability in bridging the power gap in India. The Indian Economic Journal. October-December. Volume 49, n°2. 17p.
Sassi O., Crassous, R., Hourcade, J.-C., Gitz, V., Waisman H., Guivarch, C., 2007. Imaclim-R: a modelling framework to simulate sustainable development pathways. International Journal of Global Environmental Issues (accepted).
Shukla M., (1998) Elasticities of electricity demand in India. Energy Policy 27, 137-146.
Shukla, P.R., 2006. India's GHG emission scenarios: Aligning development and stabilization paths. Current Science, 90(3), 10 February 2006.
Thakur, T., Deshmukh, S.G., and Kaushik, S.C., 2006. "Efficiency evaluation of the state owned electric utilities in India" Energy Policy 34, 2788-2804.
Tongia, R. and R. Banerjee. "Price of Power in India." *Energy Policy* 26 (1998), 557-575.
World Bank (1998) Power sector reform and the privatization of distribution in India. Internal working document prepared by H. Salgo et al. March 1998.

Annex The IMACLIM-R model

Technically IMACLIM-R is a multi-sector (5 energy sectors (coal, gas, crude oil, refined products, electricity), 3 mobility sectors (road transports, air transport and other transport), construction, agriculture, industries and services) multi-region (12) dynamic recursive hybrid model. The growth path is described as a sequence of static short-term equilibria, on a yearly base, articulated with dynamic equations giving the new conditions for the following equilibria, as sketched in figure 1.

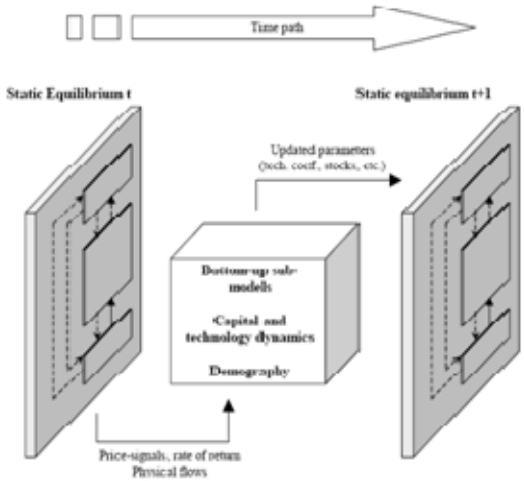
At each point of time, **a static equilibrium** links regional inter-dependent supplies and demands for goods. This is done by solving a general walrasian equilibrium following behavioral equations for all agents, namely households, firms and states, and accounting for regional and international flows of goods in quantities and values, as well as international investment flows. The crucial point is that behavioral equations encompass some constraints: specific installed capital, technologies (input-output coefficients), household's equipments, public infrastructures. It means that there is no substitution of factors in a given year. Some factor markets may not be perfectly cleared in this process, allowing for unemployment, excess or shortage of production capacities, unequal rates of profitability of capital across sectors and regions

Then the economic values derived from the equilibrium at *t* (relative prices, level of output, profitability rates, investments flows) inform both:

- the *macroeconomic growth engine*, composed of (i) exogenous demographic trends derived from UN estimations and corrected with migration flows capable to stabilize populations in low fertility regions; (ii) technical change governed by exogenous or endogenous trends of labour productivity (depending on the version of the model) and by capital deepening mechanisms; (iii) dynamics of production capacities obeying the usual law of capital accumulation, with a full description of vintages and sector-specific lifetimes for some sectors.
- *various submodels* concerning energy systems, transport infrastructures or end-use equipments and which are reduced forms of more detailed Bottom-Up models. Producers' and consumers' behavioral parameters that are fixed in each static equilibrium are here subject to changes. Dynamic submodels describe how each economic

agent will adapt, on the demand or supply side, in response to past economic signals (variables obtained as result of former static equilibria such as relative prices or investment flows).

Figure 1: The recursive dynamic framework of IMACLIM-R



Structural parameters of the static equilibrium (structure of demand, input-output coefficients and state of embodied technologies, installed capacities, infrastructures) are thus updated for the following time step. Then we calculate the following equilibrium on the basis of these new coefficients. The long-term growth pathway results from how the economy adjusts to the successive changes of the level of equipments and of the technical frontier. Beyond its advantages in terms of computation, this recursive structure rests on a useful schematic representation of the growth process, made of both short-term economic variations (inside the static equilibrium) and long-term evolutions of growth drivers (in the dynamic modules).

A complete description of the model is detailed in Sassi et al. 2007; Crassous et al. 2006a, 2006b.

Acknowledgements

The authors wish to thank Jean-Charles Hourcade, Stéphane Hallegatte and Olivier Sassi for their useful comments and suggestions on a previous version of this article, as well as all the team who contributed to Imaclim-R development. Part of this article is based on studies which have realized thanks to the GICC (Gestion et Impacts du Changement Climatique) research program of the French environmental department