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What if energy decoupling of emerging economies were not so spontaneous? *An illustrative example on India*

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Abstract:

Reference GHG emissions scenarios are critical for estimates of the costs of stabilization and for climate policy recommendations. But recently, existing reference scenarios, notably the SRES, have been the target of criticisms that question their relevance in the light of current emissions trends, dispute the suitability, for developing countries, of the modeling methodologies used and suggest they convey too optimistic views on spontaneous energy decoupling of emerging countries economies. This article focuses on an illustrative example on India. It proposes an alternative reference scenario built with a modeling framework representing as realistically as possible the processes driving energy intensity and carbon intensity changes, in particular accounting for the interactions between energy systems and economic constraints and capturing the sub-optimalities of the energy sector. The mechanisms leading to moderate energy decoupling in this alternative scenario are analysed. From a methodological point of view, our results call for the improvement of the realism of modeling tools for scenarios elaboration. From a mitigation point of view, it appears that the challenge for climate policies to lift the barriers to the diffusion of energy efficiency improvement in India is considerable, but we identify a potential for synergies between development policies and climate policies.

***Keywords**: India, energy-GDP decoupling, investment constraint, power sector, reference scenario.*

Résumé:

Les scénarios de référence pour les émissions de GES sont cruciaux pour l’estimation des coûts de stabilisation et les recommandations des politiques climatiques. Mais récemment, les scénarios de référence existants, notamment le SRES, ont été la cible de critiques remettant en question leur intérêt à la lumière des tendances d’émission courantes, discutent la pertinence pour les pays en développement des méthodes de modélisation utilisées, et suggèrent qu’ils transmettent une vision trop optimiste d’un découplage énergétique spontané des économies des pays émergents. Cet article est consacré à un exemple illustratif, l’Inde. Il propose un scénario de référence alternatif construit à partir d’un cadre de modélisation représentant de façon aussi réaliste que possible les processus guidant les changements d’intensité énergétique et d’intensité en carbone, rendant compte en particulier des interactions entre systèmes énergétiques et contraintes économiques et reproduisant les sous-optimalités du secteur de l’énergie. Les mécanismes modérateurs d’un découplage énergétique dans ce scénario alternatif sont analysés. D’un point de vue méthodologique, nos résultats appellent à une amélioration du réalisme des outils de modélisation dans l’élaboration des scénarios. Du point de vue de la réduction des émissions, le défi des politiques climatiques pour lever les barrières à la diffusion de l’efficacité énergétique en Inde est considérable, mais nous identifions un potentiel de synergie entre les politiques de développement et les politiques climatiques.

Mots-clés:
Inde, découplage énergie-croissance, contrainte d’investissement, secteur électrique, scénario de référence

What if energy decoupling of emerging economies were not so spontaneous? An illustrative example on India

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Introduction

The concept of reference scenarios was developed by the international scientific community as the basis for the definition of GHG emission mitigation actions. Many reference scenarios were developed either at the national, the regional or the international level. The IPCC community developed reference scenarios at the international level, the SRES report, which is at the core of mitigation cost evaluation in the TAR (2001) and the AR4 (2007) by the WG3 of the IPCC. Therefore, reference scenarios play a critical role in the message conveyed to policy makers.

Recently, the modelling works related to the elaboration of reference scenarios, either for the SRES or for other studies using global energy models, have been the target of repeated criticisms.

First, the relevance of reference scenarios is questioned by actual observations, as Raupach et al. (2008) and Sheehan (2008) showed that GHG emissions are increasing faster than predicted in the large panel of SRES modeling exercises (IPCC, 2000). One of the major reasons for the discrepancy between short term GHG emissions projection from models and recent trends is the persistent very high levels of economic growth in emerging countries. Until recently economic growth rates considered for these countries in models were significantly lower than currently observed growth rates. This pushed modellers to recalibrate their modelling exercises on recent trends: Blandford et al. (2008) revised emission growth projections from MERGE for China with recent trends, the World Energy Outlook 2007 (IEA, 2007) and the International Energy Outlook 2008 (DOE, 2008) adopted much higher economic growth rates for China and India compared to preceding publications.

A second side of criticisms (Urban et al. 2007, Van Ruijven et al. 2008) discusses the suitability of methodologies used in existing global energy models to represent the specificities of the developing countries' energy systems. In particular, it appears that most models neglect some characteristics such as supply shortages, poor performance of the power sector, economic structural change, urban-rural divide, traditional bio-fuels etc, which may bias results.

A third trend of criticism, lead by an article from Pielke et al. (2008) published in *Nature*, questions the optimistic views on the automatic (without policies) decarbonisation of economies that are reflected by existing reference scenarios, in particular SRES scenarios. Moreover they emphasize the "danger" of such reference scenarios with very significant automatic decarbonisation, as they may under-estimate the challenge for climate change mitigation and convey biased views to policy makers. Indeed, for the same level of GHG emissions, whether a reference scenario assumes spontaneous technological change without climate policies, or inertia in technological change, will lead to contrasted recommendations and costs in term of mitigation actions.

Acknowledging these criticisms, this article proposes to build an alternative reference scenario for India. Our objective is to disentangle the mechanisms driving decarbonisation of the economy and the constraints that may stall this process. With this illustrative example on India, we will show that, indeed, the spontaneous energy decoupling of emerging economies embodied in existing reference scenario may appear too optimistic.
We start, in the first section, with an analysis of some existing Indian reference scenarios in the literature. We show the very high energy intensity decrease described in these scenarios may be questioned in the light of the significant institutional and market failure that characterize the Indian energy system today and that are likely to persist over an important period of time. This leads us to establish, in the second section, a modelling roadmap for an Indian reference scenario over the 2008-2050 period responding to some of the limits raised by Urban et al. (2007) and Van Ruijvan et al. (2008) and emphasized in the first section, particularly by taking into account sub-optimalities of the Indian energy system. To do so, we adopt a modeling framework that, although considering general equilibrium effects, does not assume a first best world: IMACLIM-R (Crassous et al., 2006a, 2006b and Sassi et al., 2007). In Section three, we compare our projection results to existing projections for both economic growth and energy supply and consumption, and show our scenario is characterized by GHG emissions comparable to GHG emissions from the International Energy Agency's World Energy Outlook 2007 in particular, but associated to much lower energy-GDP decoupling. We disentangle the mechanisms at play in our baseline scenario explaining the differences with other prospective exercises, and show these mechanisms lie in the interactions between economic growth and energy decoupling. We conclude with lessons which can be drawn for a methodological perspective and for the design of climate policies perspective, highlighting possible synergies between climate mitigation and economic development.

1. Is the optimistic energy decoupling advanced in existing scenarios coherent in the Indian context?

In this part, we first analyse existing reference scenarios, and confront their assumptions and results to past trends of GDP growth, primary energy supply and electricity consumption growth rates, as well as to the current Indian context.

1.1. Analysis of existing reference scenarios

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, International Energy Outlooks (IEO) from the Department of Energy of the United States, 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, and GHG emissions till a medium/long term horizon (2030 or 2050). Table 1 compares their economic assumptions (GDP growth rate), and their results in terms of energy supply and demand (primary energy supply and electricity consumption mean annual growth rate), and of GHG emissions growth rates over the overall period considered. Table 1 shows also past tendencies for comparison purposes To ease scenarios comparison, the elasticity of primary energy demand to GDP growth, and the elasticity of GHG emissions to GDP growth are given in the two last columns. The energy decoupling of the GDP growth is related to the evolution of the structural composition of growth and of energy efficiency on the demand and/or supply side. The higher the elasticity the more the economy is relying on highly energy intensive industries and/or on highly inefficient energy systems.

Table 1: Comparison of GDP, primary energy consumption, electricity consumption and GHG emission growth rates of some existing prospective energy scenarios to past tendencies

	Period	GDP growth rate	Electricity consumption growth rate	Primary energy consumption growth rate	**Elasticity of energy consumption to GDP**	GHG growth rate	Elasticity of GHG emission to GDP
Past tendencies (Enerdata)	*1975-95*	*5%*			***1.4***	*6,13%*	***0.82***
	1995-05	*6.4%*			***0.9***	*4,12%*	***0.64***
WEO 2007 reference scenario	2005-15	7.2%	7,10%	3.7%	**0.51**	4.6%	**0.64**
	2015-30	5.8%	6,10%	3.6%	**0.60**	4.1%	**0.71**
WEO 2007 Alternative	2005-15	7.2%	6.8%	3.0%	**0.42**	3.4%	**0.47**
	2015-30	5.8%	5.7%	2.8%	**0.48**	2.8%	**0.48**
WEO 2007 high growth	2005-15	8.3%	6.6%	4.1%	**0.49**	5.2%	**0.62**
	2015-30	7.5%		4.3%	**0.57**	4.9%	**0.65**
WEO 2006 reference scenario	2004-30	5.1%	3,80%	2.6%	**0.51**	3.3%	**0.65**
WEO 2006 Alternative scenario	2004-30	5.1%	3.3%	2.0%	**0.39**	2.3%	**0.45**
IEO 2006	2004-30	5.7%	3,90%	2.8%	**0.49**		
IEO 2008	2008-15	7.1%		2.9%	**0.50**		
	2015-30	4.6%					
IA1 (Shukla, 2006)	2000-2030	7.5%				3.9%	**0.52**
IA2 (Shukla, 2006)	2000-2030	5.5%				3.3%	**0.60**
IB1 (Shukla, 2006)	2000-2030	6.5%				2.6%	**0.40**
IB2 (Shukla, 2006)	2000-2030	4.5%				3.1%	**0.69**

Some elements of this table need to be emphasized:

First of all, economic growth assumptions implemented in modelling works realized from 2007 on have been revaluated. Before 2007, all modelling exercises rely on exogenous moderate GDP growth rates: between 5.1% and 5.7% on average until 2030. These assumptions have proved to be to low compared to GDP growth rates observed after 2003 as between 2003 and 2007, the GDP growth rate never went below 7%. This claimed for the revision upwards of economic assumptions (WEO07, IEO08) particularly for the 2005-2015 period, with GDP growth rates reevaluated at least at 7.1%, and even 8.3% for the high growth scenario of the WEO07.

Secondly, all scenarios including the revised ones express optimistic views on energy decoupling of GDP. In reference scenarios realized before 2007, the moderate economic growth is associated with significant energy-GDP decoupling equal approximately to 0.50. The reevaluation of scenarios in 2007 leads to roughly the same level of decoupling particularly during the 2005-2015 period. Even if the last WEO published in 2007 forecasts higher trends in energy consumption than preceding WEO (particularly for the period 2005-15), assumptions related to energy decoupling remain very high.

These levels of decoupling 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 1.4, 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). The elasticity of total primary energy supply to GDP 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) show that nearly constant or increasing trends in energy intensity have been recently observed in both developed and developing countries particularly in rapidly developing economies. Pielke *et al.* (2008) also show that the IPCC assumptions for decarbonisation, both the change of energy intensity of GDP and the change of carbon intensity of energy, 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 Pielke et al.: “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”.

It appears that this high energy decoupling in existing reference scenarios is determined by underlying optimistic views on both the dematerialisation of consumption styles (and the associated structural change towards services) and the automatic energy efficiency improvement :

-The dematerialisation of consumption styles. In the reference scenario of WEO07, there is a sectoral shift towards service and a decrease in the share of industry, which reveals optimistic assumptions related to the dematerialisation of the economy It is true that India's economic growth today relies largely on the development of the services sector, for exports in particular. Whether this trend will persist is though questionable. With rapid economic growth, one may think equipment diffusion for households (electric devices, cars…) will accelerate. The level of consumption preferences will be of decisive importance. Whether emerging countries choose to reproduce industrialized countries consumption standards (mimetic development) with high levels of saturations for equipments (number of squared meters of building stock per capita, household end-use equipments, transport structures relying on private cars…) or dematerialized modes of consumptions will induce, upstream different structures of economies, and downstream have contrasted effects on climate..

- The automatic energy efficiency improvement and the leapfrogging assumption. Forecasting such high levels of energy decoupling as the ones forecasted in WEO and IEO scenarios is coherent with the branch of literature (Goldemberg 1997, 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.

In the following sub-section, we will question the validity of this optimism in the Indian context. We will in particular concentrate on the energy efficiency improvement in the power sector.

1.2. Market and institutional failures which could stall energy decoupling of GDP

India power 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 are decisive for the evaluation of GHG emissions trajectories because, in 2007, 55% of electricity relies on coal (which represents 57% of total CO_2 emissions in 2005).

1.2.1. Capacity shortage

The Indian power sector is characterized by considerable weaknesses, in particular 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 according to the Planning Commission, even though the installed power capacity has increased from 66 GW in 1990-91 to 146 GW 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.

1.2.2. Structural under-investment

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).

1.2.3. Effects of cross subsidies

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 and so increase the magnitude of capacity shortage. 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[1,2].

- low revenues from electricity sales induce maintenance under financing and increasing inefficiencies in transmission and distribution (T&D) as technical and

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

[2] 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

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 may help absorbing the capacity shortage, but the revenue 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 costs.

This diagnosis of the Indian power sector gives the intuition that high energy decoupling in the near future in India might be unattainable and calls for a reference scenarios representing explicitly and as realistically as possible the process driving energy intensity improvement or increase, which means to represent the direct drivers of energy demand such as the sectoral shift of economic activities (manufacturing *vs*. services), the level of diffusion of end-use equipments (in the residential sector and in transport), the diffusion of energy efficient technologies, but also economic constraints which may stall these processes, in particular capital scarcity. This can only be embarked in models taking into account interaction and feedbacks between energy systems and economic constraints. These questions are addressed in the following section, which defines the roadmap for building an alternative reference scenario.

2. Road map for an alternative reference scenario

In response to each point addressed in the preceding section, we present in this section the specificities for the elaboration of an reference scenario which will respond to the following terms of reference (i) to consider the necessary coherence between energy systems and macroeconomic constraints; (ii) to represent the diffusion of energy efficiency, and in particular the interactions between technological change, capital allocation and inertia in equipments; (iii) to explicitly describe the development style (dematerialization of the economy, sectoral shift of economic activities, consumption preferences); (iv) to capture market and institutional failures of the Indian energy system. The modelling framework we will use will thus respond to some of the methodological limits of global energy models (namely that they neglect supply shortages, poor performance of the power sector and structural economic change) raised by Urban et al. (2007) and Van Ruijven et al. (2008), which make them unsuitable to represent some of the specificities of the developing countries energy systems. Specifically, it models endogenous economic structural change, and allows encompassing supply shortages and poor performance of the power sector.

2.1. Imaclim-R: an attempt to represent the coherence between energy systems and macroeconomic dynamics

The model Imaclim-R (Sassi et al., 2007), developed in CIRED, is a global CGE model with 12 regions and 12 sectors, its architecture is based on a recursive general equilibrium model with sectoral technico-economic modules inserted. It is a hybrid model, i.e. its structure is designed to combine Bottom-Up information in a Top-Down consistent macroeconomic framework. Energy is explicitly represented in both monetary metric values and physical quantities so as to capture the specific role of energy sectors and their interactions with the rest of the economy. The existence of explicit physical variables allows indeed a rigorous incorporation of sector based information about how final demand and technical systems are transformed by economic incentives.

A short description of the model's architecture is given in annex and a detailed description can be found in Crassous et al. (2006b).

The model's architecture rests on modeling choices that incorporate many sources of "frictions" that arise in real-world markets, which may induce excess or shortage of production factors, unemployment and unequal profitability of capital across sectors. This modeling architecture departs from the pictures of a "first best" world and allows for endogenous disequilibrium generated by the inertia in adapting to current economic conditions.

Our model growth engine is composed of exogenous demographic trends and technical progress that increases labor productivity, as in Solow's neoclassical model of economic growth (Solow, 1956). The demographic assumptions are drawn from the most recent United Nations projections "median variant" scenario with an Indian population growing from 1.03 billion in 2001 to 1.66 billion in 2050. We also use exogenous trends of productivity growth, as it is a common practice in the energy-environment modelling community (e.g. Edmonds et al., 2004, Paltsev et al., 2005). To build these trends we draw on stylized facts from the literature, in particular the convergence assumption (Barro and Sala-i-Martin, 1992) and two empirical analyses on economic convergence, one investigating the past trends by Maddison (1995), and the other one looking at future trends, by Oliveira Martins (2005). For India, default assumptions for labor productivity growth lie between 5% and 3.5% over the 2008-2050 period.

The two sets of assumptions on demography and technical change, although exogenous, only prescribe potential growth. Effective growth results endogenously from the interaction of these driving forces with short-term constraints that may prevent the full utilization of production factors (labor and/or capital): (i) the possible inadequacy between flexible relative prices (including wages) and inert capital vintages characteristics (putty-clay technologies) and (ii) available capital flows for investments.

2.2. Embodiment of technologies and inertia of equipement

To take into account the short-term constraints bearing on productive capacities and end-use equipment, our modelling framework abandons the classical production functions with an explicit mathematical expression (such as CES) and resorts to Leontieff coefficients that evolve along the time horizon according to agents' investment decisions. The inertia of equipment and the embodiment of technologies are modelled through the description of capital generations and their technological characteristics. To represent the evolution of capital vintages characteristics, in particular energy efficiency evolution and substitution among energy sources in major sectors, especially in the electricity sector, the model lies on an explicit detail of production technologies (a portfolio of 26 technologies is represented for the electricity sector). Investment decisions determine the volume and technical content of the new capital generation at each date. They follow an optimal planning approach under imperfect foresight and under the constraint of available investment flows. The estimated need for investments is given by the level of investment in additional plants needed to satisfy a demand that anticipates the prolonging of current demand growth trends. Realized investments for all sectors follow available investment flows (from households' savings, investments from firms, public investments and foreign capital flows), and the allocation of available investments among sectors follows sectors profitability and estimated need of investments.

2.3. Development/consumption style and structural change

Most analysis related to climate policies focus exclusively on technological change and the question of structural change is much less debated. Uncertainties related to structural change are however also great. For instance, between 1900 and 1990, the share of agriculture has dropped down from 17% to 2% in United States and in Japan from 34% to 3%. These evolutions may be perceived as natural laws but they result from the combined action of the evolution of demand addressed to different sectors and of the relative speed of productivity gains which determine the unitary cost of production for each good and service. On the one hand, the evolution of demand depends upon household preferences, upon demand for investment in function of technological change and upon the position of each country on international markets. On the other hand, productivity gains in each sector modify relative prices of goods and move progressively equilibrium between offer and demand.

In most models, demand functions related to long term projections are not modified along decades, or even for a one century projection. This is however determining for the evaluation of the interface between economy, energy and environment for long term periods. The existence of saturation levels for the consumption of specific material goods (food calories and household equipments such as cars or electric devices) may go with the explosion of the consumption of other goods (mobility) which is all the more determining for the sustainability of trajectories.

In Imaclim-R, this is taken into account by i) the decrease of the share of expenditures dedicated to food with the income increase; ii) the existence of asymptotes for final consumption of manufactured good per capita (this describes the dematerialisation process of consumption styles with the income increase); iii) impact of infrastructure policies and of the modal distribution related to passenger transport on the variation of transport consumption.

2.4. Embarking market and institutional failures of the power sector

The specificities of the Indian power sector namely (i) power generation capacity shortage, (ii) under-investment, (iii) tariffs not reflecting costs and subsidies to electricity consumption for farmers and households and (iv) inefficiencies and T&D losses, are embarked in this modelling framework as follows:

(i) Power generation capacity shortage is represented by over utilization of generation capacities. In the model, a utilization rate superior to 0.8 means that the capacity is overused. In 2007, the utilization rate of electricity production capacities is 0.86, which corresponds to 7.5% of capacity shortage (i.e. 7.5% more capacities would be needed to reach a utilization rate of 0.8) and is consistent with estimations given in previous section. This over utilization of productive capacities entails extra generation costs[3] and raises the electricity usage cost, which is a stylized representation of electricity shortage (power cuts) for the Indian economy.

(ii) Under-investment in the power sector is represented by a gap between the estimated need of investments and realized investments in the power sector. Realized investments for all sectors are constrained by available investment flows. Additionally, investments in the power sector are limited to a maximum share of GDP to represent at the aggregate level the capital scarcity in this sector. This limit is set to 2.2% for India, which is consistent with data from the Word Energy Investment Outlook 2003. In 2008, realized investments in the power sector equal to 14 billion US$ and 21.5 billion US$ would be needed to respond to total demand (i.e. the investment gap is equal to 7.5 billion US$ or 35%of estimated needs for investments). It is interesting to realize that this 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.

(iii) Tariffs and subsidies for all commodities, including electricity, are encompassed in the sectors cost structure of the Social Accounting Matrix for India from GTAP-6 database (Dimaranan and McDougall, 2002) that is used to calibrate our model on the year 2001.

(iv) Power plants characteristics, in particular their efficiencies, as well as transmission and distribution losses are calibrated on the sectoral model POLES (LEPII-EPE, 2006). In 2001, the calibration date, overall efficiency of power generation is equal to 32% and Transmission and Distribution losses are 35%.

3. A baseline characterized by low energy decoupling: what are the mechanisms at stake?

Main characteristics of the Imaclim-R scenario are given in table 2 in order to compare them to existing scenarios and to past trends in table 1.

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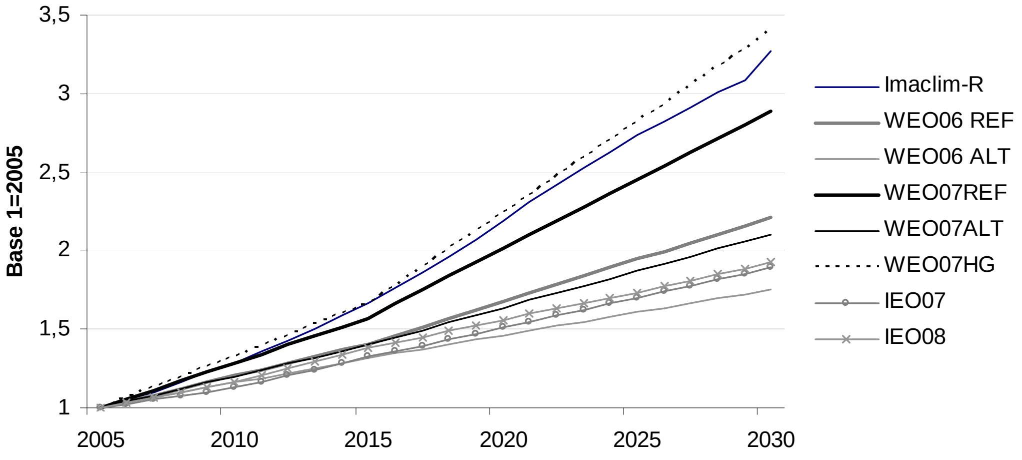
[3] Mean generation costs increase when capacity is overused due to the existence of static decreasing returns because less efficient units are switched on at last at the aggregate level (Corrado and Mattey, 1997).

Table 2: **Main characteristics of the Imaclim-R scenario**

	Period	GDP growth rate	Electricity consumption growth rate	Primary energy consumption growth rate	**Elasticity of energy consumption to GDP**	GHG growth rate	**Elasticity of GHG emission to GDP**
Imaclim-R reference scenario	**2005-2015**	7.1%	7.3%	5.2%	**0.74**	5.3%	**0.75**
	2015-2030	5.0%	4.9%	4.1%	**0.82**	4.6%	**0.92**
	2030-2050	4.4%	3.6%	3.4%	**0.77**	3.3%	**0.75**

In our reference scenario, CO_2 emissions are multiplied by 3.3 between 2005 and 2030 and by 6.2 between 2005 and 2050. Compared to CO_2 emissions from other scenarios we have presented in the first section, the Imaclim-R reference scenario, is just below the WEO07HG (CO_2 emissions are multiplied by 3.4 in 2030) and above the WEO07REF (CO_2 emissions are multiplied by 2.9 in 2030). Other CO2 emissions from other scenarios are far below (CO_2 emissions multiplied by 1.8 to 2.2).

Graph 1: **Comparison of CO_2 emissions trajectories (GtC) between WEO and IEO scenarios and of IMACLIM-R scenario (2005-2030)**



Even if CO2 emissions are not far from WEO07REF and WEO07HG scenarios, determinants may be contrasted. To disentangle the content of CO_2 emission trajectories, we operate a decomposition of the results according to the Kaya identity.

$$E = POP.gdp.IE.IC$$

where *E* is the GHG emissions, *POP* the population, *gdp* the per capita GDP, *IE* the energy intensity of GDP and *IC* the carbon intensity of the energy. The Kaya identity decomposes the contribution of each of this parameter in the evolution of GHG emissions. This identity can be written as follows:

$$\log\frac{E_t}{E_0} = \log\frac{POP_t}{POP_0} + \log\frac{gdp_t}{gdp_0} + \log\frac{IE_t}{IE_0} + \log\frac{IC_t}{IC_0} \dots$$

We use this identity as an ex-post analysis filter of the reference scenario and the alternative scenario of the WEO 2006, of the reference, and the alternative and the high growth scenario of the WEO 2007 for the periods that are considered in the WEOs: 2005-2015 and 2015-2030, and we compare results to our reference scenario in Table 3[4].

Table 3: Kaya identity decomposition for the WEO 2006, the WEO 2007 and the IMACLIM-R reference scenario for the periods: 2005-2015 and 2015-2030.

	log ΔPOP	log Δpib	Log ΔIE	log ΔIC	log ΔEm
2005-2015					
WEO06REF	0,058	0,212	-0,112	0,009	0,167
WEO06ALT	0,058	0,212	-0,134	-0,001	0,134
WEO07REF	0,060	0,242	-0,103	-0,002	0,197
WEO07ALT	0,060	0,242	-0,139	-0,016	0,146
WEO07HG	0,060	0,283	-0,118	-0,005	0,221
REF IMACLIM	0,060	0,237	-0,076	0,008	0,228
2015-2030					
WEO06REF	0,046	0,222	-0,070	-0,002	0,196
WEO06ALT	0,046	0,222	-0,116	-0,028	0,124
WEO07REF	0,063	0,304	-0,101	-0,002	0,264
WEO07ALT	0,063	0,304	-0,168	-0,022	0,177
WEO07HG	0,063	0,408	-0,153	-0,007	0,311
REF IMACLIM	0,063	0,254	-0,055	-0,003	0,259
2005-2030					
WEO06REF	0,104	0,433	-0,182	0,008	0,363
WEO06ALT	0,104	0,433	-0,250	-0,030	0,258
WEO07REF	0,123	0,546	-0,205	-0,004	0,461
WEO07ALT	0,123	0,546	-0,308	-0,038	0,323
WEO07HG	0,123	0,691	-0,271	-0,012	0,532
REF IMACLIM	0,123	0,491	-0,131	0,005	0,487

First it is interesting to note that the re-evaluation of the emissions upwards between the WEO 2006 and the WEO 2007 is significant, and that this re-evaluation is mainly due to more optimistic projections related to economic growth that are only partly compensated by more decrease in energy intensity.

Second, even if the level of CO_2 emissions growth in our scenario is comparable to the WEO 2007 Reference scenario, the components of Kaya decomposition are contrasted. Overall, our scenario is characterized by lower per capita GDP growth (gdp), lower reduction of the energy intensity (IE) but also a light increase of the carbon content of energy (IC) compared to WEO scenarios.

During the 2005-2015 period, in the WEO reference scenarios, the contribution of per capita GDP growth is the most important component in the GHG emission increase. This contribution is at least for 40-50% compensated by the reduction of the energy intensity (for 60% in the alternative scenarios). Over the same period, in our scenario the reduction of the energy intensity is much more limited and it

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[4] For clarity, we do not present the Kaya decomposition of all scenarios considered in Table 1, but it wouldn't modify our analysis.

only compensates for 30% the contribution of the per capita GDP growth. The smaller contribution of energy intensity improvements is reinforced by a slight increase in the carbon intensity of energy.

During the following period 2015-2030, in the WEO Reference and High Growth scenarios, the contribution of the GDP growth is only offset at 30-40% by the decrease in the energy intensity, while in the Alternative scenario the ratio is still 50%.

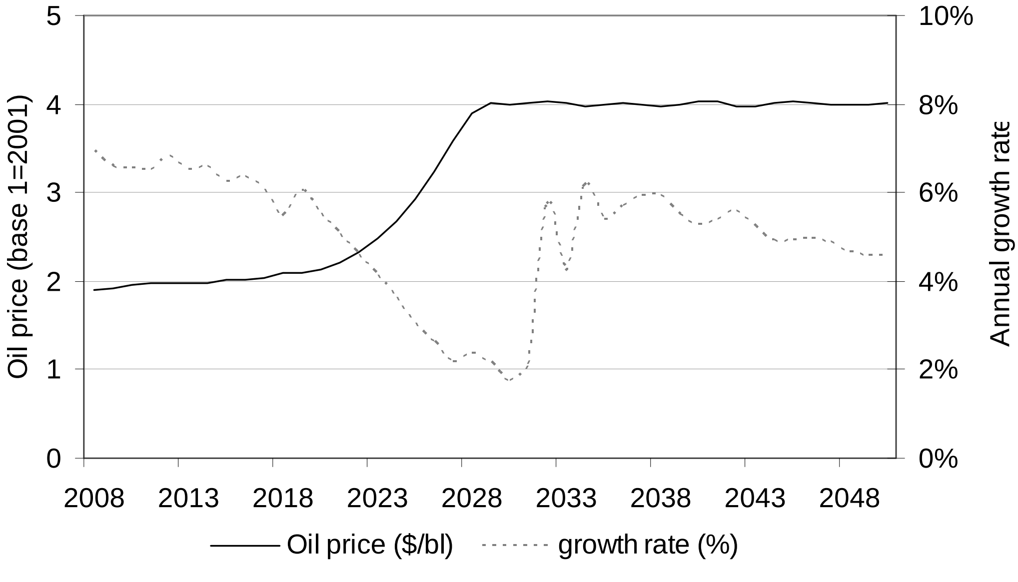
Our reference scenario is more pessimistic as the decrease in energy intensity only compensates for 20% of the GDP growth. The carbon content of energy slightly decreases on this period but, on the whole period, the carbon content of the Imaclim-R scenario is the only one with the WEO06REF scenario to increase.

In the three following sections, we will analyze each of the three elements of Kaya decomposition (the population is put aside from this analysis as all the scenarios considered rely on exogenous assumptions and WEO 2007 and IMACLIM-R share the same exogenous trend from UN projections) and try and highlight the mechanisms explaining why our scenario exhibits lower per capita GDP growth (section 3.1), lower reduction of the energy intensity (section 3.2) but also the increase of the carbon content of energy (section 3.3).

3.1. GDP growth

The first difference in Kaya decomposition that we study is the lower per capita GDP growth in our scenario compared to WEO07 scenarios, in particular during the 2015-2030 period. Graph 2 presents the GDP growth in our scenario over the first half of the century. It shows a significant decline of the growth rate from 5.75% in 2019 to 3.81% in 2027. The reason for this growth profile is due to the interplay between a permanent characteristic of the domestic energy system in India, namely a structural capacity shortage of the power sector, and the rising profile of oil prices.

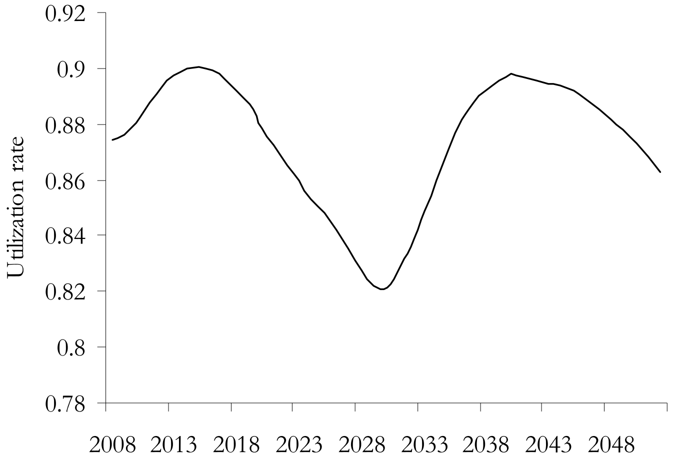
Graph 2: **World crude oil price and GDP growth rate in the reference scenario**



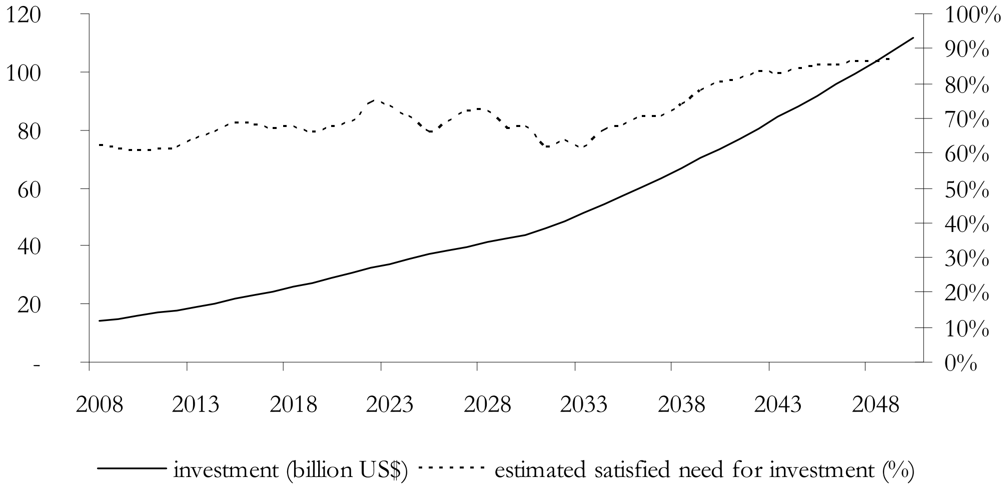
Our scenario is characterized by a lasting structural capacity shortage in the power sector, as shown by the evolution of the utilization rate of power capacities (Graph 3). In the model, a utilization rate superior to 0.8 means indeed that the capacity is overused. From the utilization rates over the simulation period, capacity shortage can be estimated to represent between 2.5% and 12.5% of installed capacity, depending on the date. During the 2020s, capacity shortage is reduced as this period corresponds to a slower growth and therefore less tension on electricity demand.

As described in Section 3, over utilization of productive capacities leads, in the model, to extra generation costs. Over the simulation period, extra-costs represent between 1.5% and 15% of the generation costs. They raise the electricity usage cost, which is a stylized representation of electricity shortage for the Indian economy and limits the development of electricity use by productive sectors as well as by households. Electricity shortage therefore appears as a lasting constraint on growth of production, in particular of the industry sector, over the simulation period.

Graph 3: **Utilization rate of installed capacities in the power sector**



Graph 4: **Estimated needs for investments and realized investments in the power sector**



This evolution of the utilization rate is due to the constraint on investments in the power sector that can be deducted from the continuous gap shown in Graph 4 between the estimated need for investments and realized investments. In 2008, only 65% of the estimated need for investment in the power sector is satisfied with investments equal to 14 billions US, and in 2030, the gap is still equal to 33%. Producers have no choice but using more the existing capacities.

Electricity shortage described above is a limit to substitution from other energy sources, in particular oil, to electricity, for instance industries are forced to resort to diesel generators to compensate for deficiencies of the centralized power supply. Therefore India's economy remains dependent on oil, the majority of which has to be imported. That is why India is highly vulnerable to the rise of oil price, as higher oil import bill implies a transfer of wealth to oil exporting countries, while contrary to China, it is difficult for India to compensate for the increase of energy bill by more exportations[5].

From 2020 to 2030, in our scenario, international oil prices experience a steep rise[6]. As a result India is deeply affected by its oil dependency: oil imports reach 10% of GDP and GDP growth slows down from 5.75% in 2019 to 3.81% in 2027.

The mechanisms described in the previous paragraphs, and the fact they do not materialize in the other prospective exercises we compare our results to, are directly linked to a crucial methodological issue. Indeed, our model, as described in Section 3, accounts for a rich representation of interaction between the energy system and the economic system and encompasses feedbacks from the energy system on economic growth. On the contrary, in partial equilibrium models, economic growth rates are exogenously postulated and feedbacks from the energy systems on economic development are not represented. For example, the WEO 2006 alternative scenario relies upon the same GDP growth assumptions than the reference scenario (page 170 in the WEO 2006) « although there may be some feedback from the new policies to economic performance in practice, this factor was considered too complex and uncertain to model ».

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[5] This has to be interpreted with care, as it reaches one of the main limits of the model that does not represent countries debts dynamics and makes the exogenous assumption of a gradual reduction of international capital flows over the time horizon.

[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. Assumptions concerning oil reserves amount to 2.200 Gbl of conventional oil and 1.200Gbl of non conventional oil (including extra-oil in Venezuela and tar sands in Canada). This is in line with estimates from the US Geological Survey. In the scenario we study here, the interplay described above leads to a steep rise in oil prices between 2020 and 2030 when oil producers are constrained by the depletion of reserves. WEO reference scenarios lie on exogenous assumptions for oil prices (experts says) and reflects a more optimistic vision, relying upon increased exploration efforts and increased levels of enhanced oil recovery. The increase in oil prices is then limited: in the WEO2006, oil price assumptions are 25$/bl in 2025 and 29$/bl in 2030. Nevertheless, because of the recent tightness of crude oil and refined-product prices, markets assumptions were adapted in WEO2007 and crude oil price reaches 62US$2006 in 2030. In our scenario, oil price stabilizes after 2030 at 100$/bl because with such an oil price, the coal-to-liquid technology becomes competitive and penetrates the market, following the model's assumptions on the costs and the development rate of the technology.

3.2. Energy intensity of GDP

In this section, we investigate why our scenario is characterized by significantly lower reduction of energy intensity than the WEO scenarios.

In the previous section we demonstrated how weaknesses in the energy system hinder economic development; we will now look at the other side of the coin and show how, in turn, economic growth has a controlling effect on energy decoupling. Indeed, in the model's version we used to build this scenario, GDP growth constrains energy efficiency improvement in two ways: through the (limited) capacity to finance "clean" technologies for productive capital or final equipment, and through the pace of capital vintages replacement: the lower the GDP growth, the lower the investment in new capital, the older is the average capital age, the worse its average energy efficiency. Therefore with important constraints on investments in India, in particular in the power sector, energy efficiency improvements are mechanically also constrained.

As already described, the power sector is structurally suffering from under-investment in our scenario. The more rapid decrease of the energy inefficiencies of energy supply in the WEO 2007 scenario is directly linked to the high level of investments granted to the energy sector: in the WEO 2007 Reference scenario, investments in new power infrastructure amounts to 956 US$ billion over the period 2006-2030 (i.e. more than 38 US$ billion each years), while in our scenario, only 664 US$ billion (i.e. 70% of the WEO07 value) are invested between 2008 and 2030. In the WEO 2007 Alternative scenario the cumulated investment requirement in the power sector is reduced by 100 US$ billion but is compensated by nearly 60 US$ billion invested in demand side equipment. Even if the WEO 2007 points extensively the fact that "For the sizeable investments that India will need over the two-and-a-half next decades, improving the investment conditions in the sector and moving continuously towards a transparent, predictable and consistent power-sector framework based on market principles and financially profitable will remain paramount importance" (page 529 of WEO 2007), the IEA makes the assumption in the WEO 2007 Reference scenario that these challenges are fully addressed. On the contrary, our scenario is built on the assumption that capital scarcity is a lasting constraint on investments in India. Obviously this assumption is debatable. 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 our scenario should be considered seriously for at least one reason: during the coming decades, 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.

For other productive sectors capacities as well as for households end-use equipment the efficiency improvement is also constrained by the pace of capital replacement (which is linked to economic growth) and by the limited capacity to finance clean technologies. Moreover, substitution possibilities towards electricity are limited by power capacity shortage.

This explains that the overall energy efficiency improvement of the technico-economic system is less optimistic than other prospective scenarios and that electricity consumption growth rate is moderate in our scenario compared to other estimations.

3.3. Carbon content of the energy

We focus now on the last element of the Kaya decomposition, the carbon content of energy.

Our scenario is slightly less optimistic than WEO scenarios in terms of carbon content of energy. The difference comes from the fact that in the WEO scenario, the light oil share decrease (from 34% to 30%) is compensated by a 2 point increase in the share in renewable in 2015, plus in 2030 a 2 point increase in the coal share. On overall the net balance in term of carbon content of energy is slightly negative (IC decrease). In the Imaclim-R scenario, oil share in total primary energy supply falls down (15 points), and this decrease is mainly compensated by coal share increase (10 points), the rest corresponding to gas share increase and nuclear, hydro and renewable (no carbon content). On overall, the carbon content slightly increases.

Table 3: Comparison of energy shares of Total Primary Energy Supply in Imaclim-R and WEO 2007 Reference scenarios in 2005, 2015 and 2030.[7]

	2005		2015		2030	
	Imaclim-R	WEO07 REF	Imaclim-R	WEO07 REF	Imaclim-R	WEO07 REF
Coal	56%	55%	61%	55%	66%	57%
Oil	34%	34%	30%	32%	19%	30%
Gas	6%	8%	7%	8%	10%	8%
Nuclear	1%	1%	1%	3%	2%	3%
Hydro	2%	2%	2%	2%	2%	2%
Renewables	0%		1%		2%	

The lower importance of oil in TPES in our scenario compared to WEO 2007 Reference scenario is mainly due to lower households' fuel consumption for both residential usage and private vehicles, coming from both a revenue effect and a price effect. The revenue effect[8] implies a slower access to equipment for households, in particular we may note a slower development of private cars ownership in our scenario compared to WEO 2007 Reference scenario: car ownership evolves from the current 13 vehicles per 1000 people to 59 in 2030 in our scenario while it reaches 93 in WEO 2007 Reference scenario at the same date. The price effect[9] increases the usage cost of transports and therefore limits mobility. The same price effect applies to limit oil usage in the residential sector.

This evolution of carbon content of energy announces two critical issues for India's growth pathways: (i) the development of households' energy consumption,

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[7] The share of commercial renewables is not given for WEO 2007 Reference scenario, in which it is aggregated with traditional biomass. Therefore, Table 3 gives, for WEO 2007 scenario, the shares of each types of energy in Total Primary Energy Supply excluding renewables and traditional biomass.

[8] Additionally to the revenue effect, the slower access to car ownership (and end-use equipment in the residential sector) is also most probably due to a difference in the modelling of the equipment rate evolution in function of households income.

[9] In 2030, oil price is multiplied by 2 compared to 2008 in our scenario, whereas in WEO07 Reference scenario oil price in 2030 is almost equal to 2006 price.

in particular through widespread use of private cars and (ii) the use of coal in power generation.

(i) the development of residential energy usage and of transports. In spite of the slower development of transports experienced in the Imaclim-R scenario, we may postulate that if the barriers to growth we described are successfully removed, Indian's growth pathway would be associated with more transports, thus with even higher emissions. Therefore, from a mitigation point of view, transports development appears critical; and special attention should be devoted to urban planning and infrastructures so as to avoid the explosion of transports (and associated emissions). The same reasoning applies to end-uses in the residential sector, for which the control of the energy efficiency will be essential.

(ii) the use of coal in power generation. Table 3 shows that coal share within the energy mix grows from 56% in 2005 to 66% in 2030 and 64% in 2050. Most of the coal is used in the power sector. The increased share of coal in the energy mix is due to the fact that the increase in coal price is lower than the increase in oil and gas prices and as coal plant investment cost is low compared to other technologies. From a mitigation point of view, one of the challenges will therefore be to improve the efficiency of the power generation sector and limit the use of coal.

Conclusion

The starting point of this article was to question the realism of optimistic energy decoupling forecasted in many reference scenarios related to India. From the analysis presented in the first part of this article, it appears that the trajectories depicted in these scenarios might stumble over barriers to the diffusion of technological change and decarbonisation of the economy. Notably, institutional and market failures of the energy system seem unlikely to be corrected rapidly, especially the capital scarcity in the power sector incurred by structural non-recovery of costs. We therefore propose an alternative reference scenario, built with a modelling framework representing explicitly and as realistically as possible the processes driving energy intensity and carbon intensity changes, in particular taking into account the aforementioned weaknesses of the power sector. Our scenario is not significantly different from WEO07 trajectories in terms of GHG emissions trends, but the components of Kaya decomposition are sharply contrasted: our scenario is characterised by slower economic growth and also slower energy intensity decline. The underlying mechanisms explaining these differences lie in the interactions between economic growth and energy decoupling.

As emphasized by Sheehan (2008) and Pielke et al. (2008), the realism of the reference scenario is critical for estimates of the costs of stabilization at a given GHG concentration and for policy recommendations. A realistic reference case is also necessary for the international negociations, as the evaluation of economic impacts of any international climate policy scheme will be heavily influenced by the reference case assumed. Therefore, it appears that three kinds of conclusions can be drawn from this illustrative exercise related to the Indian reference scenario:

- First, it supports the criticisms that suggest existing reference scenarios might be too optimistic on the automatic (without policies) decarbonisation of economies.

- Second, from a methodological point of view, it emphasizes the importance to improve the realism of modelling tools and to use methodologies that allow representing for each country specificities and sub-optimalities, and to consider the interactions and feedbacks between the energy system and economic mechanisms. We may suggest similar modelling methodologies, focusing on other emerging countries, China in particular, would bring valuable insights to a comprehensive understanding of energy and economic interactions driving current and future GHG emissions trends.

- Third, regarding climate policies and negotiations, it appears that the challenge for climate policies to lift the barriers to the diffusion of energy efficiency improvement in India is considerable, but that there is a potential for synergies between development policies and climate policies. Indeed, in the Indian context, we have shown that the diffusion of more efficient technologies and of cleaner technologies is stalled by persisting failures. And, the economic pathway we described is characterized by important feedbacks between the weaknesses of the energy sector and the economic development, with important environmental impacts. This is particularly manifest in the power sector. On the one hand structural under-investment in the power sector leads to electricity shortage, which plays as a barrier to development and induces slow reduction of the inefficiencies of the power sector, which implies high GHG emissions. And on the other hand economic growth pace constrains investment possibilities. These elements will be crucial in the evaluation of different strategies for GHG concentration stabilization and corresponding mitigation scenarios in India. In particular, reducing the inefficiencies of the power sector would both lift barriers to development and reduce GHG emissions. Therefore there is a potential for synergies between development policies and climate policies, which might give the possibility to get out of the environment-development deadlock in international negociations. But a particular attention will have to be carried in this process to the possible larger diffusion of end-use equipments, particularly private vehicles, and therefore more important households’ energy consumption due to a revenue effect following the alleviation of barriers to development, through carefully and early planning of infrastructures.

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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. It is calibrated on GTAP-6 database (Dimaranan and McDougall, 2002) that provides, for the year 2001, a balanced Social Accounting Matrix (SAM) of the world economy. The original GTAP-6 dataset has been modified (i) to aggregate regions and sectors according to the IMACLIM-R mapping (ii) to produce a hybrid matrix with the 2001 IEA energy balances.

The growth path is described as a sequence of static short-term equilibriums, on a yearly base, articulated with dynamic equations giving the new conditions for the following equilibriums, 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 short-term 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.

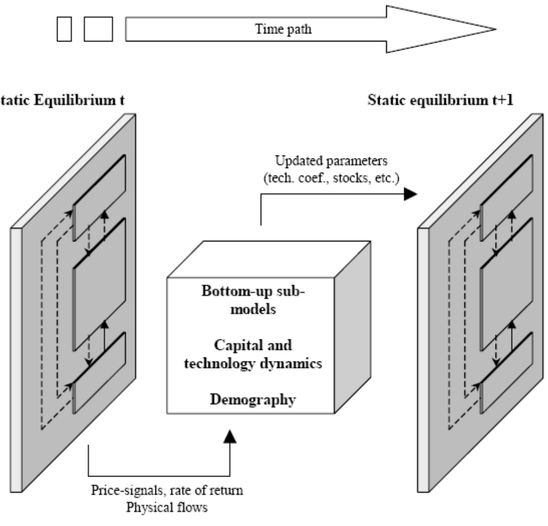

Figure 1: The recursive dynamic framework of IMACLIM-R

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; (ii) technical change governed by exogenous or endogenous trends of labor 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 the main sectors of the energy system, in particular the power sector.

- *various submodels*, concerning energy systems, transport infrastructures or end-use equipments, 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 equilibriums such as relative prices or investment flows).

Structural parameters of the static equilibrium (structure of demand, input-output coefficients 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 full description of the model is given in Crassous et al. (2006b).