Energy Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Copenhagen commitments and implications: A comparative analysis of India and China

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ARTICLE INFO

Article history:
Received 23 February 2010
Accepted 17 August 2010

Keywords:
Analysis of India and China
Intensity targets
Stringency factor

ABSTRACT

Dynamic targets have been long advocated as a participatory tool for developing countries in climate change mitigation. Copenhagen commitments of India and China resume this trend after the unsuccessful attempt of Argentina a decade ago. However, linear intensity targets are prone to 'hot air' problems or non-compliance risks. Intensity targets of India and China are analyzed using their elasticity parameters. The relationship of these parameters to the structural nature of emissions and GDP profiles has been demonstrated and a method of comparing the probability indices of target achievement has been formulated in this paper, showing a lower probability for China compared to India. Similarly, a method of defining stringency factor for linear targets has been suggested and stringency factors evaluated for India (40%) and China (90%), which shows the relative stability of India's targets. This paper evaluates an energy–GDP–emissions index (EYE index) to indicate the extent of coupling/decoupling of economic growth from emissions. The three indices developed in this paper, namely, elasticity parameter, stringency factor and EYE index can be effectively used to analyze the economy–emissions relationships for policy making and target setting.

1. Introduction

India and China are faced with the challenge of sustaining rapid economic growth while dealing with the threat of global climate change. While India sustains 17% of the world population in a land mass of about 2.4% of the world's geographical area, China has 21% of the world population in about 6.5% of the world's area. The threat of climate change has the potential to strain the development efforts of these economies. Both countries have been actively promoting policies for energy efficiency and emissions reduction to deal with climate change. Recently India announced[1] a reduction of 20–25% cut in emission intensity by 2020 compared to 2005 levels after China announced intensity cut of 40–45%.

Intensity targets, as announced by both the countries, have been suggested for effective participation of developing countries in the emission mitigation effort (Baumert et al., 1999; Pizer, 2005). Another alternative is the observation of Lutter (2000) that India and China could potentially gain from trade by accepting emission caps at Business-As-Usual (BAU). Herzog et al. (2006) point out that intensity targets are attractive instruments for framing climate change policies and linking them to other policy goals, but their stringency and legal character are important criteria for assessing environmental effectiveness. Philibert and Pershing (2001) suggest that a dynamic target can achieve higher accuracy compared to a fixed target system in the context of international trading, which could significantly reduce the associated "hot air" problems.

Jotzo and Pezzey (2007) derive a rule for the optimum degree of indexation to GDP and show that intensity targets could make it more attractive for all countries to join an international climate treaty. Fischer and Springborn (2009) undertake a comparative analysis of the effects of *no policy*, *emissions cap*, *emissions tax and intensity targets* in both deterministic and stochastic scenarios to observe that an intensity target encourages greater economic growth than a cap or a tax, with no adverse impact on the business cycle. The present analysis looks at intensity targets with a view to identifying the impact of GDP uncertainties on target achievement. It formulates a stringency factor to measure the dynamic stability of the targets and other indices to help policy makers in optimal target setting.

2. Climate change in a development framework

The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report observed that, "warming of climate system is now unequivocal, as is now evident from observations

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[1] Summary of the pledges of developing countries is available at: http://pdf.wri.org/summary_of_non_annex1_pledges_2009-12.pdf.

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doi:10.1016/j.enpol.2010.08.026

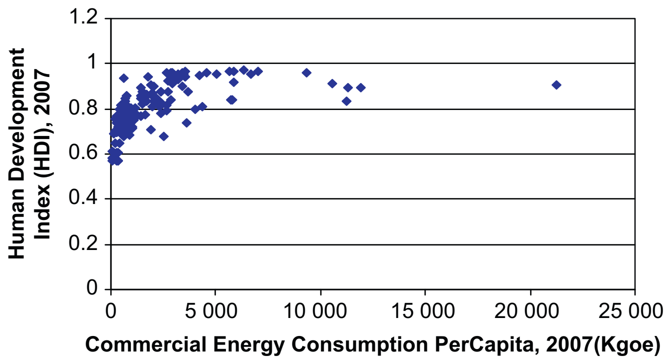

Fig. 1. Correlation between HDI and per capita energy consumption, 2007. *Source*: HDI Trends: http://hdrstats.undp.org/en/indicators/74.html, Per Capita Energy Consumption Trends: http://unstats.un.org/unsd/ENVIRONMENT/Energy.htm.

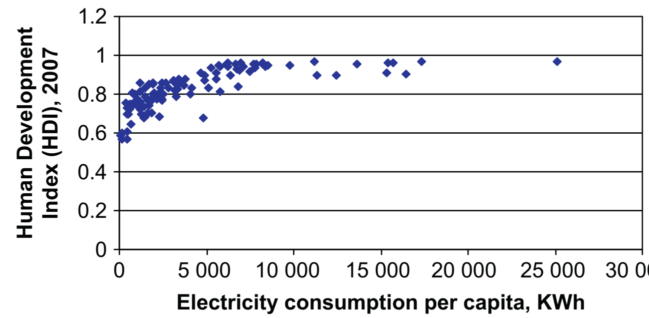

Fig. 2. Correlation between Human Development Index and Per Capita electricity Consumption for various countries, 2002. *Source*: HDI Trends: http://hdrstats.undp.org/en/indicators/74.html, Per Capita Electricity Consumption Trends: http://earthtrends.wri.org/searchable_db/results.php?years=all&variable_ID=574&theme=6&country_ID=all&country_classification_ID=all.

of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global sea level" (IPCC, 2007). Initial National Communications of India and China (NATCOM Report, India, 2004a; NATCOM Report, China, 2004b) to UNFCCC identify the predicted impacts of climate change in the respective countries. Countries with low rates of growth, rapid increases in population, and ecological degradation are more vulnerable to climate change (IPCC, 1995). India, at 134th position in the World Human Development Index,[2] needs energy to sustain its economic growth. China at 92nd position is comparably better off in terms of development indicators.

Narain et al. (2009) point out that 'no country in history has improved its level of human development without corresponding increase in per capita use of energy.' An inequitable aspect of climate change is that the poor are the most vulnerable to climate change and women are particularly affected. With climate change, there would be increasing scarcity of water, reduction in yields of forest biomass, and increased risks to human health, with children, women and the elderly becoming the most vulnerable. With the possibility of decline in the availability of food grains, threat of malnutrition may also increase. In view of these, development and poverty eradication will be the best form of adaptation to climate change (Shukla et al., 2003).

The developmental impact of climate change is based on the correlation between human development index (HDI) and per capita commercial energy consumption. Fig. 1 shows the human development indices of a number of countries plotted against per capita energy consumption, which shows a declining marginal addition to human development at higher energy levels.

In 2007, India's per capita commercial energy consumption was 365 Kgoe and the HDI was 0.6. To achieve an HDI of about 0.9, the per capita energy consumption should be about 2500 Kgoe as in the case of Poland or Portugal. While a threshold commercial energy of 2500 Kgoe per capita is required to achieve an HDI value of about 0.9, excessive consumption meets with diminishing marginal improvement. A similar correlation exists (Fig. 2) between HDI and per capita electricity consumption which shows a threshold of about 4000 KWh for an HDI value of 0.9.

As against this threshold, India has a per capita electricity consumption[3] of 481 KWh while that of China is 1781 KWh in 2005. With a low per capita electricity consumption, it is imperative that India pursues a development-friendly approach to any strategy of emissions reduction. India's National Action Plan on Climate Change rightly emphasizes the need to avoid compromising national economic growth (Fransen et al., 2009). Comparatively, China's per capita energy consumption is higher. The World Development Report (2010) observes that developing countries can shift to low-carbon trajectories, if financial and technical assistance from high-income countries are available. Appropriate target setting is also important for achieving these trajectories.

3. GHG intensity

GHG intensity is a performance index for greenhouse gas (GHG) emissions which measures the quantity of emissions with respect to economic performance (Herzog, et al., 2006). The Kaya identity (Kaya, 1989) relating to energy-related carbon emissions, states:

$$\text{Carbon emissions from energy} = \text{Carbon emissions per unit of energy consumed} \times \text{Energy consumed per unit of GDP} \times \text{GDP per capita} \times \text{Population}$$

This may be written as

$$\text{Carbon emission rate(GtC/person-year)} = \text{Carbon Intensity of Energy(GtC/EJ)} \times \text{Energy Intensity of GDP(EJ/\$)} \times \text{GDP Per capita(\$/person-year)}$$

Economic growth translates to carbon emission growth primarily through economy specific parameters such as energy intensity and carbon intensity. There is wide variability of these parameters among various countries. Carbon intensity of GDP is the product of energy intensity of GDP and carbon intensity of energy. As emission intensity of a country includes emission of all greenhouse gases across various sectors, it is determined by (i) energy efficiency, (ii) fuel mix, (iii) sectoral composition of GDP and (iv) emission factors of greenhouse gases in various sectors.

$$\text{Linear Emission Intensity (I)} = \frac{\text{GHG Emissions } (\varepsilon)}{\text{GDP } (\Upsilon)} \quad (1)$$

Stringency factor of emission intensity is a measure of the efforts required to achieve the target over a specified timeframe.

[2] The Human Development Index is the average of three indices: the life expectancy index (LEI), the education index (EI) and the GDP index (GDPI). The Education Index is itself a weighted sum of: the adult literacy index (ALI, weight=2/3) and the gross enrollment index (GEI, weight=1/3). See HDR, 2009 available at http://hdr.undp.org/en/media/HDR_2009_EN_Indicators.pdf for details.

[3] As against this threshold, India has a per capita electricity consumption of 481 KWh while that of China is 1781 KWh in 2005 (IEA Statistics Division, 2007).

4. Argentina's experience

In 1999, Argentina suggested (Argentine Republic, 1999) a voluntary adoption of intensity target under the Kyoto Protocol, as is the case of India and China now. Argentina's proposal was to adopt a General Intensity Target defined as follows:

$$\text{Emission Intensity } (I) = \frac{\text{GHG Emissions}}{\text{GDP}^{\alpha}} = \frac{\varepsilon}{Y^{\alpha}} \quad (2)$$

where α is a parameter linked to the structural aspect of GHG emissions in Argentina with a suggested value of 0.5. Emissions intensity (I) was projected at 151.5. Historically about one-third of GHG emissions in Argentina were being generated by the Agriculture and Livestock sector, while this sector contributed less than one-tenth of the GDP. This makes Argentina's emissions linearly correlated with the square root of GDP, which resulted in the proposal of an emission intensity target defined by Eq. (2) as against (1), so that other economic sectors are not severely strained in a low economic growth scenario. Emission reduction of 2–10% across the examined scenarios was sought to be achieved through this target.

Uncertainty in the forecasted scenarios is the fundamental problem of target setting. Fixing the environmental end independently of the economic end becomes difficult, particularly for developing countries where the economic dynamism is greater. Therefore, uncertainty reduction over economic growth rates, when constrained by emission target, demands dynamic targets. Dynamic targets are composed of relational composites of two or more variables. The intensity target proposed by Argentina had inherent advantage of reducing the uncertainty over the economic impact of the proposed commitments, since intensity, being a relational composite, can modulate the emissions target according to the actual performance of the economy. However, this uncertainty reduction over the adverse economic impact is achieved by means of a trade-off, which increases the uncertainty over the emission reduction achievement, besides increasing the complexity of the instrumental mechanism.

Argentina's proposal for a general intensity target required an amendment to the Kyoto Protocol, which was not widely supported by the developing countries and not legally possible given that the Protocol had not yet entered into force (Bouille and Girardi, 2002). It is interesting to note that recently Copenhagen witnessed a return of Argentina's proposal, though with linear intensity targets, when countries like India and China announced voluntary targets for emissions reduction.

5. Intensity targets

The problem with a linear intensity target as defined by Eq. (1) is that its stringency depends on the economic growth rate of a country. If actual GDP growth rate exceeds projected GDP growth rate substantially, the target will become meaningless as its achievement is ensured by GDP growth with a little additional effort on emission reduction. This is the genesis of the 'hot air' problem. On the other hand, if the actual GDP growth rate is proportionately lower than projected, the target would become relatively more stringent on emission reduction front leading to non-compliance risk. Therefore, Lutter (2000) and later, Kim and Baumert (2002) evolved modified intensity indices to generate a more meaningful target for emission reduction to be adopted particularly by developing countries.

Lutter (2000) suggested an emissions indexing approach with a GDP elasticity of 0.6, past emissions elasticity of 0.5 and past per capita GDP elasticity of 0.06. Kim and Baumert (2002) combined the concepts of dual targets and intensity targets to formulate a hybrid variant called dual intensity targets. This idea can be paraphrased as follows: There are basically two ways of introducing relational composites for reducing uncertainty: (i) dual targets in the form of a selling target and a buying target (Philibert, 2000) (ii) dynamic intensity target which combines the two relevant variables into a composite as in the Argentina's proposal. Kim and Baumert (2002) argue that it is possible to reduce uncertainty still further by combining these two approaches in the form of a dual intensity target, which involves two separate targets for buying and selling, both being intensity targets. The lower (more stringent) target provides an incentive to reduce emissions as reduction below this target would enable the country to sell emission allowances. The higher (less stringent) target would be punitive in the sense that exceeding this target would require the country to purchase excess emission allowances in order to remain in compliance. Thus, the lower target would be the "selling target" and the higher one, "compliance target", both being intensity targets defined as follows:

Selling Target: Emissions $= \mathbf{I_1} \times \mathbf{GDP}^{\boldsymbol{\alpha}}$
Compliance Target: Emissions $= \mathbf{I_2} \times \mathbf{GDP}^{\boldsymbol{\alpha}}$ ($I_2 \geq I_1$).

Different combinations of fixed targets, linear intensity targets and general intensity targets are possible (Philibert and Pershing, 2001; Kim and Baumert, 2002; Sue Wing et al., 2006). These approaches to target setting show an increasing complexity of the target instruments with the objective of reducing uncertainty and consequent 'hot air' and non-compliance risks. Fig. 3 depicts this hierarchical overview.

6. Indexed intensity targets

The more the complexity of a target, the more is the difficulty of target setting and compliance monitoring. Target setting being a trade-off between economic and environmental uncertainties, would ideally seek a balance between these uncertainties. A suitably indexed intensity target could approach such a balance, particularly for developing countries. Marschinski and Lecocq (2006) confirm that a well-calibrated general intensity target can always dominate a quota with regard to the uncertainty on marginal abatement costs as well.

However, it appears that the linear intensity targets announced in Copenhagen lead to excessive uncertainties of 'hot air' and non-compliance problems, particularly in respect of China. A suitable indexation could correct this to a large extent. The value of the index α may be determined on the basis of the historic relationship between emissions and GDP in a given country. Economically, this parameter represents the GDP elasticity of emissions. This result follows by taking the natural logarithm of Eq. (2) which gives:

$$\mathbf{ln}\,\varepsilon = \mathbf{ln\,I} + \boldsymbol{\alpha}\,\mathbf{ln\,Y} \quad (3)$$

Partial differentiation of Eq. (3) assuming constant intensity for annual variations yields:

$$\alpha = \frac{\partial(\text{GHG})}{\text{GHG}} \times \frac{\text{GDP}}{\partial(\text{GDP})} = \frac{\dot{\varepsilon}}{\varepsilon} \Big/ \frac{\dot{Y}}{Y} \quad (4)$$

A dot over the symbol indicates its time rate of change. α represents the sensitivity of emission rates to GDP growth rates, which can be obtained by regression of GHG emission data. Table 1 gives the data[4] relating to the GHG emissions and GDP of

[4] The data has been utilized mainly to capture the trends regarding the emission intensities as there is variability of the emissions and GDP ($PPP) data used in the estimates of the World Resources Institute and other estimates. For

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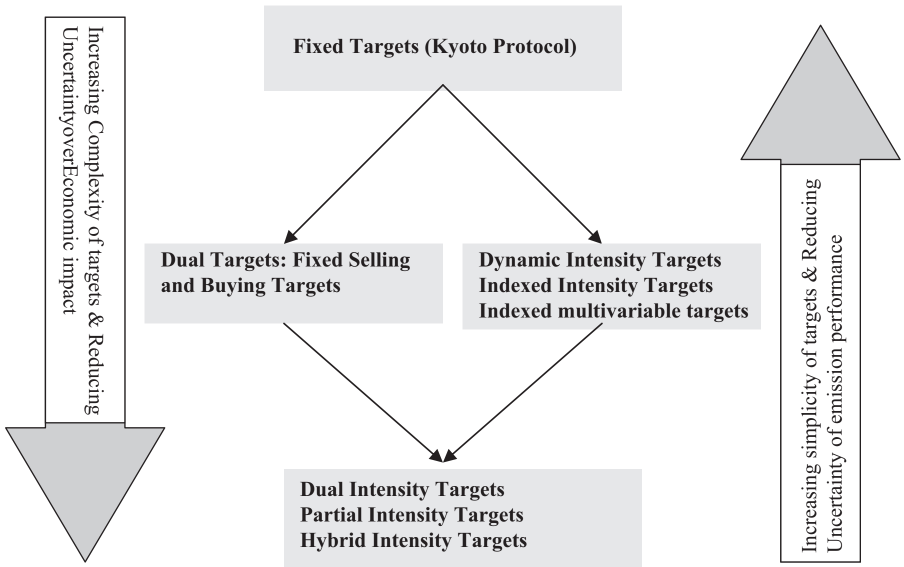

Fig. 3. Intensity targets: a hierarchical overview.

Table 1
GHG emissions and GDP of China and India (1990–2005).
Source: Climate Analysis Indicators Tool, World Resources Institute, available at: http://cait.wri.org/

Indicators		1990	1995	2000	2005
China	Population (Million)	1135	1205	1263	1304
	Emissions GHG ($MtCO_2Eq$)	3594	4662	4818	7234
	GDP (Billion$ PPP,2005)	1248	2225	3364	5314
	Energy use (000 Tons Oil Eq	863.2	1048	1105.9	1720.1
	GHG intensity (Tons CO_2Eq./Mill. $,2005)	2879.81	2095.28	1432.22	1361.31
India	Population (Million)	849.5	932.2	1015.9	1094.6
	Emissions GHG ($MtCO_2Eq$)	1106	1338	1660	1866
	GDP (Billion $PPP 2005)	1026	1315	1745	2445
	Energy use (000 Tons Oil Eq	319.9	387.5	459.8	538.1
	GHG intensity (Tons CO_2Eq./Mill. $,2005)	1077.97	1017.49	951.289	763.19

China and India. Both India and China are massive economies and following Lutter (2000), we assume that forecast errors being inversely correlated with economy size, data measurements are reasonably accurate.

Comparative emission intensities of India and China are shown in Fig. 4. There is a distinct divergence between the variations for the two countries with year 2000 as the critical year. While China's emission intensity stagnated after 2000, India's emission intensity declined faster.[5] Auffhammer and Carson (2008) corroborate this trend in China since 2000 and suggest aggregate emission elasticity with respect to GDP slightly above unity (1.03–1.11) during 2000–2010. Junsong and Canfei (2009) analyze the causes of China's energy intensity trends by logarithmic mean divisia index techniques to conclude that while technological change is the dominant contributor to the decline of energy intensity, its contribution has decreased in China since 2001. Moreover, while the change in industry structure has reduced the energy intensity before 1998, it has raised the intensity after 1998 with the heavy industrialization strategy and the rise in proportion of energy intensive industries.

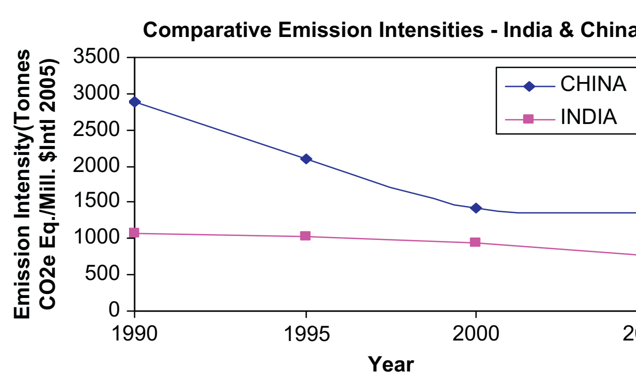

Fig. 4. Comparative emission intensities of India and China (1990–2005).

The emission elasticity parameter α of a country ($0 \leq \alpha \leq 1$) can be considered as a proxy for the probability estimate or certainty index of achieving a linear intensity target as defined by Eq. (1), in

(*footnote continued*)
example, the estimates projected in India specific studies, namely, 'Results of Five Climate Modeling Studies: GHG Emissions Profile' (available at moef.nic.in/downloads/home/GHG-report.pdf) projects a GHG intensity of 0.37 $kgCO_2$/$GDP, PPP for India in 2005.Also see the UNDP projections of GDP ($PPP2005) data for India and China (Human Development Report, 2007/08 available at http://hdr.undp.org/en/media/HDR_20072008_EN_Complete.pdf). Leggett et al. (2008) point out the wide variability of the official emissions estimates of China with those of other international agencies.

[5] In fact, the stagnation of emission intensity after 2000 has been a worldwide phenomenon as evidenced by the global trend. See Human Development Report, 2007/2008, p. 57 for details. India appears to be an exception to this trend.

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Table 2
Regression results of GHG emissions of India and China.

Regression statistics		Parameter values	Remarks
India	Correlation coefficient *R*	0.98428	$R^2=0.96881$
	α	0.61084	
	t-statistic α	7.88243	Null hypothesis ($\alpha=0$) is rejected at a *p*-value of 0.79%.
	Significance of statistic for one-sided test (*p*-value)	0.0079	
	Intensity	16.471	
	t-Statistic intensity	4.91707	Null hypothesis (intensity=1) is rejected at a *p*-value of 1.9%.
	Significance of statistic for one-sided test (*p*-value)	0.019	
China	Correlation coefficient *R*	0.95318	$R^2=0.90855$
	α	0.44713	
	t-Statistic α	4.45763	Null hypothesis ($\alpha=0$) is rejected at a *p*-value of 2.34%
	Significance of statistic for one-sided test (*p*-value)	0.0234	
	Intensity	144.75082	
	t-Statistic intensity	6.27656	Null hypothesis (Intensity=1) is rejected at a *p*-value of 1.22%.
	Significance of statistic for one-sided test (*p*-value)	0.0122	

all economic growth scenarios. A value of $\alpha=1$ indicates perfect synchronism between emissions and economic growth which implies achievement of a linear intensity target in all scenarios of growth. In other words, higher α reduces the scenario uncertainty with regard to growth and vice versa.

The values of elasticity parameter α can be determined by regression of the GHG emissions and GDP data relating to the respective countries. Table 2 gives the regression results of the data in Table 1 using Eq. (3), which indicates an elasticity value of 0.611 for India and 0.447 for China.

7. Probability index of achieving intensity targets

The value of α is highly correlated with the probability of achieving specified targets. The achievement of specified intensity target depends on two key factors: (1) the nature of specification of the target (2) Economic and emission abatement performance during the period. α isolates the first of these effects. A low value of α of the economy increases the compliance risk for linear intensity targets. In fact, Sue Wing et al. (2006) find that a positive correlation between emissions and GDP is a necessary but not sufficient condition for preferring an intensity target. GDP elasticity of emissions must be large enough to make it variance reducing. A very low value of α makes linear intensity targets variance increasing and therefore linear intensity targets are not advisable for such economies. We demonstrate the relationship of α to the probability of target achievement (due to the first factor stated above) for certain special cases.

Differentiating Eq. (3) we get

$$\frac{\dot{I}}{I}=\frac{\dot{\varepsilon}}{\varepsilon}-\alpha\frac{\dot{\Upsilon}}{\Upsilon} \quad (5)$$

In terms of targeted (achieved) values, the above equation can be written as

$$\frac{\dot{I}^*}{I^*}=\frac{\dot{\varepsilon}^*}{\varepsilon^*}-\alpha\frac{\dot{\Upsilon}^*}{\Upsilon^*} \quad (6)$$

where the * sign indicates that the variables represent the targeted(achieved) values at the end of the mitigation period. It is appropriate to define the probability index of achieving the general intensity target ($0\le P\le 1$) based on Eq. (6) as follows:

$$\left.\begin{aligned} P &= e^{-((\dot{\varepsilon}^*/\varepsilon^*)-\alpha(\dot{\Upsilon}^*/\Upsilon^*))} && \text{for}(\dot{I}^*/I^*)>0 \\ &=1 && \text{for}(\dot{I}^*/I^*)\le 0 \end{aligned}\right\} \quad (7)$$

This definition follows from the fact that if the intensity target is achieved, $(\dot{I}^*/I^*)\le 0$ and probability index is unity, assuming that the achievement is by real emission reduction performance and not merely by 'hot air'. A positive value of $(\dot{I}^*/I^*)$ indicates achievement gap, which reduces the probability exponentially.

For linear intensity $\boldsymbol{\alpha=1}$ and the corresponding equations are:

$$\left.\begin{aligned} \overline{P} &= e^{-\left((\dot{\bar{\varepsilon}}^*/\bar{\varepsilon}^*)-(\dot{\bar{\Upsilon}}^*/\bar{\Upsilon}^*)\right)} && \text{for } (\dot{\bar{I}}^*/\bar{I}^*)>0 \\ &=1 && \text{for } (\dot{\bar{I}}^*/\bar{I}^*)\le 0 \end{aligned}\right\} \quad (8)$$

From Eqs. (7) and (8), for positive relative intensity variation, we get

$$\frac{\ln(\overline{P})}{\ln(P)}=\frac{(\dot{\bar{\varepsilon}}^*/\bar{\varepsilon}^*)-(\dot{\bar{\Upsilon}}^*/\bar{\Upsilon}^*)}{(\dot{\varepsilon}^*/\varepsilon^*)-\alpha(\dot{\Upsilon}^*/\Upsilon^*)} \quad (9)$$

Let us consider the special case of target emissions being realized in practice so that the first term of the numerator and denominator of the right hand side of Eq. (9) becomes zero. Assuming that the actual relative variations in GDP are the same both for the linear intensity and general intensity targets, we get

$$\overline{P}=P^{(1/\alpha)} \quad (10)$$

Assuming equal probability (P) of achieving an optimal α-weighted general intensity target for both China and India, we get:

$$\text{For India}: \quad \overline{P}i=P^{(1/\alpha_i)}=P^{1.64} \quad (11)$$

$$\text{For China}: \quad \overline{P}_c=P^{(1/\alpha_c)}=P^{2.24} \quad (12)$$

$$\overline{P}_c=(\overline{P}_i)^{(\alpha_i/\alpha_c)}=(\overline{P}_i)^{1.37} \quad (13)$$

Eq. (13) demonstrates that a linear specification of intensity targets leads to a lower probability of achievement (on account of the nature of specification of targets) for China than for India due to the lower α value of China.

8. Elasticity parameter and the structural nature of emissions

Baksi and Green (2007) describe a method, using the Divisia Index approach, of computing the rate of decline in energy

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intensity by combining technical efficiency improvements in various sectors of the economy, and shifts in economic activity among these sectors. This approach for computing the share of various underlying causal factors is based on the factor decomposition method outlined in US Department of Energy (2003). We follow this approach to disaggregate the emission intensity into its causal factors and then to specify a formula for $\boldsymbol{\alpha}$:

$$\text{Emissions,}\ \varepsilon=\sum_i \varepsilon_i=\sum_i Y\times\frac{Y_i}{Y}\times\frac{\varepsilon_i}{Y_i}=\sum_i YS_i\bar{I}_i \quad (14)$$

where ε_i is the emissions from the ith sector, Y_i the gross domestic product (GDP) from ith sector, S_i the sectoral share of GDP, $\bar{I}_i$ the linear emission intensity of ith sector

Differentiating Eq. (14) to disaggregate the components and dividing by ε, we have

$$\frac{\dot{\varepsilon}}{\varepsilon}=\sum_i \mathrm{xi}(\dot{\mathrm{Y}}/\mathrm{Y}+\dot{\mathrm{S}}_\mathrm{i}/\mathrm{S}_\mathrm{i}+\dot{\bar{\mathrm{I}}}_\mathrm{i}/\bar{\mathrm{I}}_\mathrm{i}) \quad (15)$$

x_i represents the share of emissions from the ith sector given by $\boldsymbol{x_i}=(\varepsilon_i/\varepsilon)$. Other components on the right hand side of Eq. (15) may be called the activity factor, structural factor and the intensity factor (US Department of Energy, 2003), respectively.

Differentiating Eq. (3) and combining with Eq. (15) we get

$$\alpha=1-\frac{(\dot{I}/I)-\sum_i[xi(\dot{\bar{I}}_i/\bar{I}_i)]-\sum_i[x_i(\dot{S}_i/S_i)]}{\dot{Y}/Y} \quad (16)$$

Integrating (16) over the time period from initial to final year (t), we get

$$\alpha=1-\frac{\ln(I^t/I^0)-\sum_i[x_i^*\ln(\bar{I}_i^t/\bar{I}_i^0)]-\sum_i[x_i^*\ln(S_i^t/S_i^0)]}{\ln(Y^t/Y^0)} \quad (17)$$

where x_i^* indicates the logarithmic mean of the sectoral shares given by

$$x_i^*=\frac{(x_{i,t}-x_{i,0})/\ln(x_{i,t}/x_{i,0})}{\sum_i[(x_{i,t}-x_{i,0})/\ln(x_{i,t}/x_{i,0})]} \quad (18)$$

Eq. (16) identifies the causal factors for the divergence of α from unity. If emission variation with respect to GDP of the economy is linear, the numerator of the second term of Eq. (16) will be equal to zero leading to $\alpha=1$(linear intensity target). However, if the emission profile of the actual economy is nonlinear, then for any chosen linear intensity target, $(1-\alpha)$ represents the departure of the linear target from the structural nature of actual emissions of the economy. Essentially this departure depends on two factors (1) extent to which the intensity target would diverge from the emissions-weighted average of sectoral linear intensity variations (2) emissions-weighted average of the sectoral GDP share variations.

Eq. (17) captures this departure in terms of the initial and final values of the respective variables. A further decomposition of the first factor into the technology factor and the energy source factor (fuel mix factor) is possible for energy intensive economies as described below:

$$\text{Emissions,}\ \varepsilon=\sum_i \varepsilon_i=\sum_i Y\times\frac{Y_i}{Y}\times\frac{E_i}{Y_i}\times\frac{\varepsilon_i}{E_i}=\sum_i YS_iT_iF_i \quad (19)$$

where S_i is the share of output from the ith sector (structural factor), T_i the energy intensity of ith sector(technology factor), F_i the emission per unit energy from ith sector (energy source or fuel mix factor)

The above product can be disaggregated by differentiating Eq. (19) to get:

$$\frac{\dot{\varepsilon}}{\varepsilon}=\sum_i x_i(\dot{Y}/Y+\dot{S}_i/S_i+\dot{T}_i/T_i+\dot{F}_i/F_i) \quad (20)$$

Combining Eqs. (3) and (20), we get

$$1-\alpha=\frac{(\dot{I}/I)-\sum_i x_i[(\dot{S}_i/S_i)+(\dot{T}_i/T_i)+(\dot{F}_i/F_i)]}{\dot{Y}/Y} \quad (21)$$

The value of $(1-\alpha)$, which represents the deviation of the chosen intensity target from the structural variation of emissions in the economy, depends on the expression in the numerator of the right hand side of Eq. (21). Two important cases arise in the interpretation of this expression for linear intensity targets: (i) If the chosen linear target corresponds to the structural variations represented by the second term of the expression, the entire expression is equal to zero leading to $\alpha=1$. (ii) If the chosen linear target deviates from the structural variation of the emission profile of the economy, the result would be $(\alpha\neq 1)$. The second case is relevant in the present situation relating to India and China. If we substitute the declared linear intensity target variation and the actual structural variations in Eq. (21), we obtain the corresponding value of α. Conversely, the value of $(1-\alpha)$ calculated from the historical nature of emissions, yields an indicative value of the departure of a linear intensity target from the structural nature of emissions. Integrating (21) over the time period from initial to final year (t), we express this departure in terms of end point parameters as in the previous case:

$$\alpha=1-\frac{\ln(I^t/I^0)-\sum_i[x_i^*[\ln(S_i^t/S_i^0)+\ln(T_i^t/T_i^0)+\ln(F_i^t/F_i^0)]}{\ln(Y^t/Y^0)} \quad (22)$$

Eq. (21) can be used to estimate the relative uncertainty in GDP introduced as a result of the adoption of linear intensity target as against α-weighted general intensity target. This uncertainty will introduce a similar uncertainty in the achievement of linear targets. For achieving a chosen linear intensity target, Eq. (22) can estimate the value of target GDP to be achieved, taking into account the variation of structural nature of emissions and the elasticity parameter α.

9. Stringency factor for target achievement

It has been shown above that for a specified linear intensity target, which may be at variance with the structural nature of emissions, α will move away from the unity value, depending on the extent of such variation. The more the linear intensity target deviates from the structural nature of emissions, the more is the difficulty to achieve it. Target stringency, which indicates the additional effort required to achieve the target in all growth scenarios, becomes correspondingly higher. Therefore, the stringency factor must be proportional to $(1-\alpha)$. Besides this dependency, the stringency factor must also be proportional to the difference between the target rate of intensity decline and the observed trend rate of intensity decline of the economy.

This leads to the conclusion that the stringency factor must be proportional to $(1-\alpha)$, if target rate of intensity reduction is equal to the trend rate and it must be proportional to (target rate–trend rate) if $\alpha=1$. These twin criteria can be combined to give a definition of the stringency factor as proportional to (Target rate$-\alpha\times$Trend rate). Since the maximum value of α for real economies is unity and the maximum possible trend rate will generally be fixed as the target rate, the first term of this expression, namely, target rate, is the idealized value of the second term, ($\alpha \times$ Trend rate). Therefore, the stringency factor may be defined as a percentage deviation of the actual from the idealized value:

$$\text{Stringency factor for target achievement(\%)} = (\text{Target rate-}\alpha \times \text{Trend rate}) \times 100/(\alpha \times \text{Trend Rate}) \quad (23)$$

For a linear intensity target, stringency depends on trends in the past emissions trajectory captured by the elasticity parameter α. For India, the annual intensity reduction during 1990–2005 is 1.947% and for China it is 3.52%. These may be considered as trend rates. This yields 40.1% target stringency for India (for 25% intensity reduction by 2020 in all growth scenarios) and 90.1% for China (for 45% intensity reduction by 2020 in all growth scenarios). Moreover, if the short term trend rate of 2000–2005 is applied, it is seen that China's target becomes extremely stringent whereas that for India gets further relaxed due to higher growth rate of emissions of China during this period. On the whole, it is seen that intensity targets of India are stable and achievable in all scenarios of economic growth compared to China. It has been reported that China already faces serious challenges meeting the previously announced intensity targets (Leggett et al., 2008). It appears that a linear intensity target may not be suitable for a country, if its stringency factor is more than 50%. Appropriate indexation would be required in that case to do away with the inherent instability of the target against growth rate variations.

10. Energy–GDP–emissions index (EYE index)

The elasticity parameter $\boldsymbol{\alpha}$ is highly correlated with the carbon intensity of energy in energy intensive economies. In 2005, 67.1% of India's emissions and 73.4% of China's emissions were from the energy related sectors (Climate Analysis Indicators Tool, World Resources Institute). Therefore, the influence of energy as the coupling factor of emissions and GDP profiles in these economies is obvious. We construct an index called EYE index as a defining factor of the state of the economy indicating the extent of coupling/decoupling of GDP and emission profiles:

We define β as the energy elasticity of GDP and γ as the energy elasticity of emissions. Then,

$$\beta = \frac{\dot{\Upsilon}}{\Upsilon} \Big/ \frac{\dot{E}}{E} \quad (24)$$

$$\gamma = \frac{\dot{\varepsilon}}{\varepsilon} \Big/ \frac{\dot{E}}{E} \quad (25)$$

From Eqs. (4), (24) and (25),

$$\alpha\beta = \gamma \quad (26)$$

The values of β and γ can be estimated from the regression of GDP-energy use data as well as emissions-energy use data, respectively (Table 1).

The results of regression are shown in Table 3. Ideally, the last column, namely, $(\alpha\beta/\gamma)$ must be unity as shown by Eq. (26), which would indicate perfectly coupled energy–GDP–emission profiles with constant intensities. We define $(\alpha\beta/\gamma)$ as the EYE index to represent the extent of deviation of the energy–GDP–emissions profile from a strictly log-linear form on account of variable intensities. This index gives an insight into the energy↔GDP↔emissions interactive chain in the economy. In particular, EYE index indicates the nature of variations of general intensities relating to energy–GDP–emissions triad. As the coupling of economic growth with emissions occurs mainly through the energy route, EYE index represents the extent of *coupling/decoupling of economic growth from emissions*, with a lower value of index indicating higher decoupling.

Table 3
Energy–GDP–Emissions (EYE) index for India and China.

Country	α	β	$\alpha\beta$	γ	EYE index $(\alpha\beta/\gamma)$
India	0.61084	1.65988	1.01392	1.03285	0.98
China	0.44714	1.97687	0.88394	0.98669	0.90

Energy efficiency improvements and energy related emissions reduction lead to the decoupling of growth and emissions. The more decoupled the economy, the less the manoeuvrability of emission intensity. The EYE index is higher for India (0.98) compared to China (0.90) for the period 1990–2005. Reduced manoeuvrability of emission intensity for China leads to reduced probability of achievement of intensity targets. This result corroborates our earlier comparison of probability indices in Eq. (13). The underlying reasons for the extent of coupling/decoupling can be found in the growth trajectories of both the countries. For instance, Valli and Saccone (2009) identify the differing patterns of development and structural transformation of China since 1978 and India since 1992 with the Fordist model of growth operating in China earlier and much more intensively than in India. A higher EYE index for India during the past period indicates greater potential for energy related emission reductions for India in the future mitigation period and a higher probability of achievement of future intensity targets.

11. Emission reduction requirements—example of India

Regression of the greenhouse gas emission data for India from 1990 to 2005 with a semi log model gives the following equation:

$$\mathbf{ln(GHG) = 7.0224 + 0.03544 \times t} \quad (27)$$

[R^2=0.98734, null hypothesis rejected at *F*-statistic significance level of 1.19E−15]

Fig. 5 shows a projection of total GHG emissions up to 2020 based on (27). The baseline level of emissions in 2020 is 3247 $MtCO_2e$ as projected in Fig. 5.

For an emission intensity reduction of 25% from 2005 level at 2020, the corresponding average GDP growth rate required is 5.77% and for an emission intensity reduction of 20% from 2005 level, the average GDP growth rate required is 5.32%. This means that if the average growth rate of 5.77% can be maintained during 2005–2020, emission intensity reduction of 25% is achievable in the baseline scenario.

The average growth rate of India during 1990–2005 was 6%. Therefore, if the average growth rate during 2005–2020 is about

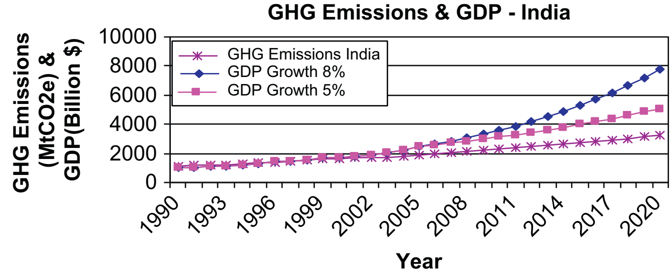

Fig. 5. GHG emissions and GDP projections of India.

Please cite this article as: Vazhayil, J.P., Balasubramanian, R., Copenhagen commitments and implications: A comparative analysis of India and China. Energy Policy (2010), doi:10.1016/j.enpol.2010.08.026

the same as that during 1990–2005, the target reduction in emission intensity can even be exceeded. If the growth rate is say 5.0%, the additional emission reduction required will be about 340 $MtCO_2e$ in 2020 with respect to the baseline level and for a growth rate of 4.0%, it will be about 725 $MtCO_2e$. However, the GDP elasticity of GHG emissions being 0.6, part of this will be accounted for by the fall in GDP. With a growth rate of 8.0%, the 25% linear intensity reduction target will generate 'hot air' problems.

12. Intensity targets for developing country participation

While intensity targets are getting accepted more and more in the mainstream as a convenient mechanism for developing country participation, it is important to evolve target frameworks suitable to the structural and emission profiles of the local economies. Bouille and Girardi (2002) identify the lessons to be learned from Argentina's voluntary targets, namely, the requirements of thorough technical assessment for realistic assessment of technology and emissions-related markets, need to carefully consider country-specific emissions conditions and to be conservative in economic projections, need to leave room for growth and for domestic policy relevance and buy-in, long-term view and realistic understanding of international order, etc.

Reducing emissions is critical for achieving intensity targets. However, this has significant impacts on growth and welfare. In the case of India, Murthy et al. (2006) estimate that as the emission restriction level is tightened from 10% to 20% and further to 30%, the effects on long run GDP and welfare become increasingly adverse. GDP falls by 0.53%, 1.36% and 4.06% and the number of poor increases by 2.1%, 5.9% and 17.5%, in the 30th year for 10%, 20% and 30% cumulative carbon emission restrictions, respectively. This brings into focus the challenge of climate change for developing countries.

This challenge requires simultaneous action on several fronts, particularly in the energy sector due to the faster growth rate of this sector in developing economies. During 1994–2007, electricity sector in India projected the highest compound annual growth rate of 5.6% among all other sectors (INCCA, 2010). Energy efficiency and decarbonization of energy supply are key strategies for balancing economic growth and climate change mitigation (Lester and Finan, 2009). An energy roadmap with an efficiency focus has been projected in India's Integrated Energy Policy (Planning Commission, India, 2006). China has already made commendable progress in energy efficiency improvements. China's successful decoupling of economic growth and carbon emissions (demonstrated by the steep decline in the carbon intensity indicator) is due largely to energy price reforms (Baumert et al., 1999). Both India and China have announced National Action Plans on Climate Change (Prime Minister's Council on Climate Change, India, 2009; National Development and Reform Commission, China, 2007).

13. Conclusions

This communication focuses on the situation of India and China in the global climate change mitigation effort post-Copenhagen. India's commitment of 20–25% reduction of emission intensity of GDP has been analyzed in comparison to China, whose announcement preceded the Indian initiative. The stringency of achievement of target depends on the nature of intensity targets as well as on the historical relationships between GDP growth rate and emissions growth rate, which is captured by the GDP elasticity of emissions. This elasticity parameter has been found to be 0.611 for India and 0.447 for China. As the ideal value of this elasticity parameter is 1.0 for uniform stringency of target in all possible growth scenarios, it is seen that a higher elasticity parameter of India gives a better probability of achieving the emission intensity target, with respect to sensitivity in economic growth scenarios. The elasticity parameter for India is very close to the value of 0.6 suggested by Lutter (2000) for universal application to all countries. It has been shown that a linear specification of intensity target leads to a higher probability of target achievement for India compared to China, due to less divergence of the structural nature of India's emissions and GDP from those corresponding to the linear intensity trajectory.

Conceptually, this means that the emissions profile of India's economy is better aligned to its GDP growth compared to that of China, which makes the achievement of committed reduction possible in various scenarios. For China, the committed reduction leads to compliance risk in a low-growth scenario. Linear intensity targets can generate 'hot air' problem at high growth rates in both countries. The relationship of the elasticity parameter to the structural nature of emissions and economic growth has been explored in this paper. It has been found that the departure of the elasticity parameter from unity depends on two factors (1) emissions-weighted average of sectoral linear intensity variations and (2) emissions-weighted average of the sectoral GDP share variations. A further decomposition of the first factor into the technology factor and the energy source factor (fuel mix factor) has been made for energy intensive economies.

A target stringency factor has been devised to capture the difficulty level of its achievement. It is seen that the stringency factor is 40% for India whereas that for China is 90%. If the short term trend rates of 2000–2005 is applied, the target of China becomes extremely stringent whereas that for India gets relaxed implying the divergence between the emission pathways of India and China in the recent past. The structural nature of emissions as well as the past growth trajectory has placed India not only with a lower value of emission intensity but also with a greater stability in reducing its emissions uninfluenced by fluctuations in the growth rate of GDP.

In order to gain an insight into the energy–GDP–emissions coupling in an economy, we construct EYE index to indicate the extent of *coupling/decoupling of economic growth from emissions*, with a lower value of index indicating higher decoupling. This decoupling is a result of energy efficiency improvement as well as carbon intensity reduction. The index is higher for India (0.98) compared to China (0.90) for the period 1990–2005 indicating a more coupled economy of India than that of China. With China's Fordist model of growth preceding India's similar growth trajectory, the decoupling efforts also started earlier in China. As a consequence, China's economy is today more decoupled than that of India with less manoeuvrability of emission intensity in future. This corroborates our results regarding the probability indices of India and China to achieve linear intensity targets.

Various findings of this paper point to the considerations regarding optimal intensity target for an economy. This decision can be facilitated by the analysis of indices developed in this paper, namely, elasticity parameter (α), Stringency factor and EYE index. Empirically, it appears that for values of $\alpha \leq 0.5$, stringency factor $\geq 50\%$ and EYE index ≤ 0.9, either fixed targets or indexed intensity targets may be more suitable for a country. These indices can be effectively used to analyze the state of the economy with regard to its emission characteristics as well as to make appropriate policy decisions regarding target setting.

The close correlation, albeit at lower energy consumption levels, between human development index and energy consumption, points to the developmental paradox that all developing countries face with regard to the climate change imperatives.

Please cite this article as: Vazhayil, J.P., Balasubramanian, R., Copenhagen commitments and implications: A comparative analysis of India and China. Energy Policy (2010), doi:10.1016/j.enpol.2010.08.026

While accelerated development is the best route to a feasible climate change adaptation strategy, it has the potential to raise challenges in climate change mitigation through its causal relationship with energy consumption. While energy consumption needs to be enhanced on a per capita basis and extended to the population living in energy poverty, developing countries have to address the challenge of reducing carbon intensity of GDP for climate change mitigation. Thus development and climate change adaptation goals compete with mitigation responsibilities in the policy action space. These challenges call for policy options that seek to align these often contradictory goals. Properly designed general intensity targets with sufficient stringency level appear to be effective instruments to indicate the development trajectory to achieve these policy options.

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