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AN ASSESSMENT OF INDIA'S 2020 CARBON INTENSITY TARGET

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Executive Summary

India is a signatory of the Copenhagen Accord, developed at the Copenhagen climate summit in December 2009, which recognised that deep cuts in global emissions were required "with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius"[1]. As part of international mitigation efforts, India registered with the UNFCCC its voluntary endeavour to reduce the emissions intensity of its GDP by 20 - 25% by 2020 in comparison to the 2005 level[2].

This Report assesses the feasibility and ambition of these targets, given the scale of global emissions reductions required to hold the rise in global mean temperatures to 2°C, and identifies some of the key domestic and international policy issues and challenges.

Is the Indian target feasible?

A continuation of India's long term trend of declining CO_2 intensity since 1996 would be sufficient to achieve the top end (25%) of India's CO_2 intensity target for 2020. But this does not mean that achieving India's target will be easy. If India was to undergo a period of rapid industrial growth, such as the one China has experienced, there is a possibility that this would lead to an increase in CO_2 intensity, at least for a transitional period. Our Baseline case, which takes account of the rapid growth in power generation that India needs for its development, suggests that on existing policies the CO_2 intensity of the Indian economy will decline by only 13.2%, and that continuing efforts will be needed to reach the target range.

How ambitious is it?

By meeting its target, India would be saving more than 500m tonnes of CO_2 emissions per annum by 2020, roughly equivalent to the UK's total energy related CO_2 emissions today. This would be an important contribution to global climate change mitigation. Even so, the target may not be demanding enough to deliver the aims of the Copenhagen Accord. The absolute level of India's CO_2 emissions would still have risen from just over 1 billion tonnes of CO_2 per annum today to just over 2 billion tonnes in 2020. When the Indian Environment

Minister originally announced the Indian target, he said that India would be willing to do more if nations arrived at a “comprehensive and equitable agreement”[3].

What is the Savings Potential?

Our conclusion is that the targets that India has set are probably within reach through strong policies and provided that the necessary resources can be made available. A growth pattern for India with a higher share of heavy industry than we have projected would, however, make this a tougher challenge.

Reform of the Indian power sector to reduce losses and modernise the (mainly coal) generating fleet, combined with the modernisation of the steel and cement industries, and stricter efficiency regulation of lighting, appliances, and vehicles, would be sufficient to meet the lower end (20%) of India’s target range. These measures would have a net economic benefit in addition to the carbon savings. They are being pursued energetically by the Indian Government, but the social, institutional, and financial barriers are considerable and shortages of skilled manpower may constrain the rate of progress.

Reaching the high end of the range requires additional investment in low cost options including nuclear power, large hydro, and wind, and co-firing of coal power stations with bio-fuels. Switching from coal to natural gas can also make a useful contribution, although India’s access to natural gas is likely to be restricted, at least to 2020.

Looking to 2050

In the longer term all major economies will need to achieve much lower levels of carbon intensity to meet a 2°C target. For this, India will need some combination of technologies such as solar power, advanced nuclear, Carbon Capture and Storage (CCS), and electric vehicles, as well as even more intensive application of many of the policies that are relevant to 2020. Solar power, both Photovoltaic (PV) and Concentrated Solar Power (CSP), represents a particular opportunity for India, and the Indian government has articulated a “Solar Mission” with the aim that solar power should become competitive with coal by 2030.

Introduction

India’s Commitment

India played an important part in the Copenhagen Accord which underlines that “climate change is one of the greatest challenges of our time” and recognises the objective of containing the increase in global temperatures to below 2°C. The parties to the Accord agreed to co-operate to achieve the peaking of global and national emissions as soon as possible, but with a longer time frame for developing countries. They also recognised that, "social and economic development and poverty eradication are the first and overriding priorities of developing countries"[1]. These development objectives are central to India's energy policies. More recently, India's consent was critical for the decision reached in Durban in 2011 to adopt a universal legal agreement on climate change by 2015[4].

The next decade is critical for international mitigation efforts. According to the International Energy Agency (IEA)[5], if global emissions do not peak by around 2020 and decline consistently thereafter, the emissions reductions needed to meet a 2°C target will become much more costly or even infeasible. In assessing India's contribution to this, however, it is important to recognise that India starts from a position where CO_2 emissions per person are less than 30% of the world average, and less than 12% of the average for the OECD.

India's voluntary commitment to reduce the emissions intensity of its GDP by 20 - 25% by 2020 in comparison to the 2005 level is an important contribution to the global effort to mitigate climate change. As a party to the 1992 Framework Convention on Climate Change, India has for many years recognised the importance of stabilising the level of greenhouse gases in the atmosphere. But as a developing country, India did not need to commit itself to any national emission reduction targets under the Kyoto Protocol.

India has also committed itself to ensuring that per capita carbon emissions will never exceed the average of the per capita emissions of developed industrial countries[6]. At 1.25 tonnes per capita, this measure is, however, currently far below OECD (10.61) and World (4.39) averages[7].

Achievability of India's Target

In this Paper, we assess the feasibility and ambition of India's voluntary targets, given the scale of global emissions reductions required to hold the rise in global mean temperatures to 2°C, and identify some of the key domestic and international policy issues and challenges.

Figure 1 shows the historic decline in the carbon intensity of India's economy over the period 1995 to 2008. A continuation of this trend to 2020 would lead to India just exceeding the top end of her target range, and even in the case of 1% per annum lower economic growth the outcome is well inside the target range. But this does not mean that India's target is easy. The CO_2 intensity of India's economy (0.33 Kg CO_2 per $ppp) is already well below that of China (0.60), and significantly below that of the US (0.48)[7]. A key question is whether India can continue to develop with declining level of carbon intensity or whether rapid industrialisation might lead to an increase in carbon intensity such as China experienced in the period 2002 – 2004.

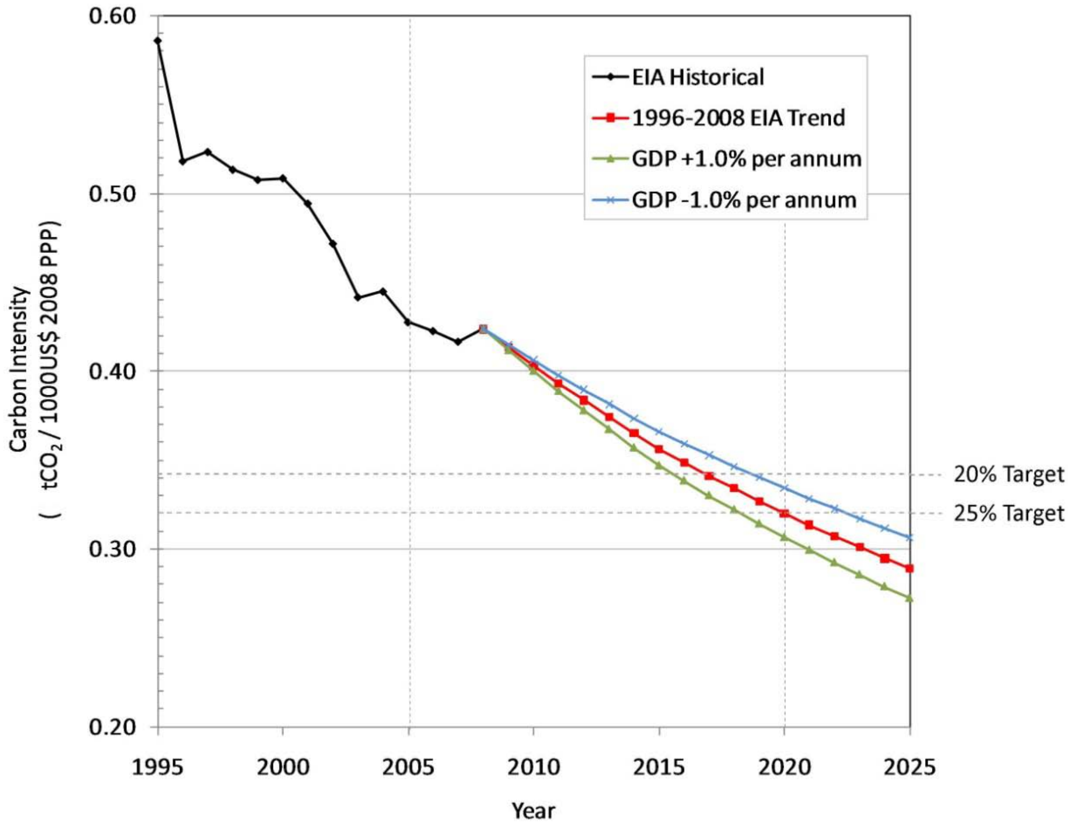

Figure 1: Indian carbon intensity trend extrapolation (Source: EIA, Own Analysis)

We have categorised the carbon saving options available to India according to their difficulty in implementation. Our Green case is a mid-range estimate of what we judge reasonably attainable. Our Stretch case is closer to the absolute, theoretical potential.

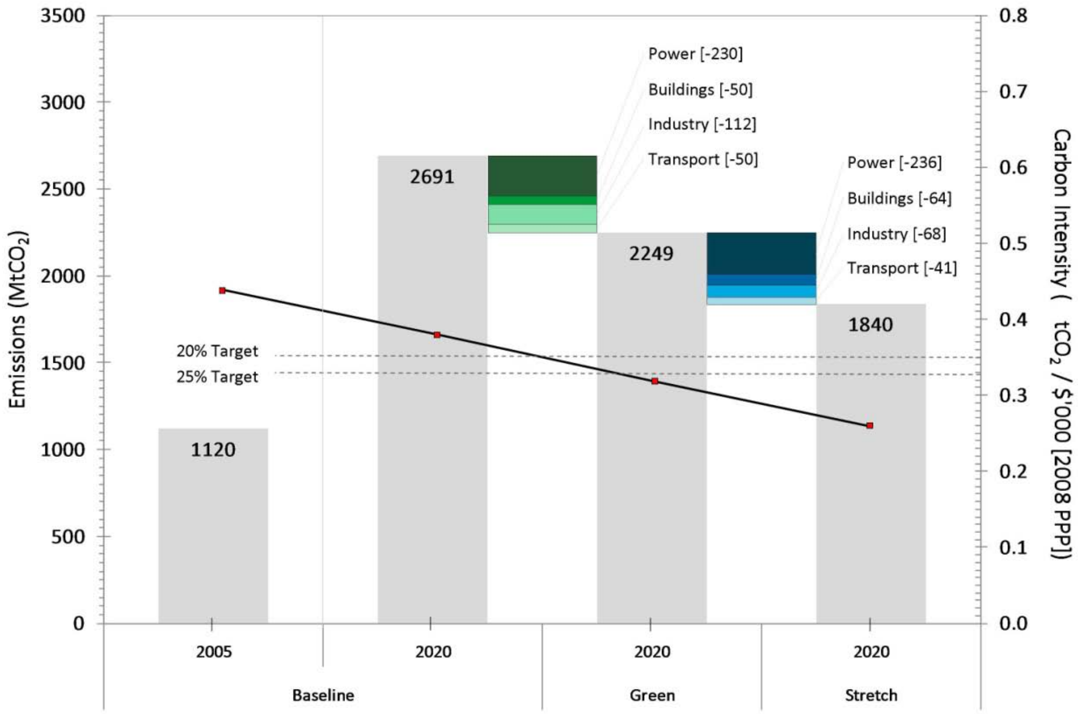

Figure 2: India scenario emissions and carbon intensity metrics (Source: IEA, Own Analysis)

Figure 2 shows the impact of the potential savings on India's CO_2 emissions. In the base case these emissions rise from 1.1 billion tonnes per annum in 2005 to nearly 2.7 billion tonnes per annum in 2020. The Green savings in power, buildings, industry, and transport, reduce the 2020 emissions by 442 million tonnes to 2.2 billion tonnes per annum. The Stretch savings reduce them by a further 409 million tonnes to 1.8 billion tonnes. The solid line crossing the figure shows that in the Baseline case India would fall significantly short of the target range of reducing carbon intensity by 20 - 25%. However, the carbon savings in the Green case would exceed the high end (25%) of the target range and the savings in the Stretch case would enable it to be exceeded by a wide margin. Most of the savings in both the Green and the Stretch scenarios come from the power sector, which contributes just over half the totals, with significant further savings coming from each of buildings, industry, and transport.

Cost Options	Negative	Low	Medium	High
Baseline	13.20%			
Green	20.3%	23.8%	26.9%	27.5%
Stretch	23.2%	32.0%	38.9%	40.7%

Table 1: Reduction in India carbon intensity achieved for range of technology cost categories (Source: Own Analysis)

We have also categorised the savings according to their cost, ranging from Negative to Low (less than $10 per tonne of CO_2 saved), Medium ($10 - 50), and High (over $50). Table 1 shows the reductions in carbon intensity attainable by adopting measures of different cost and difficulty. The lower end of the target range (20%) is reachable with Green policies that will also reduce costs. However, reaching the higher (25%) end of the range requires either the adoption of Green policies with low and medium cost or the adoption of Stretch policies with low costs. To some extent, therefore, there is a choice between policies that are more costly and policies that face greater barriers to implementation.

An Expert Group of the Planning Commission of the Government of India, in its recent interim report[8] on Low Carbon Strategies for Inclusive Growth, has reached broadly similar conclusions. Their "Determined Effort" case, in which "policies that are already in place or contemplated are pursued vigorously and implemented effectively", would yield a reduction in carbon intensity in the range of 23 - 25% by 2020, while their "Aggressive Effort" case, which requires new policies and technology, would yield reductions in the range of 33 - 35% . The areas in which reductions are found are broadly similar to those in this study, except that the forestry sector, not included in this report, is covered by the Expert Group.

Methodology

The underlying analysis on which this Paper is based was carried out for the UK government as part of the Avoid O Programme[9]. This was a bottom-up detailed technological analysis of the potential for reducing CO_2 emissions from energy consumption in each of the main sectors – power, industry, buildings and transport, which together account for more than 90% of India's energy related CO_2 emissions. We have largely relied on published forecasts by the IEA, the EIA, and the IMF, for our assumptions on GDP growth and demand in main sectors of the economy. Details of the methodology are at Annex 1.

India's Economy and Energy Policy

India is the second most populous nation on earth with a population of 1.1 billion in 2007, representing about 17% of the World's population. India's economy has been growing, on average, at 7.7% per year between 2000 and 2007, and energy related CO_2 emissions have increased by 125% between 1990 and 2007, to 1.3 billion tonnes, representing about 4.5% of the global total[10].

The service sector plays a crucial part in India's economy and in India's economic growth. 68% of India's economic growth in the period 2001 - 8 came from the service sector, whereas in China the figure was 42%. Conversely, 52% of China's growth was from Industry, which accounted for only 27% of India's growth[11].

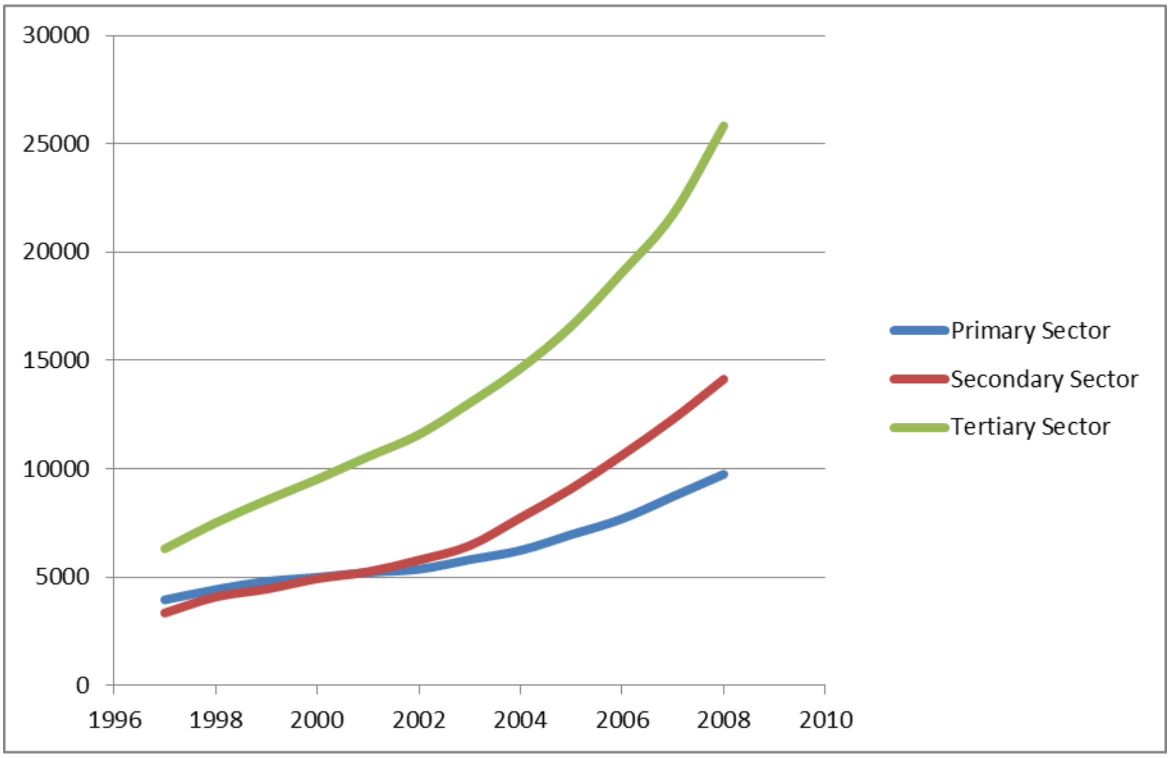

Figure 3: Indian GDP (Billions of Rupees) by Sector (1997 - 2008), (IMF Data)

India's energy economy is largely coal based, with 68% of power generation derived from coal plants in 2007[12]. India is currently the world's third largest coal producer, projected by the IEA to become the second largest, after China, by 2030. India has about 7% of the World's proven coal reserves, representing about 122 years of production at current rates[13]. However, India's coal reserves are generally of poor quality and coal supply is constrained by environmental restrictions on access and by inefficient mining technologies. Also, India's coal reserves are concentrated in the North East, and it is uneconomic to transport domestic coal to the South and West of the country. For these reasons substantial coal imports, mainly from Australia and Indonesia, are likely to be needed.

Increased energy supplies are critical for the success of India's strategy for economic development and poverty reduction. India already suffers from chronic power shortages. These are partly the result of very high technical and commercial losses in the power system. Reform of the power sector, increasing the quantity and quality of coal supply, and investment in new and efficient coal generating capacity are all, therefore, major government priorities.

India depends on imports for more than three quarters of its oil supply. Gas contributes a relatively modest 6% of India's energy demand and a growing share of this is now imported[14]. India's Expert Committee on Integrated Energy Policy, reporting in 2006, recognised that India faced formidable challenges in meeting its energy needs. Their vision required that India "pursues all available fuel options and forms of energy, both conventional and non-conventional. Further, India must seek to expand its energy resource base and seek new and emerging energy sources. Finally and most importantly, India must pursue technologies that maximise energy efficiency."[15].

In June 2008, the Prime Minister of India released India's first National Action Plan on Climate Change (NAPCC), which identified eight core national missions running to 2017[16]. These included a national solar mission and a mission for enhanced energy efficiency. The Perform, Achieve, and Trade (PAT) scheme, now in the process of implementation, is a key element of the energy efficiency mission and will focus on improving the efficiency of more than 700 of the most energy intensive installations in India. Due to India's outstanding growth prospects, the increase in India's CO_2 emissions between 2007 and 2020 are projected by the IEA, in their Baseline case[12] to constitute more than 15% of the global increase.

In the following section we assess the potential for CO_2 emissions savings in the four major energy using sectors of the Indian economy: electricity generation, industry, buildings (including appliances) and transport.

CO_2 Savings Potential by Sector

Electricity Generation

Estimates of the growth in Indian power demand vary widely from as low as 5.9% to as high as 9.8% [12, 17, 18]. Our analysis is based on average growth of 7.5% to 2020. This growth is driven by the rapidly increasing use of electricity by industry and in homes. Constraints on the supply of coal mean that there are strong incentives to improve the efficiency of power generation and supply. Further, the high degree of reliance on coal leads to a shortage of peaking supply and underlines the need for peak load technologies such as reservoir hydro, combined cycle gas plant, and solar power[17].

Our Baseline scenario reflects the extensive policies that the Government of India has in place to expand, modernise, and diversify the power system to 2020. This includes a substantial reduction in grid losses, as well as investment in 36 GW of advanced supercritical coal generation, 15 GW of large scale hydropower, 10 GW of nuclear, and significant renewable capacity, especially wind.

Implementing clean coal technologies

The Indian government's "Ultra-Mega" power project has already delivered 16 GW of modern supercritical coal plant clustered in very large developments. Further capacity of around 20 GW is already planned for 2012 - 17[19], and this may include some even more advanced ultra-supercritical coal plant, although the suitability of Indian coal for ultra-supercritical technology remains open to question. Integrated gasification combined cycle (IGCC) technology has been demonstrated in India. However the high capital cost of IGCC and the relative immaturity of the technology, especially with low quality coal, mean that it is unlikely to be widely deployed before 2020. Our Baseline scenario includes all the super-critical plant already planned for 2017. Increasing the share of supercritical coal in new plant may depend on international knowledge transfer so that this technology becomes fully indigenous to India. Carbon Capture and Storage (CCS) may be a very important technology for India in the longer term, but no significant uptake of CCS is assumed by 2020. The status of CCS in India is summarised in Box 1.

Box 1: Carbon Capture and Storage (CCS) in India

Currently, the Indian Government takes a 'reserved' position towards the R&D of CCS[20, 21], due to the current immaturity of the technology[22] and the strong political resistance in India to accepting the additional costs and loss of plant efficiency without substantial international help. A further significant technical barrier is the relative shortage of feasible sequestration sites[20, 23]. It is worth noting that India is still suffering from serious electricity shortage and adding capture facilities could reduce the generation output by at least 20%. Therefore, some have suggested that the first priority in facilitating CCS deployment in the power sector is to ensure 'capture-ready' installations, paving the way for future retrofit of CCS while leaving current performance unimpaired[20]. A UK-funded study has assessed the suitability of capture-ready coal-fired plant in India. In addition, India has expressed strong interest in being involved in any international demonstration projects, and has joined several international initiatives, including the CSLF (Carbon Sequestration Leadership Forum), the Government Steering Committee for the US FutureGen project and the programmes for ultra-supercritical coal-CCS and IGCC-CCS with the Asia-Pacific Partnership on Clean Development and Climate Change and recently the Global CCS Institute.

CCS in Industry: CCS also has a large mitigation potential in industries (i.e. emissions from cement, iron and steel manufacture etc.) and will be cheaper when employed in natural gas processing fertiliser plants, which already generate CO_2 streams. The IEA ACT and BLUE map scenarios[22] identify a need for a 25 - 30% global share of demonstration-stage deployment for China and India combined by 2030. Although CCS in industry is considered to be equally important in IEA's CCS roadmap[24], current demonstration projects worldwide are focussed on applications in power and upstream sectors, with a very limited number of projects targeting industrial sources. This imbalance has begun to be addressed with the recent launch of a road-mapping study specifically for industrial CCS, carried out by UNIDO and supported by the Norwegian Ministry of Petroleum and Energy and the Global CCS Institute.

In our Green case, we assume that 75% of all new plant built after 2015 adopts supercritical coal technology, leading to efficiency gains of 49 $MtCO_2$ at negative cost. Ultra-supercritical coal and IGCC technologies only enter into the Stretch case. The Stretch case, ironically, has reduced savings of 34 $MtCO_2$ from clean coal, also at negative cost, because improved system efficiency and additional nuclear and renewable capacity reduce the scope for investment in efficient coal.

Reducing losses in the power system

About 30% of the electric power generated in India is lost in the system[25]. Commercial losses represent around 11 - 15%[26] and the balance of losses are technical. India's Accelerated Power Development and Reform Programme has had some success in reducing losses, but its effect has recently waned. New efforts are needed. Experience has shown that initiatives such as the separation of agricultural and non-agricultural feeders and partial or full privatisation of distribution companies can significantly reduce technical and commercial losses, although there are social and political barriers. In the State of Gujarat, total losses were reduced from 30% to 21% during 2005 to 2008[17]. Modernisation options such as the use of smart cards and meters can help reduce losses further, with technical losses as low as 4 - 8% possible, as in developed nations[17]. Our Baseline scenario, which takes account of current trends in improvement, assumes average losses of 21.5% in 2020.

In our Green scenario we assume that losses are further reduced to 17% by 2020, saving 39 $MtCO_2$ per annum by 2020 at negative cost. Our Stretch scenario assumes that losses are reduced to 12%, saving 56 $MtCO_2$, also at negative cost.

Large Scale Hydro

Large hydropower is well established in India, with 36 GW installed in 2010[27]. After a period of declining growth, the Hydro Initiative was launched in 2005, aiming to bring a further 50 GW on line by 2017[28]. The programme has faced delays and unforeseen costs arising from population re-location and environmental issues as well as shortages of skilled workers. Of the 50 GW targeted, 34 GW has reached an advanced planning stage. In our base case we assume that 15 GW of additional capacity are installed by 2020, bringing total installed capacity to 51 GW.

In our Green case we assume that 75% of the capacity now at a detailed planning stage is completed between 2010 and 2020, representing an additional 26 GW of capacity and saving 31 $MtCO_2$ per annum compared to the base case at low cost. Only in our Stretch case are all 34 GW of capacity now at advanced planning stage completed by 2017 and, in this case, building continues at the same rate to 2020, by which time a total of 50 GW of new capacity has been installed. Savings are 104 $MtCO_2$ per annum by 2020, at low cost.

Nuclear power

India has very low reserves of natural uranium, but has recently reached supply agreements with the UK, the US, Russia, and others. If these agreements are ratified, fuel supply should not be a barrier to the lower bound of India's domestic target of installing 21 - 29 GW of total capacity by 2020[28]. India is mainly installing indigenous pressurised heavy water designs, but plans exist to implement several indigenous fast-breeder reactors before 2020 and thorium-based advanced heavy water reactors after 2020. India has plentiful thorium reserves. However, the barriers which have prevented previous targets for nuclear construction from being met largely remain. These include a shortage of skilled workers for commissioning and construction, and bottlenecks in the planning process[19]. Our Baseline assumes that, due to these barriers, only 11 GW of total installed nuclear capacity is achieved by 2020.

In the Green case we assume that site banking and an expansion of the skilled labour force enables a capacity of 15 GW to be met by 2020. Also, the average capacity factor is increased from 0.68 to 0.8[29, 30]. This leads to savings of 31 $MtCO_2$ at low cost. In the Stretch case 25 GW are in place by 2020, around the middle of the target range specified by the Integrated Energy Policy[28]. This leads to savings of 104 $MtCO_2$.

Onshore wind

Wind power is the most established renewable energy source in India. It is currently incentivised by tax exemptions, preferential tariffs and purchase obligations. Our Baseline assumes a continuation of the current rate of capacity addition of around 1.5 GW per annum leading to total installed capacity of 25 GW[12, 31, 32].

In our Green case, greater incentives for the generation of wind power increase the capacity in 2020 to 40 GW [33] saving 25 $MtCO_2$ as compared to the base case, at low *cost. In the Stretch case, further incentives and regulation permit the full exploitation of the potential that has been identified using current technology and sites already surveyed. Savings are 47 $MtCO_2$ at low cost.*

Biomass - Bagasse

India's considerable potential for exploiting bagasse, a residue of sugar-cane refining, for power generation has been limited by the need to finance the investment cost of retrofitting power stations. In our base case, the current rate of additions to capacity continues, leading to a total of 1 GW of capacity in 2020[34].

In our Green case, greater investment incentives lead to a capacity of 3 GW in 2020, saving 11 $MtCO_2$ compared to the base case. In the Stretch case, the whole of India's estimated potential of around 5 GW is achieved, leading to savings of 27 $MtCO_2$.

Small Scale Hydro

In our base case, an additional 1 GW of capacity is installed by 2020[35], giving a total installed capacity of 3 GW[36].

We estimate that stronger financial incentives and regulation could achieve total capacity in 2020 of between 5 GW and 7 GW (Green and Stretch) leading to savings of 3 to 8 $MtCO_2$ respectively, at low cost.

Natural Gas

Despite constrained supplies of natural gas, gas fired plants will play an important role in meeting power demand, as well as offering a cleaner alternative to coal. The supply constraint is set at 45 Mtoe in the Baseline, based on estimates of availability from various sources[30, 21]. It is too soon to judge whether the unconventional gas production techniques that have revolutionised gas markets in the US could have similar impact elsewhere, including in India, and this possibility is not reflected in our scenarios.

In our Green scenario enhanced exploration and imports (including pipelines and LNG) result in increased supply of 55 Mtoe, and in our Stretch scenario 64 Mtoe, leading to savings of 28 to 54 $MtCO_2$ respectively in 2020 at medium cost.

Biomass – excluding bagasse

India's use of biomass other than bagasse for power generation is severely constrained by the costs of developing supply chain infrastructure. Our Baseline case assumes only 1 GW of capacity in 2020, compared to a minimum estimated potential of 16 GW[36].

In our Green case, higher levels of investment lead to 3 GW of capacity by 2020, saving 11 $MtCO_2$ at medium cost. Our Stretch case has 4 GW, saving 20 $MtCO_2$.

Solar energy

Solar power represents an immense opportunity for India. The Government's "Solar Mission" envisages the installation of 20 GW of capacity by 2020, and that solar power will become cost competitive with coal by 2030[22]. Both Photovoltaic (PV) and Concentrating Solar Power (CSP) are attractive technologies, and at present Indian policy makers are neutral as between the two[37]. Achieving the government's target would require a very large increase in investment. In our base case we assume that only the $1 billion already pledged by the Indian Government is available, leading to the installation of 1 GW of capacity between 2010 and 2020.

In our Green case we assume a higher level of investment, but still falling well below the $20 billion that would be required to meet the government's target. This requires significant participation by international investors in addition to the funds pledged by the Indian Government. 5 GW of new capacity is installed by 2020, saving 2 $MtCO_2$ as compared to the base case, at high cost. Only in the Stretch case is the Government's target of 20 GW of new capacity achieved, implying a very ambitious $19bn of additional investment. In this case 12 $MtCO_2$ are saved.

Technology/ Option	Mitigation ($MtCO_2$)		Marginal Abatement Cost	Barriers	Domestic Policy Leavers
	Green	Stretch			
Clean coal technologies	49	34	Negative	(1) Rate of incumbent retirement. (2) Capital cost higher for new technologies. (3) Non-availability of technology due to IP issues or absence of engineering capability, including for coal pre-treatment. (4) Long Lead times for site selection, design, permitting and construction, etc.	(1) Accelerate program of coal plant refurbishment and upgrading. (2) Exemption from central excise duty of equipment. State-sponsored projects to demonstrate technology. (3) Training of workers (e.g. in Industrial Technical Institutes) (4) Fast-track applications. Site banking.
Demand Side Management	See other Sectors	See other Sectors	Negative	(1) Energy subsidies and absence of metering. (2) See other sectors.	(1) Utility purchase obligations. Reduction of subsidy sizing. (2) Capacity building and outreach.
Reduction of Aggregate Technical and Commercial Losses	39	56	Negative	(1) Very high capital cost of modernisation measures. (2) Absence of knowledge base for design and monitoring.	(1) Domestic investments from government or private sector. (2) Capacity building, very suitable for international collaboration.
Hydro-Large Scale	31	104	Low	(1) High investor risk due to unforeseen additional cost of relocation, environmental and technical issues. (2) Long lead times for site selection, design, permitting and construction, etc. (3) Shortage of skilled workforce for construction/commissioning.	(1) N/A. (2) Fast-track applications. (3) Training of skilled and semi-skilled workers (e.g. via Industrial Technical Institutes)
Nuclear Fission	31	104	Low	(1) Shortage of skilled workforce for construction and commissioning. (2) Long lead times due to bottlenecks in planning, regulatory environment and the manufacturing supply chain, etc.	(1) Fast-track nuclear planning projects and localise supply chain.
Onshore Wind	25	47	Low	(1) Capital and maintenance costs higher than those of standard coal plant.	(1) Generation based incentives (e.g. similar to production tax credits in U.S.).
Biomass- Bagasse	11	27	Low	(1) Cost of investment	(1) Accelerated depreciation, concessional import duty, excise duty exemption, tax holiday and preferential tariffs.
Hydro-Small Scale	3	8	Low	(1) Cost of investment.	(1) Accelerated depreciation, concessional import duty, excise duty exemption, tax holiday and preferential tariffs.
Natural Gas	28	54	Medium	(1) Feedstock availability and cost of imports and unconventional sources.	(1) Continue domestic exploration projects, ramp up LNG projects and prioritise pipeline regions
Biomass - Power plant excl. Bagasse	11	20	Medium	(1) Feedstock cost. (2) Complex supply chain infrastructure. (3) Environmental concerns (deforestation).	(1,2) Develop demonstration business model.
Solar PV and CSP	2	12	High	(1) Cost of investment and electricity. (2) Shortage of skilled manpower. (3) Uncertain potential to supply peaking capacity reliably.	(1) Accelerated depreciation, concessional import duty, excise duty exemption, tax holiday and preferential tariffs, incentives to invest in RD&D.

Table 2: Technology options and barriers for Indian Power (own analysis)

Industry

CO_2 emissions from Industry are expected to increase rapidly from 300 $MtCO_2$ in 2005 to over 1 $GtCO_2$ in 2020[21]. The cement and steel industries are expected to make the biggest contributions to this growth[17] as India develops its national infrastructure. These two industries alone account for emissions of 700 $MtCO_2$ in 2020 (including from power stations supply industrial electricity demand).

The average energy efficiency of Indian cement plants is already at the level of global “best available technology” and there is therefore limited potential for efficiency improvements beyond our Baseline assumptions. The main potential for emissions reductions lies in clinker substitution and the use of alternative fuels. In contrast, there is large potential for efficiency gains in the Indian steel industry.

The Indian government’s “Perform, Achieve and Trade” scheme promotes energy efficiency in nine energy intensive sectors of the economy, targeting the top 714 emitting installations. The design and installation of this scheme would be very suitable for international collaboration and knowledge transfer from those involved in existing trading schemes, including EU ETS, and those developing nations who have already tackled energy efficiency in the top tier of energy intensive industries, such as China. There is a case for expanding the scheme so that it covers low carbon energy sources, in addition to energy efficiency, as well as the long tail of smaller plant where, for instance, significant gains may be possible through the deployment of more efficient motors. We highlight other possible areas for international co-operation below, including the design and construction of large-capacity integrated steel plant, the transfer of knowledge of coal pre-treatment, and investment through CDM or similar mechanisms in the use of clinker substitutes and alternative fuels in cement and other industries.

Cement – clinker substitution

One of the major opportunities for reducing the CO_2 emissions from cement production is to blend cements with increasing proportions of alternative (non-clinker) feedstocks, such as fly-ash from power stations and blast-furnace slag. In 2005 India had a ratio of cement to clinker of 0.87 compared to the world average of 0.82[38]. The IEA calculated that only around 25% of economically available fly-ash and blast-furnace slag in India was used in 2005, and that by maximising the use of these waste materials the ratio could be reduced to 0.80 in 2020[39,40]. The barriers are the initial capital cost of the non-clinker infrastructure and consumer perception of blended cement quality.

Our Green case assumes that the 0.80 ration is achieved, leading to savings of 22 $MtCO_2$ at negative cost. In the Stretch case other more costly materials are used, such as limestone and other cement extenders, reducing the cement to clinker ratio to 0.75 and taking the savings over the Baseline to 39 $MtCO_2$.

Cement – alternative fuel use

Coal is the dominant fuel for process heat in cement manufacture in India, with less than 1% of fuel derived from biomass and waste[38, 41]. By comparison, European cement-makers derived 15% of their energy needs from waste fuels in 2005[12]. The barriers to uptake are mainly the cost of adapting the plant and its supply system to handle alternative fuels without loss of cement quality. Given the limited biomass availability we estimate that a maximum of 11% of fuel could come from biomass in 2020[36]. However, a wide variety of waste is suitable for fuel in cement making.

In both the Green and Stretch scenarios we estimate that 22% of fuel for cement making could come from waste, including biomass, saving 12 $MtCO_2$ as compared to the Baseline at low cost.

Steel – best practice in blast furnace basic oxygen furnace plant

About half of India's steel output comes from large integrated Blast Furnace (BF) – Basic Oxygen Furnace (BOF) plant, the most widely used process internationally. The remainder consists of a large number of smaller, privately owned mini-mills, typically using coal-based direct reduction of iron ore followed by electric arc furnace processing (coal – DRI), a much more carbon intensive process. In addition to the potential for efficiency improvements in coal-DRI plant there are very large long-term gains available from a shift towards larger integrated plant combined with an increase in the efficiency of those integrated plant[42]. The National Steel Policy (2005)[43] sets out the aim of modernising the public sector integrated plant in this way. However, the shift away from coal-DRI will involve overcoming significant market based and social barriers, since the coal-DRI mills are more profitable in the short term, require less capital, and employ a large number of unskilled and semi-skilled workers.

Our Baseline includes a steady rate of energy efficiency improvements in large BF-BOF plant, with energy intensity of steel production dropping from 28 to 25 GJ/tcs. This includes such measures as coke dry quenching, pulverised coal injection, and improved blast furnace control[44], but this requires high quality coal not generally available in India.

Our Green and Stretch scenarios assume a 15% improvement in the efficiency of India's coal-DRI plant to 2020. This would still leave the efficiency level considerable below world best practice, reflecting in part the poor quality of Indian coal. Savings are 19 $MtCO_2$ at negative cost.

Our Green scenario does not provide for a shift from coal-DRI to large BF-BOF plant, due to market and social barriers. Only in the Stretch case do we allow for a significant shift with savings of 22 $MtCO_2$ at low cost.

Our Green and Stretch cases assume a more rapid increase, compared to Baseline, in the efficiency of BF-BOF plant, which improves to 21 GJ/tcs in 2020, saving 42 $MtCO_2$ at negative cost.

Other industry; motor systems efficiency improvements

Motors account for around 60% of all electricity used in industry[45]. In their "450" scenario the IEA envisage a 40 - 50% global deployment of efficient motor systems by 2030[22]. The average life of a motor is 12 - 20 years and, with efficiency standards in at least the most energy-intensive sectors, significant progress should be possible by 2020. In the base case, a 5% improvement on 2005 efficiency levels is achieved by 2020.

In our Green scenario stronger regulations and incentives focused on energy intensive plant covered by the PAT scheme lead to a 10% improvement in the average efficiency of industrial motors and save 12 $MtCO_2$ compared to the base case, at negative to low cost. In the Stretch scenario incentives are extended to many more enterprises, possibly through an extension of the PAT scheme, leading to a 20% efficiency gain and savings of 36 $MtCO_2$.

Other industry; co-generation

There is considerable uncertainty as to the extent of co-generation currently deployed by Indian industry[46]. Our Baseline assumes that 0.5 GW is installed between 2005 and 2020. An initial survey performed on the most energy intensive industries suggests a potential of 2 GW, although this is expected to be a large underestimate[47].

Our Green scenario assumes additional capacity above the Baseline of 1 GW of co-generation by 2020, saving 5 $MtCO_2$ at negative to low cost, while in the Stretch scenario an additional 2 GW of capacity saves 10 $MtCO_2$.

Technology/ Option	Mitigation ($MtCO_2$)		Marginal Abatement Cost	Barriers	Domestic Policy Leavers
	Green	Stretch			
Steel - best practice in blast furnace-basic oxygen furnace plant (BF-BOF)	42	42	Negative	(1) Increased discount factors due to risk with regard to enhanced coal injection, coal washing and building large blast furnaces. (2) Plants resistant to or unaware of energy efficiency strategies	(1) Incentivise through schemes such as PAT. (2) Promote schemes for renovation; administer standards
Steel-energy efficiency improvements in coal-based direct reduced iron plant (coal-DRI)	19	19	Negative	(1) Involvement of a large number of enterprises. (2) Short-term profit prioritised over energy efficiency and modernisation measures.	(1) Incentivise through schemes such as PAT. (2) Promote schemes for renovation; administer standards
Cement-clinker substitution	22	39	Negative	(1) Initial capital cost of substitution (including transport, handling, storage). (2) Lack of awareness of manufacturers to potential benefits of blended cement. (3) Consumer perception of blended cement quality.	(1) Lower excise duty and VAT rates for blended cement. Incentivise via schemes such as PAT. (2,3) Build awareness of manufacturers/consumers; modify codes to permit use of blended cements in public sector construction activities
Other industry - motor systems efficiency improvements	12	36	Low	(1) Involvement of a large number of enterprises	(1) National mandatory standards
Other industry - cogeneration	5	10	Low	(1) Capital cost. (2) Lack of awareness in industry and policy-makers.	(1) Utility purchase obligations. (2) Capacity building and outreach.
Steel - process shift from coal-DRI to efficient BF-BOF	0	22	Low	(1) Higher short terms gains of coal-DRI vs integrated plant. (2) Political sensitivity of eliminating unskilled jobs in DRI mills. (3) Mechanisms such as CDM may increase viability of coal-DRI in short term.	(1) Promote integrated steel-making in the private sector, e.g. with attractive credit options. (2) Capacity building to train DRI workforce enabling their employment at integrated plants.
Cement - use of alternative fuels	12	12	Low	(1) Capital cost of modifying plant to use biomass/waste. (2) Technical challenges in adapting processes for alternative fuels. (3) Cost of feedstock.	(1) Financial incentives. (2) Training of staff and capacity building in new/existing institutions.

Table 3: Technology options and barriers for Indian Industry (own analysis)

Buildings

Data collection and reporting from the Indian buildings sector is generally highly inconsistent. Rich energy consumption information from households is available but only from surveys by the National Sample Survey Office (NSSO) in 2005 and the National Council of Applied Economic Research (NCAER) in 2001. No comprehensive survey is available on the commercial sector. We have thus developed a bottom-up model to evaluate present and future trends in energy use and CO_2 emissions from Indian buildings.

Traditional biomass accounts for 78% of domestic energy used in India and, partly because its efficiency is so low, the share of the domestic sector in total energy consumption (42%) is one of the highest in the World[21]. Urbanization, electrification, and increased use of appliances, will all change the pattern of energy use in buildings by 2020. Nevertheless, we expect that rural households will still consume more energy than urban households, and that biomass will still account for 55% of energy use.

In the commercial sector, floor space increases by 60% to 2020, while electricity consumption grows four-fold. Our projections align with those published in other similar studies[32, 48].

As a result of these trends CO_2 emissions from Indian buildings experience a rapid increase from 205 $MtCO_2$ in 2005 to 613 $MtCO_2$ in 2020, with urbanisation rates growing closer to the OECD average at 38%, and electrification rates increasing from 52% in rural and 92% in urban areas to 82% and 98% respectively by 2020.

Energy efficient lighting

The share of electric lighting in household final energy consumption is projected to double from 2005 to 2020. India already has a considerable market for energy efficient lighting with 165 million compact fluorescent lamps sold in 2008, half the sales in the US, and a variety of programmes are in place or under development to increase their diffusion. However, light emitting diode technology is still at an immature stage of development. Costs are high and technical issues continue to hinder the achievement of its potential[22], which is why this technology is only included in the Stretch case.

> *Our analysis shows that replacing half of all incandescent bulbs in urban areas would save 23 $MtCO_2$, which is the Green case. In the Stretch case all urban bulbs are replaced with light emitting diodes, increasing the total savings to 52 $MtCO_2$*

Energy efficient appliances

Our projections show that the proportion of final energy consumed in Indian households by power appliances will rise from 9.5% in 2005 to 18% in 2020, with air conditioners and refrigerators accounting for 60% of this demand. Energy efficiency standards are currently voluntary, although there is provision for making them mandatory in the future.

In our Green scenario, inefficient appliances are substituted by current European best standard technologies, saving 21 $MtCO_2$ through reduced power demand. In the Stretch scenario best available appliance technologies are substituted, increasing the total savings to 39 $MtCO_2$, all at negative to low cost.

District Cooling, Combined Heat and Power (CHP)

India's largely tropical climate and limited heat network infrastructure limit the potential for district heating. District cooling networks have experienced recent growth in niche applications, and have potential for further growth[14]. However no nation-wide study has been carried out to assess the potential for district heating, district cooling, and CHP. However the barriers are high, including the lack of existing pipeline infrastructure and rights of way.

In view of these barriers, we have not included savings from district heating, district cooling, or CHP in our Green case. Our Stretch case includes the installation of CHP/district cooling networks in Special Economic Zones and selected industrial parks, with savings of 12 $MtCO_2$ at high cost.

Solar water heating

Solar water heating technologies have experienced strong growth in recent years, reaching 15% compound annual growth rate in 2009. However growth is not expected to continue at the same rate without strong incentives and market consolidation[49].

In our Green case the installation of solar hot water heaters in 25% of newly built homes to 2020, coupled with a retrofit of older units, saves 6 $MtCO_2$ per annum by 2020. In the Stretch case, mandatory installation of solar water heating in all new buildings increases the savings to 11 $MtCO_2$ at negative cost.

Technology/ Option	Mitigation ($MtCO_2$)		Marginal Abatement Cost	Barriers	Domestic Policy Leavers
	Green	Stretch			
Energy Efficient Lighting	23	52	Negative	(1) High cost differential with conventional bulbs. Limited number of ESCOs. (2) Regional issues around implementation of energy efficient lighting programmes.	(1) Reduction of Indian VAT for CFLs and other tax incentives geared to Energy efficiency. (2) Promotion of ESCOs via financial incentives (tax exemption). (3) Increase RD&D into LEDs.
Solar Water Heating	6	11	Negative	(1) Long payback period due to high upfront costs. (2) Fallback technology is biomass. (3) Lack of ancillary infrastructure (water piping and retrofit required in many areas). (4) Insufficient SWH equipment supply chain. (5) Highly fragmented incentive schemes, confusing to consumers - lack of visibility. (6) Incentives not sensitive to regional insolation values.	(1) Promote, merge and deliver incentives through ESCOs. (2) Tailor financial incentives to regions according to pay-back periods, link to vintage. (3) Mandatory installation in suitable new build (4) Expand BEE research into SWH potential in fast-growing urban centres. (5) Increase visibility of technology by increasing MNRE advertising and promotion.
Energy Efficient Appliances	21	39	Negative to low	(1) Lack of skilled labour and installations for inspection and certification. (2) Limited number of ESCOs. (3) Lack of awareness of accrued benefits, high upfront costs. (4) Implementation left to regional agency.	(1) Statewise and/or national tax incentives ranked according to Energy Efficiency (revenue neutral). (2) Mandatory Labeling and Standards Schemes. (3) Tax incentives to manufacturers. (4) Minimum efficiency standards. (5) Increase awareness through DSM programmes, consumer education.
District Cooling/CHP	0	12	High	(1) No standard definition of CHP and no systematic data collection. (2) Lack of knowledge base and pipeline/rights of way infrastructure. (3) No research on economy-wide potential for CHP/DC. (4) Lack of approved methodology for CO_2 emissions from CHP/DC reduces CDM potential.	(1) Create government definition of CHP and establish reliable data tracking. (2) Research on CHP/DC potential, increase industry awareness. (3) Raise awareness at regional, local and federal level for CHP. (4) Create special CHP/DC economic areas (akin to SEZs). (5) Extend feed-in tariffs and NFFOs to CHP.

Table 4: Technology options and barriers for Indian buildings (own analysis)

Transport

Large data uncertainties exist in the Indian transport sector. As a result, this study has developed its own bottom-up modelling tool.

In 1990 rail accounted for 61% of all freight transport, while rail and bus combined contributed 83% of all passenger transport. In the decade to 2010, however, road vehicle sales have boomed and, as a result, there has been a radical shift towards motorised and personal means of transport[50]. With rising population, urbanization, and income levels, this trend is expected to continue to 2020. The number of passenger cars will increase rapidly and their share in passenger transport will increase from 7% in 2005 to 22% in 2020 (Fig 4). Without new investments, the share of mass transport will dwindle, with the share of buses falling from 55% to 38% in the 15 years to 2020, and the share of rail from 16% to 10%.

A major feature in the development of freight transport will be the increase of trucking. Goods transport by truck is projected to grow by 350% from 2005 to 2020, increasing its share of all freight transport from 45% to 68%.

Figure 4: Indian passenger transport demand by mode [Passenger km travelled] (Source: Own Analysis)

The net effect of these trends is an increase in CO_2 emissions from 158 $MtCO_2$ in 2005 to 417 $MtCO_2$ in 2020, with road transport accounting for 80% of the growth. Although emissions from the transport sector will rise to 11% of the total in 2020, our analysis shows that the abatement potential is relatively low (50 - 91 $MtCO_2$).

Increased use of biofuels

A target of 5% ethanol in gasoline was set in 2007 and made mandatory in 11 States, but enforcement has not been as successful as expected[51][52]. The government has announced a new target of achieving 20% blending bioethanol and biodiesel by 2017. However, limits on the availability of feedstock, especially sugarcane molasses, and lack of available land for biofuel expansion are serious constraints, and ethanol production has been insufficient to meet present targets. For these reasons we have not included the full achievement of the government's targets in the base case.

> *In our Green case a blending of 5% of ethanol and 4% biodiesel in all passenger cars and commercial vehicles is achieved by 2020, saving 11 $MtCO_2$ at high cost, while in the Stretch scenario these penetration levels are doubled, saving 21 $MtCO_2$.*

Increased use of compressed natural gas (CNG)

India currently imports 85% of its diesel and 90% of its gasoline. In comparison to China, India has significant gas reserves (of 1,074 bcm in 2009) and for both energy security and air quality reasons the use of CNG has been encouraged at local, state, and federal levels.

> *Our Green scenario assumes that all buses and half of commercial vehicles in India's five largest cities convert to CNG by 2020, saving 7 $MtCO_2$ at medium cost. In our Stretch case, this is extended to the 23 largest cities, saving 11 $MtCO_2$.*

Efficient public transport

The existing capacity of public transport, especially buses, has been insufficient to meet increasing demand. This has contributed to the shift towards private vehicles and intermediate public transport such as auto-rickshaws and taxis[53].

> *Our Green and Stretch scenarios assume different levels of increased investment in public transport. In the Green case there is a 10% modal shift to public transport compared to the Baseline by 2020, saving 13 $MtCO_2$ at medium to high cost. In the Stretch case a shift of 20% is achieved, saving 22 $MtCO_2$.*

Fuel Efficiency

Our analysis shows that there is considerable scope for increasing the fuel efficiency of the Indian vehicle fleet to 2020.

> *In our Green case, the fuel economy of gasoline cars increases by 14%, diesel cars by 12% and commercial vehicles by 10%, to reach the European vehicle fleet fuel efficiency average. This saves 16 $MtCO_2$ by 2020, compared to Baseline, at negative to low cost. In the Stretch scenario there are further increases in fuel economy, bringing the fleet to Japanese standards, and saving a total of 32 $MtCO_2$.*

Electric two-wheelers and auto-rickshaws

Motorised two-wheelers have been the fastest growing vehicle type in India for the past 15 years, at an annual average rate of 17%[54]. Although their growth is expected to slow down with rising income levels, their large numbers still dominate passenger mobility in the Baseline scenario. Electric two wheelers and auto-rickshaws are rapidly becoming available in the Indian market, although issues such as maintenance, ancillary infrastructure, and reliability of electricity supply, all have to be addressed.

With increased incentives for their diffusion, the penetration of electric two-wheelers and auto-rickshaws reaches 20% in our Green case, saving 3 MtCO$_2$ and 30% in the Stretch case, saving 5 MtCO$_2$, all at negative cost.

Technology/ Option	Mitigation ($MtCO_2$)		Marginal Abatement Cost	Barriers	Domestic Policy Leavers
	Green	Stretch			
Increased penetration of electric 2 & 3 wheelers	3	5	Negative	(1) Limited CO_2 reductions highly contingent on power grid intensity. (2) Unreliable electricity supply. (3) High cost of batteries, repair and maintenance. (4) Lack of institutional support for electric vehicles in general and lack of distribution infrastructure. (5) Significant load shedding prevents timely recharge and presents safety and reliability issues.	(1) Soft loans, either from government or international organizations. (c.f. DANIDA in Nepal). (2) Extension of quality assurance certificates to e-bike and e-autorickshaws. (3) Subsidies for charging stations and off-peak/peak tariffs. (4) Provision of adequate means for the enforcement of Lead Acid battery disposal (i.e. extend Battery Handling Rules).
Improved fuel efficiency of ICE Vehicles	16	32	Negative to Low	(1) Lack of and access to capital for inspection, certification and maintenance facilities. (2) Adulteration of conventional fuels with kerosene. (3) Lack of institutional capacity to measure and compile data.	(1) Introduce fuel economy and fuel quality standards. (2) Bharat III and IV emissions standards. (3) Tax incentives for fuel-efficient vehicles. (4) Compulsory labelling of vehicles. (5) Regulatory mechanisms for performance standards.
Increased use of CNG in place of petroleum	7	11	Medium	(1) Limited number of refueling stations (transport limited to city centres). (2) Financial barriers to implementation of and higher upfront costs. (3) Maintenance costs can be high due to lack of suitably skilled labour and access to spares. (4) Concerns regarding safety of CNG buses and uncertain gas supply.	(1) Enforcement of CNG conversion in large Indian cities. (2) Fiscal incentives (c.f. EC alternative energy tax). (3) Continue exploration and production activities. Investment in inspection and certification facilities.
Enhanced Provision of Public Transport	13	22	Medium to High	(1) Access to capital to implement public transport systems. (2) Dedicated lanes have strong barriers in Indian cities due to congestion and urban design, and are capital intensive. (3) No dedicated taxes, investment contingent on annual budgetary appropriations. (4) Loss of revenue to private vehicles and insufficient bus capacity.	(1) Encourage private-public partnerships in mass transportation for both routes and selected functions (e.g. maintenance) (2) Increase privatization of selected routes and services. (3) Congestion charging (in preparation for selected cities). (4) Dedicated fiscal measures.
Increased use of Biofuels in place of petroleum	11	21	High	(1) Lack of available land for biofuel expansion (e.g. for large penetrations, plantation size needs to increase from 5000 km^2 to 132,000 km^2. (2) Availability of feedstock (e.g. sugarcane molasses for ethanol) dependent on yields. (3) Low biodiesel capacity and investment and lack of quality control measures. (4) Dependence on one source for ethanol: molasses cannot support long-term demand projections. (5) Lack of mature technologies for second-generation biofuel production for Lignocellulosic Biomass.	(1) Enforcement of biofuels blending standards. (2) Increased RD&D and financial incentives for Jatropha Curcas. (3) Mandatory monitoring of biofuel blends at refueling stations. (4) Phasing out of older non-compliant vehicles. (5) Phasing out of subsidies for gasoline and diesel. (6) Enhanced government collaboration with Integrated Wasteland Development Programme.

Table 5: Technology options and barriers for India transport (own analysis)

Summary of Savings Potential

Figure 2 and Table 1 give the overall impact of the carbon saving options that have been identified. Figure 2 shows that on the basis of existing policies (Baseline case) the absolute level of India's CO_2 emissions is set to increase from just over 1.1 billion tonnes per annum in 2005 to nearly 2.7 billion tonnes in 2020. The Green savings options could reduce this by over 400 million tonnes. The Stretch options, going closer to the theoretical maximum, would achieve a further reduction of 400 million tonnes, reducing the total to 1.8 billion tonnes. Most of the savings, in both the Green and the Stretch cases, come from the power sector, with more than half the savings, with significant contributions coming from buildings, industry, and transport.

The line across Figure 2 shows how the savings match up to the carbon intensity targets. In the Baseline case, although the absolute level of carbon emissions more than doubles to 2020, the carbon intensity declines significantly, but not sufficiently to reach the target range. Savings in the Green case are more than sufficient to reach the target range and in the Stretch case substantially more than sufficient.

Table 1 shows the savings available in the Green and Stretch options in different cost ranges. It shows that adopting just the Green options with negative costs is sufficient to reach the lower (20%) end of the target range, while adopting all the Green options up to "Medium" ($10 - 50 per tonne of CO_2 saved) cost is sufficient to exceed the top (25%) end of the range. Adopting the Stretch options with low cost would also be more than sufficient to reach the high end of the range and the Stretch options with Medium and High costs could, in theory, far exceed the top end of the range. However, that means achieving something close to the theoretical potential in all areas, and that could be very difficult in practice.

Our study suggests, therefore, that India's carbon intensity targets to 2020 are achievable with a range of policies with low and in many cases negative costs. The most critical areas are the reform of the power industry and investment in efficient and low carbon capacity, modernisation of the steel industry, more efficient lighting and appliances, and efficient vehicles. These challenges are recognised by the Indian Government which has major programmes to address them. These include the Perform, Achieve, and Trade programme to improve the efficiency of India's most energy intensive installations, the Ultra-Mega project for the installation of efficient new coal plant, and major investment plans for nuclear power, hydro, and wind. A Government Expert Group reported recently that the vigorous and effective implementation of policies already in place or contemplated would be sufficient to reach the target range[9].

Conclusions

India can meet its carbon intensity targets with well-established technology at negative and, to reach the higher end of the range, also low cost measures. The most critical negative cost measures are:-

- The modernisation of the coal power fleet with accelerated introduction of super-critical plant.
- Power sector reform to reduce technical and commercial losses.
- Modernisation of the less efficient sector of India's steel industry.
- Clinker substitution in the cement industry.
- Improved efficiency of lighting, appliances, and vehicles.

Additional hydro, nuclear, and wind generating capacity can also make a big contribution at positive, but low, cost. The Government of India faces a huge challenge to finance and manage these changes. A central issue is the poor financial condition of much of the Indian power industry. This is partly the result of high levels of power losses, but is also due to the subsidised prices for farmers and in the residential sector that are imposed by the Government. Unless these problems, which partly arise at State level, can be addressed, it is hard to see how India will succeed in financing the expansion and modernisation of its power sector.

International public and private sector contributions can play a part in making this finance available, as can international trading schemes such as CDM. In many areas India already has the technologies that are needed but international commercial collaboration is needed to import the most advanced coal and nuclear power technologies. There is also potential for countries with relevant national experience to support India's efforts to implement energy efficiency and trading schemes, such as PAT.

This brief is concerned only with technologies that can make a major impact on CO_2 emissions by 2020. In the longer term, if the 2°C global target agreed at Copenhagen is to be met, all nations will have to reduce their carbon emissions to very low levels. Renewables, nuclear power, electric vehicles, and carbon capture and storage (CCS), will all have important parts to play, as well as very high levels of energy efficiency.

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Annex 1: Methodology: A Bottom-Up Analysis

Trend extrapolation can provide insights into whether a country is on course to meet its carbon intensity targets. However, such a simple approach provides no insight into the technology and policy options which are required in order to sustain, steer or accelerate the underlying trends. By comparison, the published scenario literature, whilst technologically and policy rich, lacks transparency regarding the many assumptions which determine the specific scenarios. Abstracting detail from the published scenario literature (e.g. why a particular level of technology uptake is observed), and thus obtaining novel policy insights, is often not feasible. We therefore had recourse to providing a detailed bottom-up analysis of CO_2 mitigation potential within each of the 4 principal emitting sectors of the respective economies. These include (1) power generation, (2) energy intensive industry, (3) buildings, and (4) transport. We analyse a range of technologies and policies within each of these sectors and attempt to quantify the potential CO_2 emissions reductions that could be achieved with varying levels of technology uptake or policy success.

Projections of activity in each sector to 2020 (e.g. TWh of power generated, or tonnes of steel produced) are derived from literature sources, or else generated from bespoke bottom-up models (particularly in the buildings and transport sectors where published statistics are poor). These bottom-up models take into account key drivers, such as population growth, GDP growth, urbanisation and electrification rates, and existing individual sub-sectoral policy targets. The resulting demand is assumed to be met either by incumbent (e.g. current) or mitigating technologies which are not currently employed owing to excessive (additional) costs, or an array of non-technical barriers.

The level of technology uptake is differentiated into three levels (scenarios): (1) Baseline; (2) Green; and (3) Stretch. Unless otherwise stated, our Baseline case (e.g. business-as-usual scenario) accounts for current trends in technology uptake and supporting policies as of March 2010 (both already implemented and planned). It is only against this Baseline that positive mitigation potential is measured. Our Green and Stretch scenarios do not represent low and high cost cases respectively, or varying levels of uptake along a technology specific (abatement) cost curve. Instead, the Green scenario potential forms what we consider to be a feasibly attainable portfolio of technology implementation, aligned with mid-range literature potential. The Stretch scenario pushes implementation closer to the absolute/theoretical technical potentials identified in the literature.

In order to support our Green versus Stretch potentials, we also take into consideration the marginal abatement cost[55] of each technology. Owing to a lack of consistent cost data across all sectors in both countries we soften our cost analysis to consider 4 cost categories, representative of: Negative (<$0.t$CO_2$), Low (<$10.tCO_2); Medium ($10-50 t$CO_2$), or High (>$50.tCO_2) cost options. We also take into account a range of additional, non-cost, barriers to uptake. These barriers include (for example) high up-front capital costs, rates of incumbent technology retirement, infrastructural constraints (e.g. lack of grid connectivity), weaknesses in regulatory frameworks, and issues surrounding public perception.

Having completed separate sector specific analyses of Baseline 2020 emissions and mitigation potential, whole system carbon intensity can be estimated by summing the sector specific emissions and dividing by the projected GDP in 2020 (consistent with those GDP assumptions stated in Section 3). Mitigation from our Baseline is calculated by summing all mitigation potential identified in each sector, including low-carbon technologies for power generation and demand side savings, which are allocated directly to the sectors in which they are implemented (costed at an average grid emissions factor). Feedbacks from demand reduction which could potentially reduce the potential to mitigate from the Baseline in the power sector are not accounted for (e.g. when reduced demand substitutes for a marginal unit of otherwise mitigating non-fossil power generation). In theory if all demand reductions led to equivalent reductions in new nuclear and renewable generation this could eliminate a large part of the CO_2 reductions from the buildings and industry sectors. In practice, given the commitment of the Indian Government to the diversifications of power supplies, we judge this to be unlikely and that the impact of this second-order effect will be fairly modest.

Annex II: Abbreviations

BAT	Best available technology
BF-BOF	Blast furnace-basic oxygen furnace
BPT	Best Practice Technology
CCS	Carbon capture and storage
CDM	Clean development mechanism
CHP	Combined heat and power
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CPGPRC	China The Central People's Government of People's Republic of China
CSP	Concentrating solar power
CTL	Coal-to-liquids
DECC	Department of Energy and Climate Change, UK
DRI	Direct Reduced Iron
DSM	Demand-side management
EIA	Energy Information Administration, US
EU ETS	European Union Emission Trading Scheme
EV	Electric vehicle
FCV	Fuel cell vehicle
GDP	Gross Domestic Product
Gj/tcs	Gigajoule per tonne of crude steel
$GtCO_2$	Gigatonne CO_2
GW	Gigawatt
IEA	International Energy Agency
IGCC	Integrated gasification combined cycle
IMF	International Monetary Fund
LBNL	Lawrence Berkeley National Laboratory
LCC	Life cycle cost
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
$MtCO_2$	Megatonne CO_2
Mtoe	Million Tons of Oil Equivalent
MWh_e	Megawatt hour (electricity)

NCAER	National Council of Applied Economic Research, India
NFFOs	Non-fossil fuel obligation
OECD	Organisation for Economic Co-operation and Development
PAT	Perform achieve and trade
PHEVs	Plug-in hybrid electric vehicle
PIEV	Plug-in-electric-vehicle
PPP	Purchasing power parity
PV	Photovoltaics
R&D	Research and development
RD & D	Research, development and demonstration
RPS	Renewables portfolio standards
SO_2	Sulphur Dioxide
tCO_2	Tonne CO_2
TWh	Terawatt hour
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value Added Tax
WEO	World Energy Outlook

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