Imperial College London

## Grantham Institute for Climate Change

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UCL ENERGY INSTITUTE

# INDIA'S $CO_2$ EMISSIONS PATHWAYS TO 2050

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# Objective and approach

This study was undertaken as part of the AVOID programme on avoiding dangerous climate change (see www.avoid.uk.net for details). The programme is funded by the UK Government Department of Energy and Climate Change (DECC) and Department for Environment, Food and Rural Affairs (DEFRA). However, any views or opinions expressed here are those of the authors. This short report summarises the main elements of the longer report written for AVOID[1].

The study, which combines work by the Grantham Institute for Climate Change at Imperial College London and the Energy Institute at University College London, outlines potential pathways to 2050 for India to reduce its energy- and industry-related $CO_2$ emissions in line with international efforts to avoid dangerous levels of global warming. It explores three scenarios:

- A reference scenario with no future $CO_2$ emissions constraint (in this scenario, India's emissions increase from just below 2 $GtCO_2$ in 2010 to almost 8 $GtCO_2$ in 2050);
- A first low-carbon scenario with an emissions constraint of about 2.4 $GtCO_2$ by 2050, equating to about 1.3 $tCO_2$ per capita (and about 2 $tCO_2e$ per capita by 2050 in terms of all greenhouse gases), as part of a global $CO_2$ limit of 12 $GtCO_2$ by 2050, and the same per capita level of $CO_2$. The global greenhouse gas emissions pathway from which this limit is derived has an approximately 50% chance of achieving a 2 degrees C limit to global warming[2];
- A second low-carbon scenario, with the same 2050 emissions target as the first, but with certain technology parameters (constraints and investment hurdle rates) specified to account for a range of Indian energy experts' views on possible energy and technology developments in India.

The TIAM-UCL model used in this study is an integrated assessment model representing 16 different regions of the world, including a distinct India region. For each region, energy service demands are projected using socio-economic drivers, and the model determines a cost-optimal level of deployment of energy end-use and energy conversion technologies and resources to meet the energy service demands. Final energy demands depend on energy end-use technology efficiencies and primary energy demands depend on conversion efficiencies and losses.

# Context

India is still poor by global standards, with a Gross National Income (GNI) per capita of around $3,500 (in Purchasing Power Parity terms) in 2010, compared with the USA's $47,000[3]. To develop further, India will need reliable access to increasing supplies of energy. India's total primary energy supply (TPES) per capita stood at 0.53 tonnes of oil equivalent (toe) in 2007, whereas the USA's figure was closer to 8 toe/capita[4]. It will take a concerted effort to ensure that the inevitable increase in energy demand that goes in step with India's economic growth over the coming decades is of a low-carbon rather than carbon-intensive form. Thus, a focus on low-carbon long-term economic development needs to begin now.

Energy security and energy access are primary concerns for India, but there are several reasons why attention has also turned to climate issues in recent years. For one thing, India is vulnerable to climate change, which could have a number of negative impacts, such as decreased yields of wheat and rice (two of its major exports), as well as increased sea level and water stress[5]. For another, India's policy-makers are aware of the non-climate change benefits of a more diverse, indigenous energy supply, which is decreasingly reliant on fossil fuels. India's Planning Commission on integrated energy policy has stated that "it is not a question of choosing among alternative domestic energy resources but exploiting all available domestic energy resources to the maximum as long as they are competitive." [6]

The Indian government has recognised the importance of lowering the country's greenhouse gas emissions as part of an international effort to limit global warming. India has stated voluntary targets to reduce its greenhouse gas emissions per unit of economic output by 20-25% by 2020 compared to 2005 levels, as part of the Copenhagen Accord[7].

With regard to longer term action on global warming, India has – along with all other parties to the United Nations Framework Convention on Climate Change (UNFCCC) – pledged its support for the Durban Platform on enhanced cooperation, whose aim is a global agreement on climate change, to be effective from 2020, and most likely with long term binding targets for a range of developed and emerging economies alike[8]. In order to be prepared for the challenges of limiting emissions growth over the coming decades, attention in India's energy community is now beginning to focus on how different sectors within the economy could lower their carbon intensity over the long term. This study assesses how India's energy system could develop in the context of a global emissions reduction scenario which is broadly consistent with achieving a 2 degrees Celsius limit to global warming.

# Key findings

## The first low-carbon scenario

In the first low-carbon scenario (LC1) in which all technology choices within the TIAM-UCL model are available, the majority of emissions reductions occur in the electricity sector (as shown in Figure 1), which would significantly reduce its emissions to the point where electricity becomes a net sink of $CO_2$ by 2050, owing to a technology mix of nuclear, renewables (particularly solar technologies), plus fossil fuels and biomass with CCS.

The industrial sector would be the next largest source of emissions reductions, the major technological change being the widespread switch of process heating from coal to gas. The transport sector would see relatively little change compared to the reference case, although there would be an increasing uptake of hybrid cars, significantly improving the overall energy efficiency of the road transport sector. The residential buildings sector, currently heavily reliant on biomass for cooking and heating, would continue to use this fuel in rural areas (but from increasingly efficient, commercial sources) whilst new space cooling and appliance demand would be met through increasing electricity demand. The commercial buildings sector would meet future increases in heating and cooking demand with electricity, as opposed to gas in the reference case. India's energy efficiency would improve relative to the reference case, but mainly through the switch to more energy efficient fuels (such as from coal to gas in industrial process heating). This is because the TIAM-UCL model chooses energy-efficient technologies even in the reference case, provided that they are cost-effective.

This first low-carbon scenario would have an additional annual energy system cost (compared to the reference case) of about $200 billion (2005 US$) per annum by 2050, about 1.2% of India's projected GDP at that time.

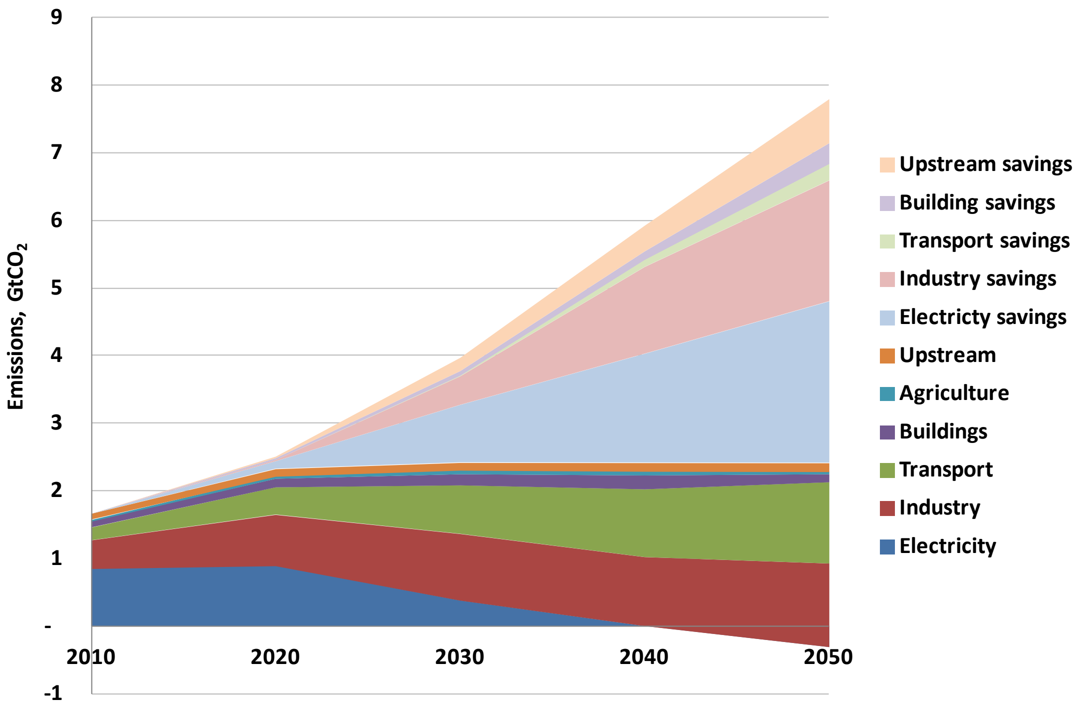


**Figure 1:** $CO_2$ emissions in India to 2050 in the Reference and First Low Carbon scenarios

Notes: Emissions for industry, transport & buildings do not include indirect emissions from electricity. Emissions from electricity are negative after 2040, which is why the Industry wedge sits below the time axis.

## The second low-carbon scenario

The first low-carbon scenario was presented to a number of energy and climate change experts in India, with a view to receiving their comments on the feasibility of the pathway and technologies chosen. The major comments are summarized in Table 1. Overall, the scenario was seen as feasible, but with reservations on the dramatic rise in gas imports, the reliance on as-yet-unproven Carbon Capture and Storage technologies and the absence of electric vehicles in the road transport sector.

**Table 1**: Comments on First Low-Carbon scenario (LC1) and changes for Second Low-Carbon scenario (LC2).

| Sector | Reviewer comment(s) | Impact on LC2 scenario design |
|---|---|---|
| Primary energy demand | Gas imports too high, leading to potentially excessive future reliance on imported gas. | Limits placed so that only shipped LNG imports are allowed, with no pipeline gas imports. |
| Power sector | Large quantity of unabated (i.e. non-CCS) coal plant in the pipeline, implying India's emissions wouldn't peak until after 2020.<br>Uncertainties around biomass availability for power generation, as a result of potential agricultural land constraints.<br>CCS a major uncertainty for India.<br>Less wind than expected given likelihood of good resource potential. | India's emissions allowed to grow as per reference case until 2030, then reduce at equal annual percentage reductions to 2050.<br>Biomass in power generation restricted to 35 GW, in line with more conservative estimates of biomass availability.<br>No CCS allowed.<br>Wind increases as a result of the restriction of biomass and CCS. |
| Transport | Would potentially be more of a role for electric vehicles, even if only minor, by 2050. | "Hurdle" rate (i.e. minimum rate of return against which investments become economically attractive) for electric vehicles lowered to reflect policy preference. |

In the second low-carbon scenario (LC2), gas imports are restricted to liquefied natural gas (LNG) shipped imports only, which reduces total 2050 primary gas demand to about 18 EJ, compared to 35 EJ in the first low-carbon scenario and 21 EJ in the reference case.

Biomass power generation is constrained to an installed capacity of 35 GW to reflect more conservative estimates over biomass availability for power generation, whilst CCS is excluded as a technology choice, to reflect a more pessimistic scenario in which this technology is not adopted in India. At the same time, the hurdle rate for fully electric vehicles is lowered to reflect the likelihood that this technology will be increasingly favoured in the future.

In this scenario India's electricity system still attains a very low $CO_2$ intensity by 2050, at less than 50 $gCO_2$/kWh, with additional solar PV and wind being installed in place of biomass with CCS. Restrictions on gas imports, combined with restrictions on biomass availability in power generation, mean that industrial coal heating switches to biomass heating (where conversion losses are much lower than in electricity generation), rather than gas-based heating as in the first low-carbon scenario. As shown by Figure 2, the industry sector contributes the most to emissions reductions in the second low-carbon scenario, compared to the reference case. In the transport sector, electric vehicles account for about 18% of all car vehicle-km by 2050, although overall the transport sector still reduces its emissions by a relatively modest amount compared to other sectors. Owing to restrictions on gas imports and a higher emissions intensity of electricity, the commercial sector does more mitigation compared to the first low-carbon scenario, and is projected to switch from the reference case where gas is used for some cooking and heating to a low-carbon scenario in which the sector is almost completely electrified – this switching is more marked than in the first low-carbon scenario.

This second low-carbon scenario would have an additional annual energy system cost (compared to the reference case) of about $400 billion (2005 US$) per annum by 2050, almost 2.4% of India's projected GDP at that time. This significant increase on the first low-carbon scenario's cost occurs because of the restriction on relatively cost-economic biomass and CCS in the power generation sector, resulting in more expensive options such as wind and solar being deployed instead. In addition, electric vehicles are relatively costly and forcing their selection has additional cost implications.

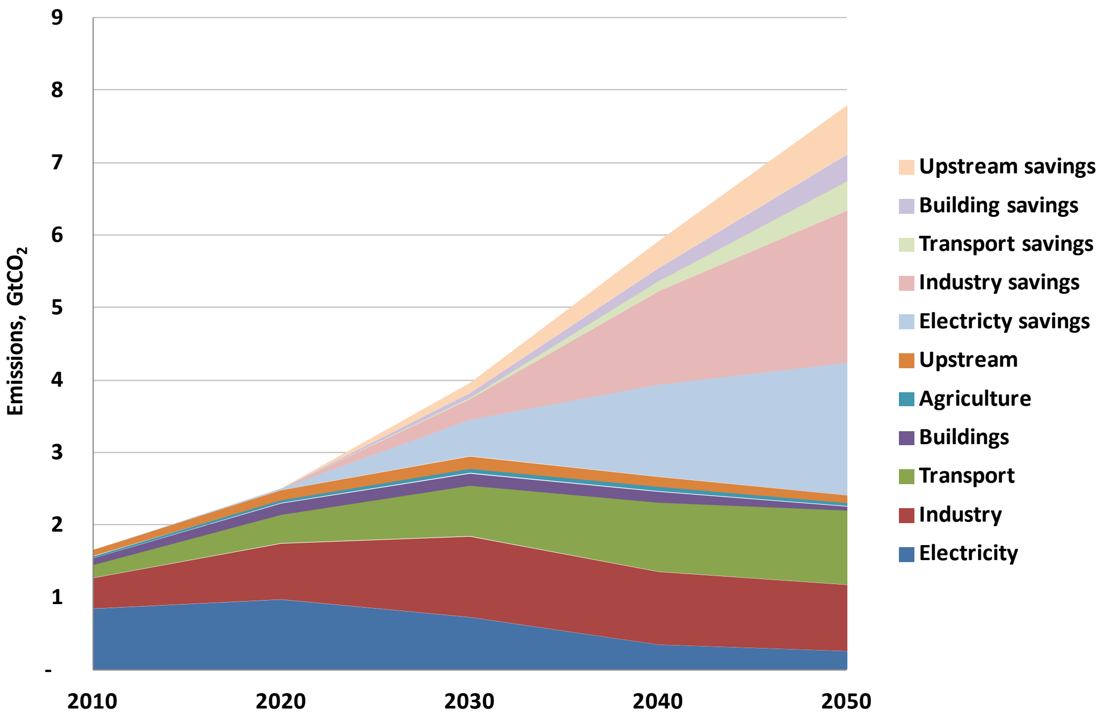


**Figure 2:** $CO_2$ emissions in India to 2050 in the Reference and Second Low Carbon scenarios

Notes: Emissions for industry, transport and buildings do not include indirect emissions from electricity

## Power generation mix in the low-carbon scenarios

Figure 3 shows the power generation mix in the two low-carbon scenarios compared to the reference case, to highlight the scale of the energy supply transformation in India in a low-carbon world. The figure highlights that electricity generation is projected to grow dramatically between 2010 and 2050 in all scenarios, as population and incomes rise. In the reference scenario, coal continues to dominate electricity generation, whereas in the first low-carbon scenario, a fairly balanced mix of nuclear, renewables and CCS make up the generation mix by 2050. In the second low-carbon scenario, without CCS, solar technologies dominate electricity generation.

The projected growth in electricity generation is greater than in the IEA's (2011) BLUE Map scenario for India (even in the high growth case, where economic growth assumptions are similar to those in this study). This is a result of greater electrification in the buildings and industry sectors in this study, compared to the IEA scenarios. In any case, achieving such a rapid increase in electricity generation will require very strong policies to support infrastructure development in the generation, transmission and distribution system.

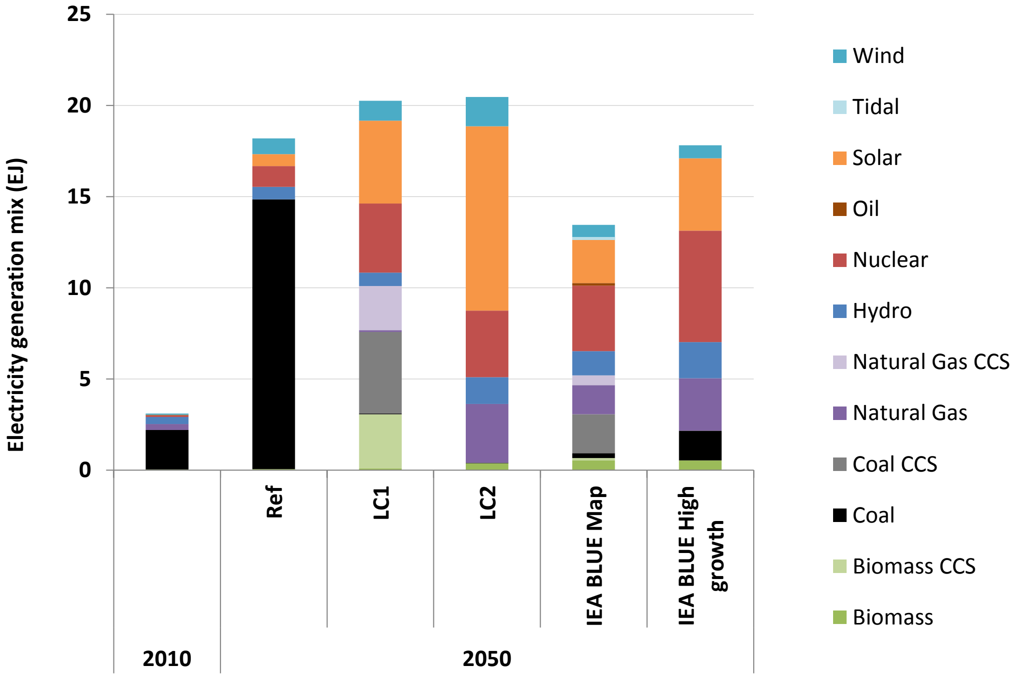


**Figure 3:** Power generation by source in 2050 in the Reference (Ref) and the two Low-Carbon (LC) scenarios

Notes: IEA BLUE scenarios refer to low-carbon scenarios broadly consistent with a 2 degrees C limit to global warming[9]

## Wider implications of the low-carbon scenarios

Both low-carbon scenarios would significantly reduce coal demand within the Indian economy, which could be advantageous given the increasing difficulty that India has had in meeting its coal demand in recent years, which has resulted in an increasing reliance on imports. However, in the first low-carbon scenario gas demand would increase relative to the reference case. In the second low-carbon scenario, gas demand increases more quickly than in the reference case before 2050, although it is slightly lower than in the reference case by 2050. This has implications for India's low-carbon technology strategy, in terms of how to secure access to this gas supply, either through imports or through (as yet largely untested) indigenous unconventional gas supplies. Neither low-carbon scenario appears to significantly reduce India's fast-growing reliance on imported oil. This could be done through increased penetration of hybrid and full electric vehicles, although this is a relatively costly strategy, so there is likely to be a trade-off between cost and energy security in this area.

Other major resource impacts worthy of consideration are the increased land and water implications of biomass and low-carbon power generation, access to uranium imports or reliance on large indigenous thorium reserves when further developing India's nuclear programme, and sourcing of the rare earth elements which go into key low-carbon technologies including wind turbines, solar modules, electric vehicles and low-energy lightbulbs.

## Opportunities, challenges & further research directions

The scenarios presented in this study are technically feasible at the costs shown (i.e. between 1.2 and 2.4% of 2050 GDP, by 2050) provided that the technological transitions can take place as quickly as indicated in the model. The study does not comment on the social, political and operational actions required to support such transitions. Further research should be focused on the speed with which different technologies can be implemented on the ground, considering a range of possible barriers. These include the degree to which electricity grid infrastructure and low carbon generation sources can be deployed within an electricity generation, transmission and distribution system that currently falls short of demand and in which blackouts are commonplace.

Other challenges include the need to formalise more of the Indian market in household appliances to ensure that energy efficiency standards are effectively met, the design of commercial buildings to allow for electrified heating and cooking, the development of more efficient vehicle technologies based on hybrid/pure electric vehicles (with supporting infrastructure in the latter case), increased electrification of the rail system, and the degree to which new industrial plants can utilise non-coal sources of heat such as gas and biomass.

There are potential opportunities to achieve emissions reductions through means not included in the modelling approach, most notably through demand management of industrial output (through increased resource efficiency) and modal switching away from personal motorised transport to public and/or non-motorised transport.

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# About the authors

This study was undertaken by Grantham Institute researchers (led by Ajay Gambhir, supported by Dr Tamaryn Napp, Chris Emmott and Lola Vallejo) and Dr Gabrial Anandarajah of University College London's Energy Institute. The Grantham Institute team undertook contextual research into India's economic development pathways. This led to the specification of scenarios in the TIAM-UCL model, which was run by Dr Gabrial Anandarajah. Results and implications were interpreted jointly by UCL and the Grantham Institute, including review comments from a number of Indian energy experts. The Grantham Institute team wrote the final report.