Long-Term Energy and Development Pathways for India

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Indo-German Centre for Sustainability
IIT Madras
Chennai – 600036
India

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Acknowledgements

This report is the product of many hands, under the guidance of Sudhir Chella Rajan, IIT Madras. Special thanks need to go to Sarada Ramaswamy, Sunita Rabindranathan, Rakesh Iyer, Eshita Mukherjee and Kavya Menon, who all played significant roles in shaping the analysis at various stages. Various students and interns were involved in different stages, including Aashish Gupta, Adaina Panmei, Aniket Pangarkar, Hari Dutt, Manasa Venkatesh, Richie Khandelwal, Roshin Unnikrishnan, Uttara Narayan, V. Vaishali, Vaishnavi Surendra, and others who may be inadvertently missed here. The Prayas Energy Group in Pune, particularly Ashwin Gambhir, Ashok Srinivas and the late Girish Sant, provided very significant support during the early stages. The Shakti team in Delhi, Kunal Sharma and Sriya Mohanti, have been enormously patient with the twists and turns that this project has taken, for which we are very grateful. The LEAP support team, particularly Charlie Heaps, was also extremely helpful throughout this effort.

The study report as well as the LEAP data files will be made available at www.energycommunity.org to provide opportunities for the energy community to update the scenarios with the help of better data sources as they become available.

Abstract

India is both the fourth largest emitter of greenhouse gas emissions and home to the largest population of the world's poor. Climate policy for India must therefore include a strong element of inclusive growth, implying that reducing conditions of deprivation must go hand in hand with reducing overall emissions. A low carbon inclusive growth strategy for India is developed in this study using a transparent, bottom-up scenario modelling effort. This study has shown that it is possible for India to reduce its greenhouse gas emissions to 2005 levels by 2030 and also provide modern energy services to more than half its population who are currently un-served or under-served in this regard. This would entail having to focus on providing energy services to at least the bottom 50 million or so households by providing LPG or advanced electric cookstoves where feasible, access to electricity for lighting, water, sanitation services, improved access to services in urban areas (involving changes in land-use and transport), improved agricultural services, and so on. At the same time, commitments would be required to improve efficiency across the board and increased penetration of renewable energy in electricity generation and to make efforts to shift transport, housing and industry towards more sustainable models.

There are indications that this could provide numerous co-benefits apart from reducing greenhouse gas emissions and improving access to clean energy for the poor. These include reduced local air pollution, improved lifestyles and a more productive workforce.

I. INTRODUCTION

Background

Universally, there is growing recognition that energy is of critical importance to human development with energy services constituting a sizeable share of total household expenditure in developing countries. The poverty-energy nexus exemplifies this relationship: about 2 billion people do not have access to modern energy carriers such as electricity and non-traditional cooking fuels like liquefied petroleum gas and rely instead on wood, dung and other biomass. The lack of adequate energy services to these people amounts to a denial of opportunities for a tolerable life and, as such, characterises their poverty starkly. Climate change provides another reason to improve the efficiency of energy use and to shift to cleaner fuels and thereby reduce greenhouse gas emissions.

Developing countries with limited capacities and growing demand for energy services are therefore placed in the tight situation of having to give equal importance to eliminating poverty and reducing greenhouse gases. This is often seen as a pull in opposite directions, although there are good reasons to believe that this is not always the case; there are many synergies between providing modern clean energy services and creating income-generation opportunities, reducing adverse health impacts and improving human development in general.

India is the fourth largest emitter of global greenhouse gases, contributing to about 5 percent of the total emissions in 2010 and at the same time is home to a third of the world's poor. In the political turnaround at Copenhagen in 2009, India had voluntarily promised to reduce its emissions intensity by 20-25 percent by 2020 from its 2005 levels, which became part of the official global deal to reduce emissions at Cancun in 2010.

Under various equity-based allocation schemes, India, along with five other large developing countries, receives relatively high allocations (see Table 1). It will have an available carbon budget of at least 108 gigatons (Gt) of carbon, and as much as 290 Gt, between 2010 and 2050. Under a business-as-usual scenario, as described by Mattoo and Subramanian (2010)[1], India will have barely exhausted its carbon budget by 2050; this implies about 2.5% annual growth in emissions during the next four decades, which seems plausible if we imagine slow decarbonisation as a result of technological change and structural shifts in the economy, but no new policies. Under an equity-based scheme involving historic responsibility, for instance, India would have roughly 180 GtC of additional space, even if the BAU scenario were borne out.

[1] Mattoo, A and A Subramanian (2010): "Equity in Climate Change: An Analytical Review." *Policy Research Working Paper 538,* The World Bank, Development Research Group.

[2] See, for instance, MoEF (2009): "India's GHG Emissions Profile: Results of five climate modelling studies". Ministry of Environment and Forests, New Delhi.

Table 1. Cumulative emissions of under alternative scenarios and proposals for major emitters, 2010-2050 (gigatons of carbon). Adapted from Mattoo and Subramanian (2010).

Proposals (all numbers in GtC)	Business as usual	Equal per capita emissions	Historic responsibility	Ability to pay	80-20 cuts	Preserving future development opportunities
China	295.2	174.8	99.2	150.5	162.2	295.2
USA	283.3	40.1	2.5	4.4	133.7	-67.9
Russia	65.8	18.7	1.5	6.1	40.1	65.8
India	108.1	150.4	289.7	278.5	57.9	108.1
Japan	43.2	16.8	2.1	2.6	28	-10.4
Germany	33.3	10.8	1	1.6	19.1	-8
Canada	25.3	4.4	0.3	0.6	13.2	-6.1
Indonesia	31.8	30	45.1	38.9	13.2	31.8
Brazil	24.2	25.3	22.8	12.4	10.9	24.2
EU	148.5	56.5	7.6	10.1	86.1	-12.8
All countries in sample	1413.6	704.0	704.0	704.0	704.0	704.0

What this implies is that India could claim a substantial portion of the available carbon budget for itself, but would nevertheless demonstrate its commitment to environmental stewardship, by gradually reducing the rate of growth of greenhouse gas emissions, while also making a serious effort to reduce poverty. A reduction in poverty will imply having to improve access to modern energy services for the poor, which in turn implies increased emissions from increased use of LPG, electricity and other modern energy carriers. These increases will need to be compensated for through additional efforts to reduce wastage and substantial shifts in lifestyles and technologies across all sectors towards sustainability.

Study Goals

While there is a significant body of work developed by the Government and various consulting organizations on energy and carbon forecasts[2], we are convinced that many of these studies are limited to the extent that:

[2] See, for instance, MoEF (2009): "India's GHG Emissions Profile: Results of five climate modelling studies". Ministry of Environment and Forests, New Delhi.

- They are non-transparent energy databases developed with top-down macro-economic models, with little opportunity to understand their assumptions and approach and/or
- They cover only certain energy demand sectors or sub-sector, and
- They do not include an explicit focus on inclusive growth.

In this study, by considering the need to mainstream energy concerns of the poor and vulnerable sections of India at the national level and also reduce greenhouse gas emissions, we develop Long-Term Energy Pathways for India that focus on **two novel features**:

- ***First-*** *A transparent, collaborative effort for bottom-up scenario development, with detailed sector-level analysis till 2030.*
- ***Second-*** *A low-carbon scenario that explicitly focuses on inclusive-growth i.e. to improve lives of the poorest households in urban and rural India.*

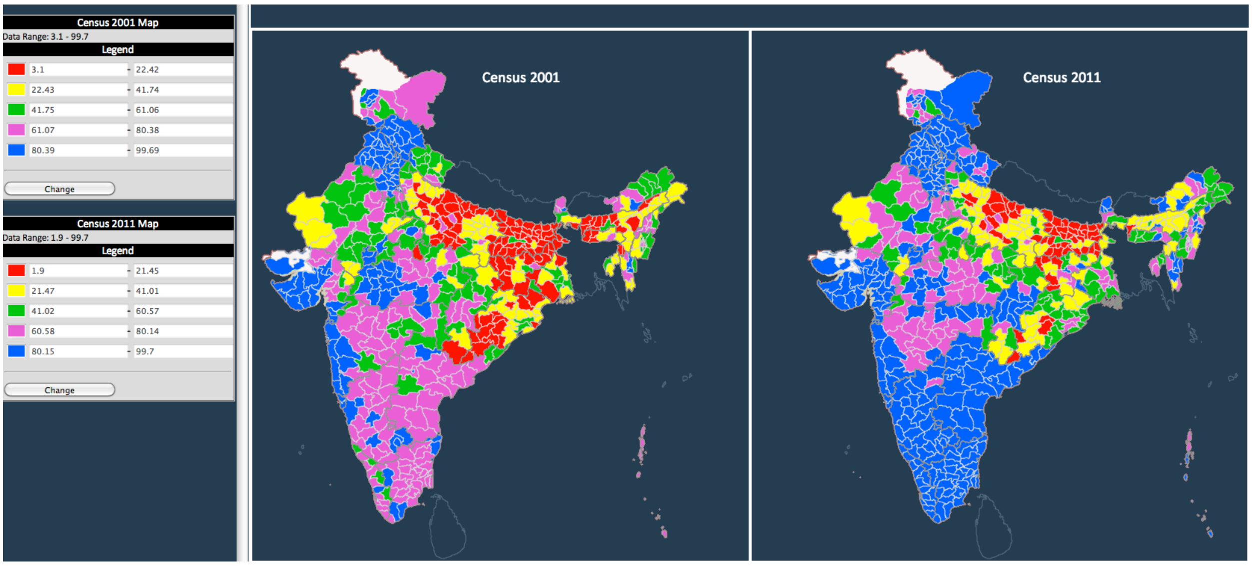
TERI (2009): "A National Energy Map for India: Technology Vision 2030". The Energy and Resources Institute, New Delhi.
IRADE (2014): "India's Energy Transition in the Global Context till 2050". Integrated Research and Action for Development, New Delhi.

II. GOALS OF THE PROJECT

1. General

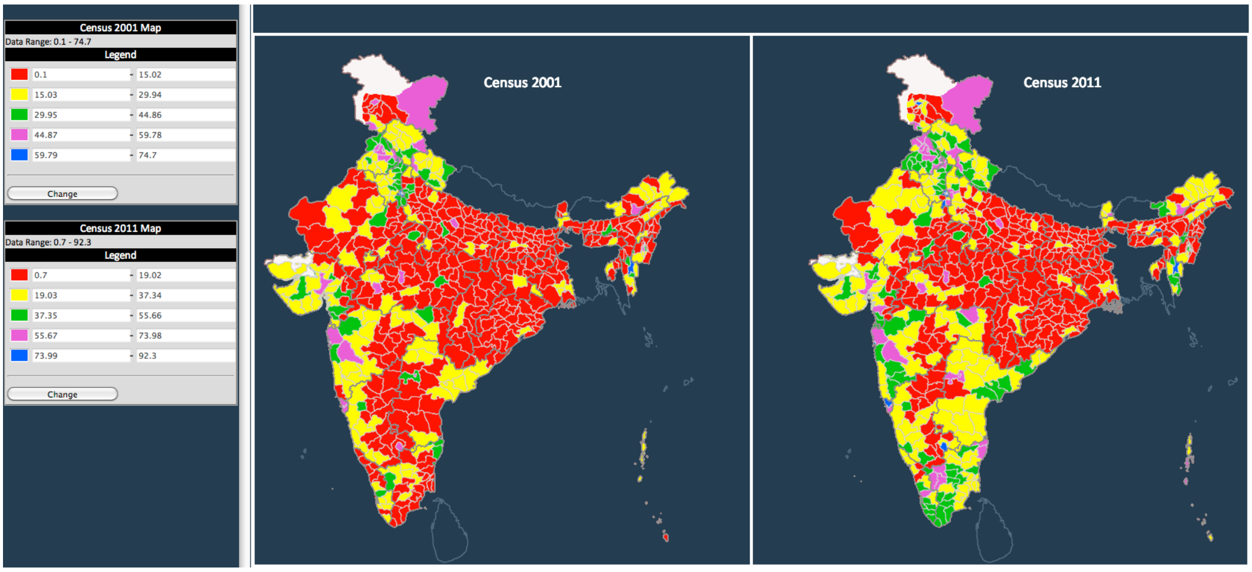
This research aims to define a carbon agenda for India, till 2030, by developing energy scenarios using a bottom-up approach, with a special emphasis on the developmental needs of people living in poverty (particularly, the poorest 30 percent, roughly making up those below the official poverty line). These scenarios are developed on the basis of demand and supply analysis, with low carbon and development options for the period 2006 to 2030. A transparent framework, quantitatively supported by LEAP (Long-Term Energy Alternative Planning) System, an energy accounting software, is used to enable scrutiny at micro and macro levels. LEAP is not a model of a particular energy system. It is a tool that has a reputation among its users for presenting complex energy analysis and concepts in a transparent, flexible, simple, intuitive and easy-to-use fashion.

The motivation for this approach should be quite clear. As Figures 1 and 2 below show, despite considerable progress in the provision of modern energy services, hundreds of millions of people remain underserved in vast parts of the country. If the poorest deciles in the population have not shown much improvement in access to energy services, it indicates that energy policies have hitherto concentrated on making aggregate improvements in the supply of energy, which have not trickled down to the poor. Rather, it is now necessary to develop an energy strategy that shifts the focus *primarily* to increasing access to the bottom deciles. This is what is assumed in the Low Carbon Inclusive Growth scenario described below.



Source: www.energytrends.org

Figure 1. Electricity as a Source of Light (Percentage of Households by District).



Source: www.energytrends.org

Figure 2. LPG as a Source of Cooking (Percentage of Households by District).

A. Scenario Description

Three scenarios, namely, the Reference of Business As Usual (BAU), Low Carbon (LC) and Low Carbon Inclusive Growth (LCIG) are discussed here. The three scenarios have been developed based on the extent in which economics, social factors and technology affects the energy consumption among three economic strata (the lowest income group – up to 30%, those in the 30 – 90% range, and the top 10%).

The Reference Scenario deals with the kind of demand where the purchasing pattern of appliances and devices would remain mainly on the basis of lowest first cost, whereby different classes of energy consumers would use appliances that are cheap even if they are not energy efficient. It assumes that current economic and energy policies will broadly continue and that major efforts to tackle climate change will not materialize.

LC and LCIG are both low carbon scenarios. LC assumes policies to achieve a substantial improvement in energy efficient technologies and increased use of renewables in all sectors. No emphasis is placed on development goals; rather, the aim is to reduce carbon emissions by 2030 to roughly match 2005 levels. The analysis in the LCIG considers clean, efficient, reliable, and affordable modern energy services for the rural and urban poor i.e. those in the bottom 30 percent income group as well as in the segment immediately above. This includes the achievement of 100 percent electricity access for lighting and cleaner cooking fuels for all well before 2030. It builds a storyline around income generating opportunities (primarily in sustainable agriculture and manufacturing) for the poor and requires that the resulting increases in emissions be off-set by reductions from those whose incomes fall in the top 10 percent. LCIG is also intentionally a less material-intensive scenario, reflecting shifts in lifestyles for the top 10 percent group, but also changes in so-called 'aspirations' across all income categories towards alternative consumption preferences that result in relatively fewer personal goods, appliances and devices, that will in turn reduce carbon emissions for the rich compared to LC.

Both scenarios also limit the availability of bioenergy and hydropower, owing to pressures on land and water resources, diminishing biodiversity, and the need to safeguard food production. Electricity demand would be met through advanced coal and substantial increases in renewable power generation (wind, solar, geothermal and, in some regions, additional hydro) as well as from savings through energy efficiency. See Table 2 below for more details.

Table 2. Assumptions and features of the three scenarios.

Sector	Reference	Low Carbon (LC)	Low Carbon Inclusive Growth (LCIG)
Transport (passenger)	Reliance on road, increase of personal motorised vehicles. Access becomes increasingly difficult and walking, cycling and other non-motorised vehicles become near prohibitive because urban designs and planning emphasize cars.	Reliance on rail, road for both intra-city and inter-city transport. Some increase in public transportation. Improved emissions regulations and fuel economy. Modest increase in access for non-motorized modes, including walking and cycling.	Emphasis is on access rather than mobility. This implies a greater sensitivity to land-use and transport issues, mixed-use planning, transit-oriented development, transport demand management, and some changes in lifestyle to reduce the need for travel. Expansion of public transport, walking and bicycling. Same level of improvement in emissions regulations and fuel economy as LC.
Transport (freight)	Road based freight increases at the expense of rail	Greater share for rail (freight corridors), higher efficiency for trucks	Freight volumes do not increase as much as in the BAU or low carbon scenarios - demand reduction, changes in consumption patterns mean greater sensitivity to local production and use

Agriculture	Decline in agricultural productivity and contribution to GDP	Reduction in the rate of decrease in agricultural productivity due to more energy efficient services and some renewables. Improvements in energy efficiency in rural areas, some spread of renewables.	Rural energy, agricultural services, improved sustainable water management through surface water storage. Diversification of agricultural varieties for resilience to changes in climate. Diversification of agriculture and financial instruments to promote low chemical input. Removal of most subsidies for electricity. Increase in the contribution of agriculture to GDP. This implies greater employment in the agricultural sector and more labour-intensive farming techniques, such as System of Rice Intensification (SRI) and organic agriculture.
Industry	Industrial growth rates in different industries grow roughly at rates determined from 2000-2005. No major changes in emissions intensity, but gradual evolutionary shifts towards more efficient technologies.	Growth rates in output of different industries mirror the Reference scenario, but faster changes towards best-in-class technologies take place driven largely by policy shifts.	The same technological improvements as in the LC, but substantial reductions in the growth of some energy-intensive sectors, such as cement, steel, other metals and fertilizers. This is assumed to be consistent with a general shift towards more sustainable materials in construction and housing in particular, and in the more efficient use of input services for agriculture.

Livelihoods	Employment opportunities increase mainly through market-based investment in economic activities by domestic and foreign companies.	Some increase in employment in energy efficiency industry, additional opportunities through energy innovation and renewables.	Diversification of agriculture and financial instruments to promote low chemical input agriculture will increase the labour needs in rural areas thus increasing employment. Income-generation opportunities also in small and medium enterprises promoting sustainable use of materials and energy.
Household energy (rural)	Unmet rural energy needs, slow growth in electrification	Unmet rural energy needs remain since this is not a priority. Expansion of some existing decentralised rural electrification programmes involving renewables.	Increase in energy efficiency in energy services, 100% access to electricity and modern cooking fuels. Increased use of renewables such as agricultural waste, biogas thermal, solar. Cleaner cooking fuel, including electricity and LPG. Reduced demand for household electricity in appliances, particularly for highest income group.
Household energy (urban)	Expansion of appliances	Expansion of appliances but some energy reduction due to energy efficiency. But 'rebound effect' strong - people use more appliances because they perceive lower expenses due to savings from energy efficiency	Serious commitment to reducing per capita energy use among households in the highest income-level. Cleaner cooking fuel, including electricity and LPG. Reduced demand for household electricity in appliances, particularly for highest income group Conscious decisions to avoid waste, combination of behavioural

			and technological change.
Employment	Unemployment rate is affected by business cycles and growth in population of unskilled labour, which in the absence of focused policies to emphasize technical and vocational education, will magnify problems of both unemployment and labour shortages.	Improvements in efficiencies and in public transportation will increase opportunities for employment in some sectors. In addition, the renewable energy industry may provide additional jobs for trained technicians and service personnel.	Rural jobs in agriculture and sustainable non-farm enterprises will likely increase. Improved access to jobs in urban areas will reduce barriers for women to enter the workforce in particular. Most significantly, a substantial number (tens to hundreds of millions) of new workers could enter the workforce, given their improved functioning's and capabilities arising from poverty reduction and improved access to energy services. If these individuals are given substantial preparatory vocational training, their jobs in industry and services will be assured, given the market for sustainable goods and services, which are typically labour-intensive.
Migration	Migration to Tier one and two cities. Migration keeps up at the current rate, which in any case is supposed to be	Migration will shift to Tier 2 primarily with some degree of reverse migration to rural communities because of better	Significant reduction in migration to urban areas life in rural areas improves with energy services, agriculture and management of local resources.

	lower for Asian cities than for Latin America and Africa	services in rural areas than for the urban poor	
Standard of living	Will continue to deteriorate with the poor suffering the most both in urban and rural areas. Social inequalities increase.	Will improve slightly if energy services improve along with increase in efficiencies and some investment in public transportation. Health, food security, education will likely remain the same or improve slightly, since there is no real focus on the poor. Social inequalities remain.	Large numbers of people will come out of poverty with as a result of improved energy services (water, lighting, cooking, space heating and cooling), better management of water and improvements to low-chemical input agriculture. Will lead to an improvement in quality of life in urban and rural areas and promote health and employment opportunities. Social as well as economic inequalities are likely to improve under these conditions.

B. LEAP Analysis

LEAP analysis involves a bottom-up approach of energy demand across various economic strata in various sectors. The primary and secondary energy resources, transformation of energy and the final demand of energy in various sectors such as transport, industry, residential, farming and commercial sectors is the path in which energy flow is analysed. The residential sector is further divided according to the income into 0-30 percentile, 30-90 and top 10 percentile; and according to region as rural and urban.

LEAP follows an end-use, demand-driven approach, that is, the analysis starts from the end-use of energy. The demand program divides the society in a hierarchical tree structure of four levels: sectors, sub-sectors, end-uses and devices. For example, if a branch of this structure is households (sector), rural households (sub-sector), cooking (end-use) and charcoal stove (device). For each device, a fuel type (e.g. fuelwood, charcoal, LPG) and the average consumption (e.g. 20 MJ per household per year) should be specified.

For a given area different scenarios can be developed, assuming different conditions for future development of demand and supply of energy. The change of the values of variables over time can be specified according to several methods. This can be through entering future values, giving a growth percentage, linking it to a macro-driver (e.g. GDP or population) through elasticities, or a combination of these methods. With the evaluation module, the alternative scenarios can be compared to find the most satisfying solution to meet future goals. The evaluation can consider physical, energy, environmental and economic cost factors.

III. DATA AND METHODS

1. Sources of Data

The study includes demographic, economic, general energy, demand, transformation and fuels data taken mostly from the 61st household survey of the National Sample Survey Organization (NSSO) conducted in July 2004-June 2005, the World Energy Report 2007, various Government of India reports and databases and commercially available sources (e.g., Society of Indian Automobile Manufacturers). In some cases, 'guesstimates' of parameters and energy intensities were made on the basis of consultation with energy experts.

2. Data Structures

The first step in an energy analysis is the design of data structure. The structure will determine what kinds of technologies, policies, and alternative development paths can be analyzed. It will be guided by the information collected (data and assumptions) and by the relationships. An example of the tree structure as represented in LEAP is shown in Figure 3. Of the 231.7 million households in 2005, about 70% live in rural areas and the remaining 30% in urban centres. This ratio shifts fairly rapidly over the next 25 years, with increasing urbanisation resulting in about 45% of the population living in urban areas by 2030. For each demand sector, i.e., transport, industry, residential, commercial and farming, different categories of activity and energy intensity by fuel use are provided. The total consumption per fuel for each data year is calculated by summing up the consumption for all sub-sectors and sectors.

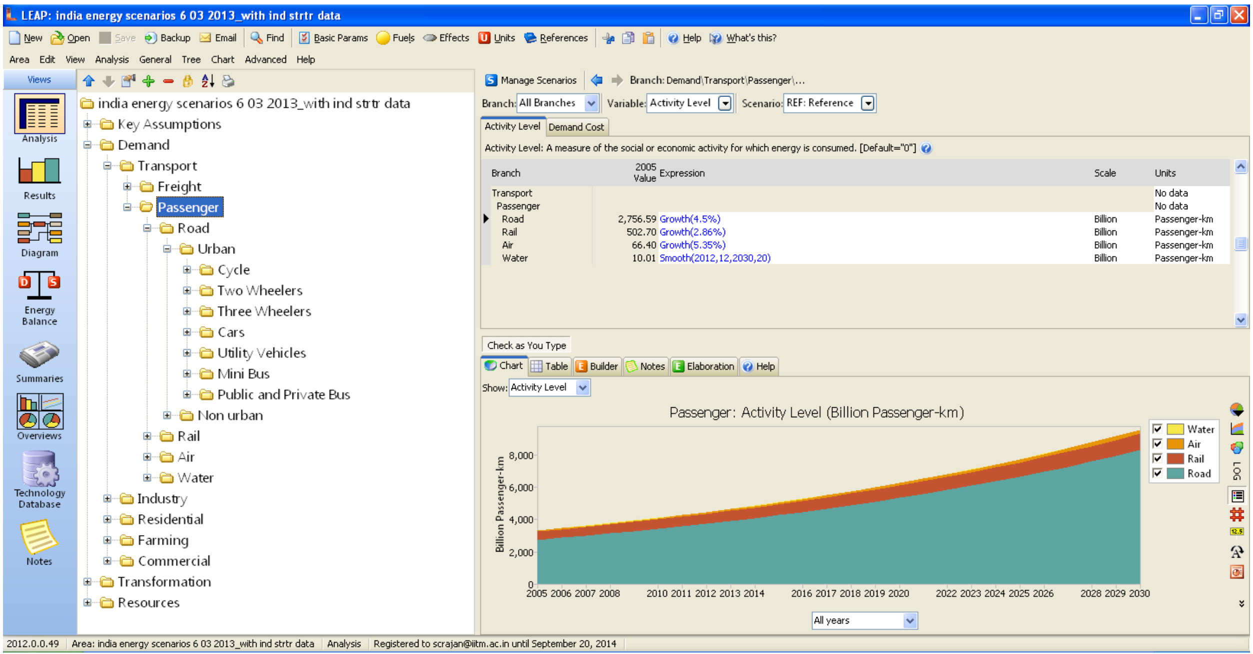


Figure 3. Example of Data Structure in LEAP

3. Transformation

Transformation of energy is the branch used to explain how the primary energy has to be transformed through secondary energy into final energy before being used by consumers. These transformation processes with their efficiencies and losses is incorporated in the model, in order to calculate the total amount of primary energy that is required to produce the final energy demanded. Different levels of complexity of the transformation processes can be distinguished, from simple (i.e. single input and single output with only one efficiency factor, e.g. wood as input into a kiln and charcoal as the output), to more complex processes with multiple in- and outputs and efficiencies (e.g. power plants). Similar to energy demand analysis, developments in the use of different conversion technologies can be simulated in scenarios. After specifying the conversion parameters for different fuels, the total fuel requirements can be calculated for different combinations of demand and transformation scenarios.

4. Bottom-up Analysis

LEAP is a simulation model used to represent the current energy situation for a given area and to develop forecasts for the future under certain assumptions. First, an overview of the current situation is created by specifying data for the starting year, and a basic scenario is developed assuming a continuation of current trends. After this, alternative interventions are evaluated by using scenarios. The bottom-up analysis involves the analysis of energy flow right from the initial point of primary energy production, secondary energy production, transformation along with the losses in transmission and distribution to the end-users who demand the energy.

IV. RESULTS

1. Transport

The transport sector is divided into two main segments, freight and passenger. Freight transport consists of road, rail, air and water modes, whose current distribution is given in Figure 4. Rail and road dominate the sector, but air and road are the fastest growing modes, with about 7 and 5 percent annual growth rates, respectively. Road freight is responsible for the most energy use (primarily diesel), which will likely dominate in the near future under a BAU scenario in spite of rail shares remaining high (see Figures 5 and 6).

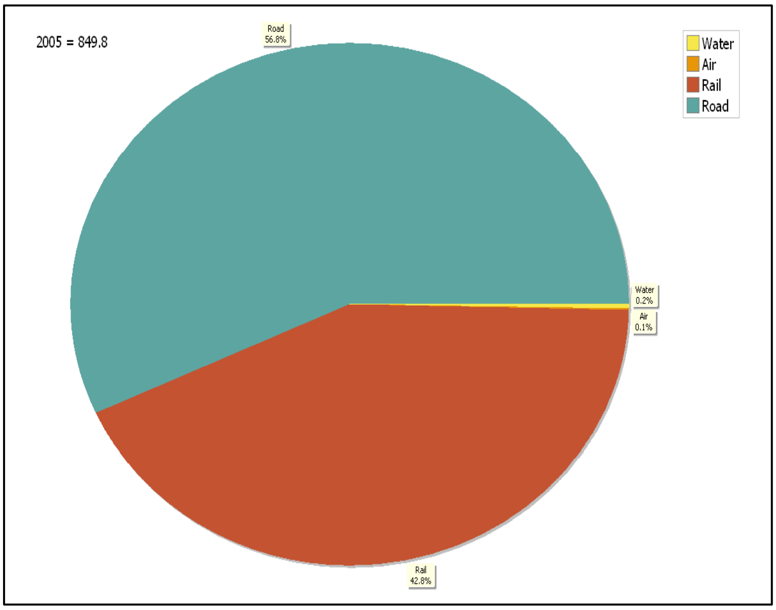


Figure 4. Distribution of Freight Activity in 2005. Total is 849.8 billion tonne-km.

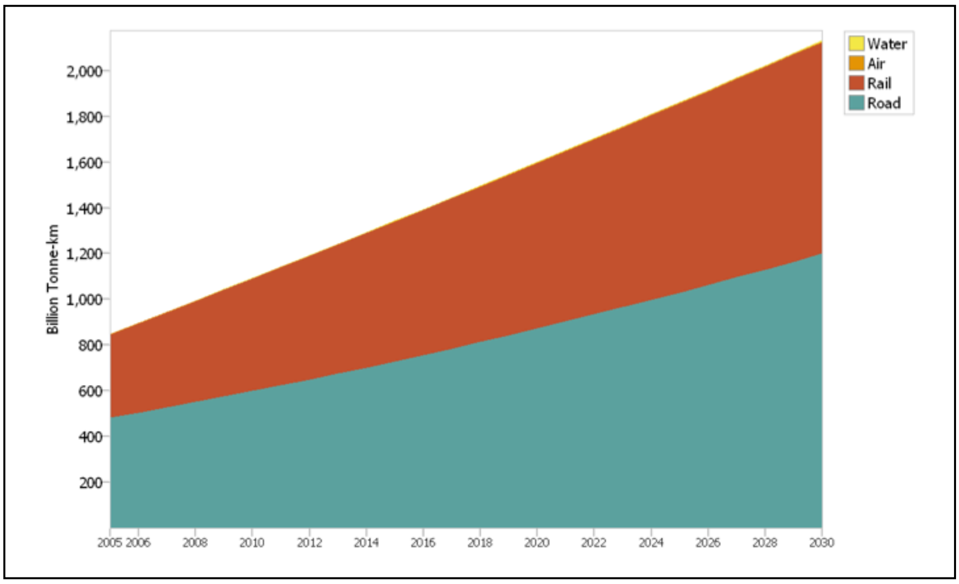


Figure 5. Growth in Freight Activity in the Reference Scenario.

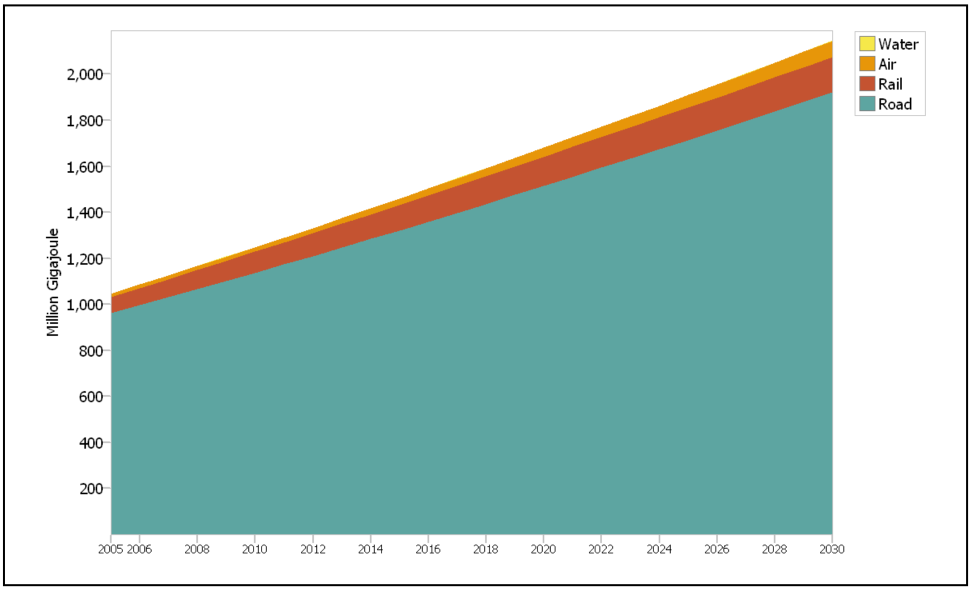


Figure 6. Growth in Freight Energy in the Reference Scenario.

In the Low Carbon scenario, the energy efficiency of all the major freight modes improves at faster rates than the Reference scenario, roughly matching international norms for best practices in the sector. The Low Carbon Inclusive Growth scenario assumes a substantial shift in freight from road to rail and a reduction in air freight compared to Reference (see Figure 7 and Figure 8).

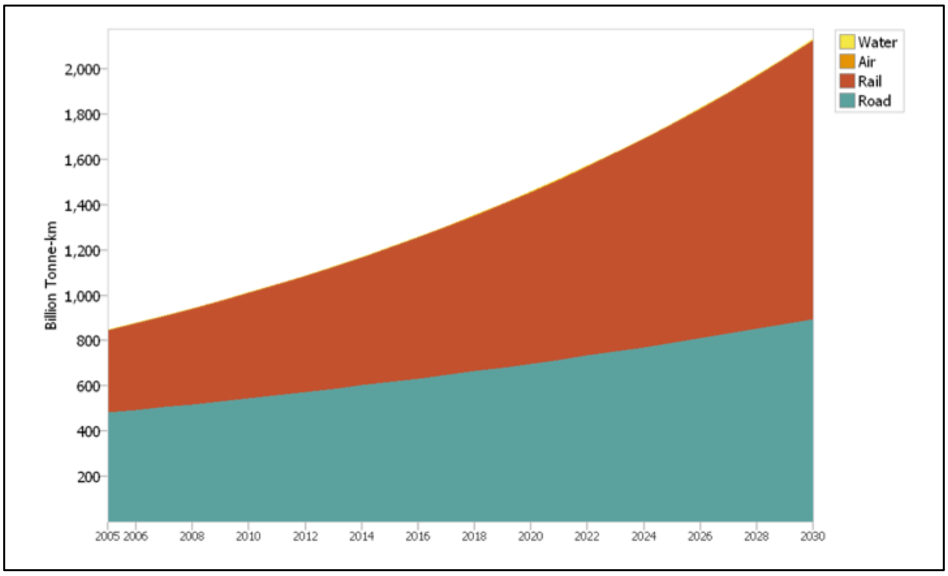


Figure 7. Growth in Freight Activity in the LCIG Scenario

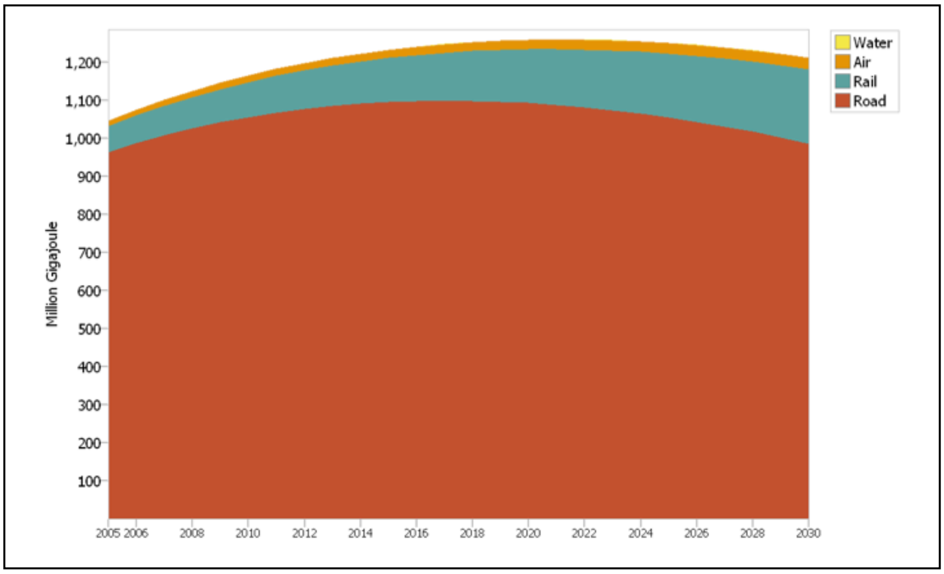


Figure 8. Growth in Freight Energy in the LCIG Scenario.

Passenger transport includes non-motorized as well as motorized modes. The former cover walking and bicycling (although only bicycling is modelled in this study). Passenger transport is further subdivided into urban and non-urban forms of travel. The Reference scenario is dominated by road transport, as shown in Figures 9 and 10.

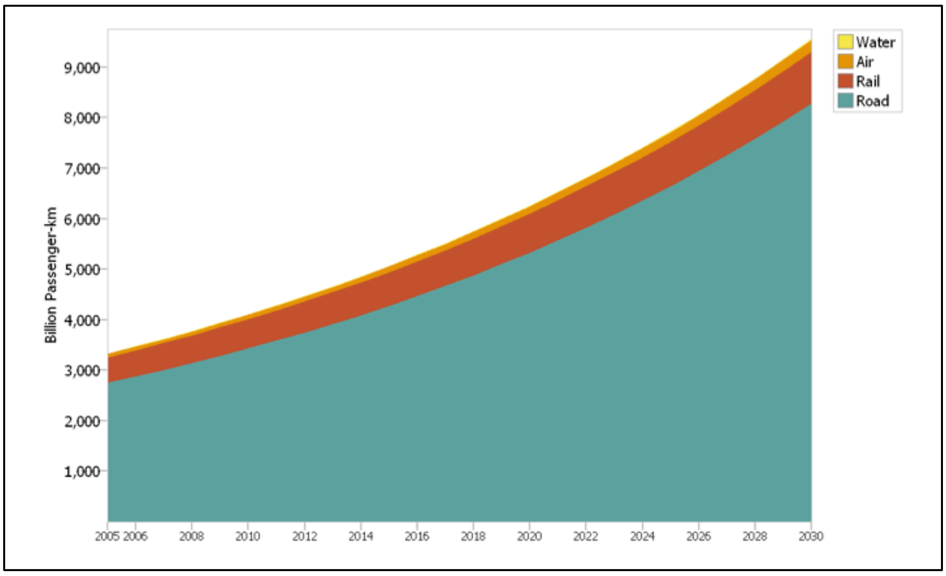


Figure 9. Broad Mode Shares in Passenger Transport in the Reference Scenario.

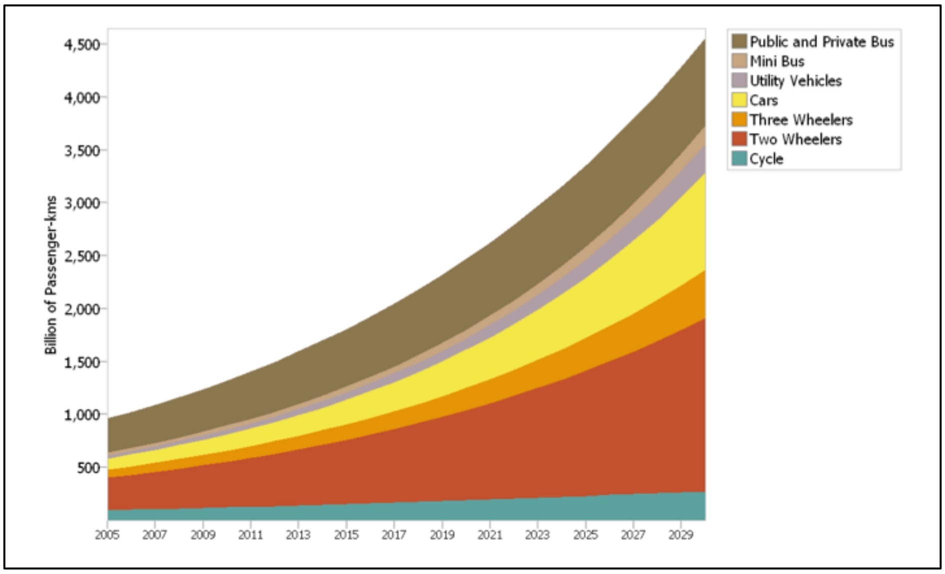


Figure 10. Mode Shares for Urban Passenger Transport in the Reference Scenario.

Energy consumption in the transport sector in the Reference scenario is dominated by growth in road transport, particularly private cars and utility vehicles (see Figures 11 and 12)

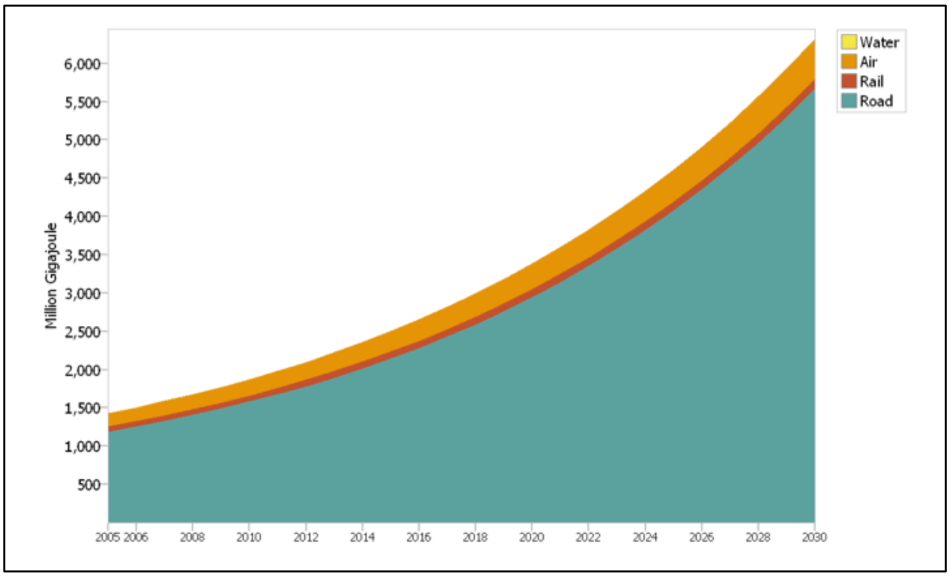


Figure 11. Energy Demand in Passenger Transport in the Reference Scenario.

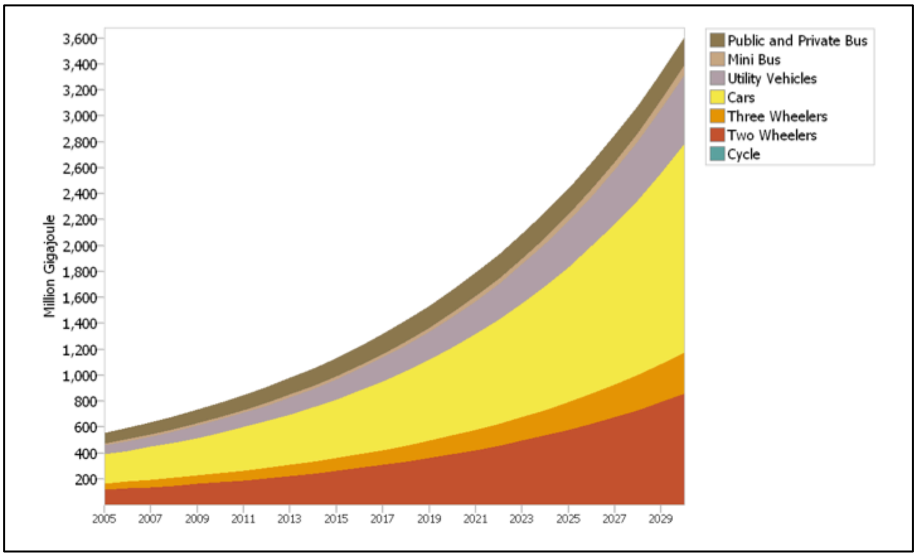


Figure 12. Energy Demand for Urban Passenger Transport in the Reference Scenario.

The Low Carbon and Low Carbon Inclusive Growth scenarios are built around improved fuel economy for all motorized vehicles, following European Union norms closely. In addition there is a modest increase in non-motorized mode shares in the LC scenario and a slight reduction in the rate of growth of private vehicles, as transport systems as a whole become more efficient with better metro rail and other public transport services. The LCIG scenario has another innovation, in the form of a substantial commitment for providing safe and clean access to transport for the poor, involving a clear mandate to reduce the overall relative share of private transport in favour of public transport and bicycles. Some broad life-style changes are also implicated, leading to net reduction in overall passenger travel. The LCIG scenario thus includes all the possible interventions in the transport sector to reduce carbon emissions (Figures 13-15).

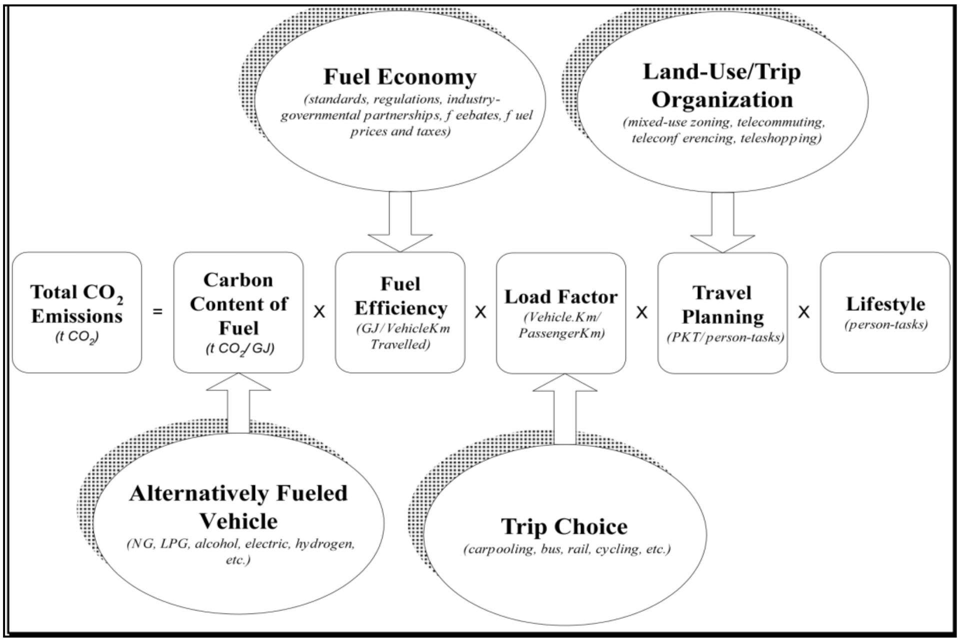


Figure 13. Drivers of CO2 Emissions in Passenger Transport (Source: Tellus Institute, private communication).

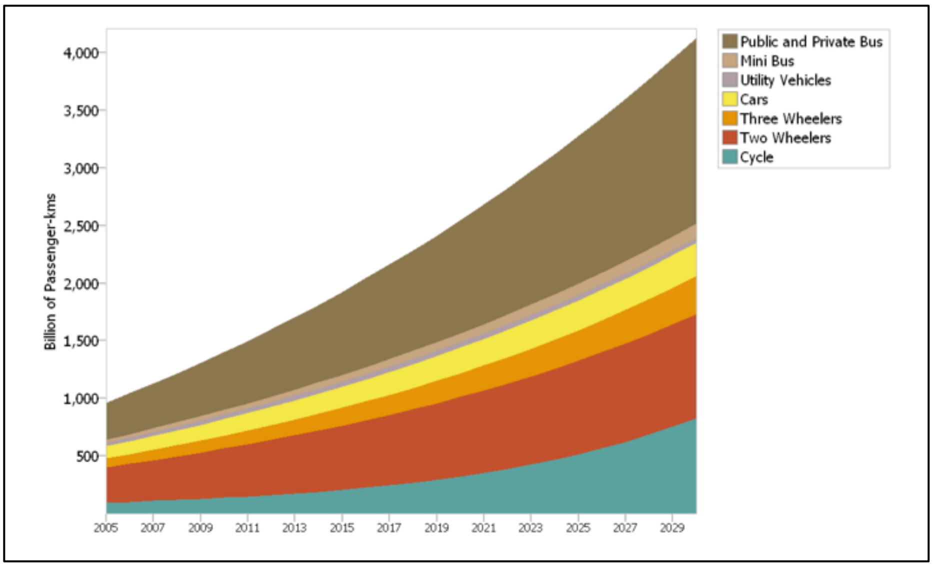


Figure 14. Mode Shares for Urban Passenger Transport in the LCIG Scenario.

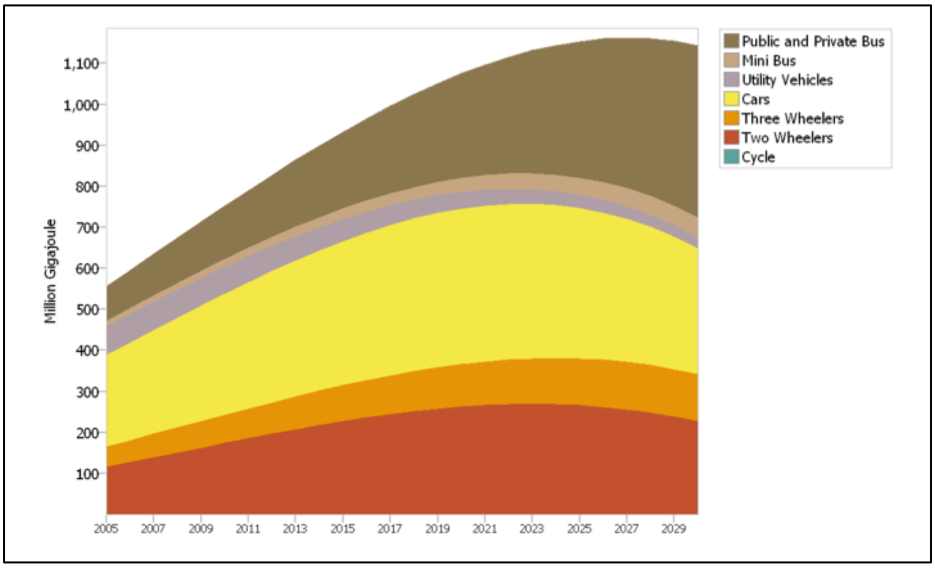


Figure 15. Energy Demand for Urban Passenger Transport in the LCIG Scenario.

Overall, substantial reductions in final energy demand as well as greenhouse gas emissions are conceivable in the transport sector as a whole by adopting the LCIG scenario (Figures 16 and 17). In addition, there are several (un-quantified) co-benefits, such as improved access, reduced local air pollution and (potentially) improved safety because of lower overall use of motorized travel.

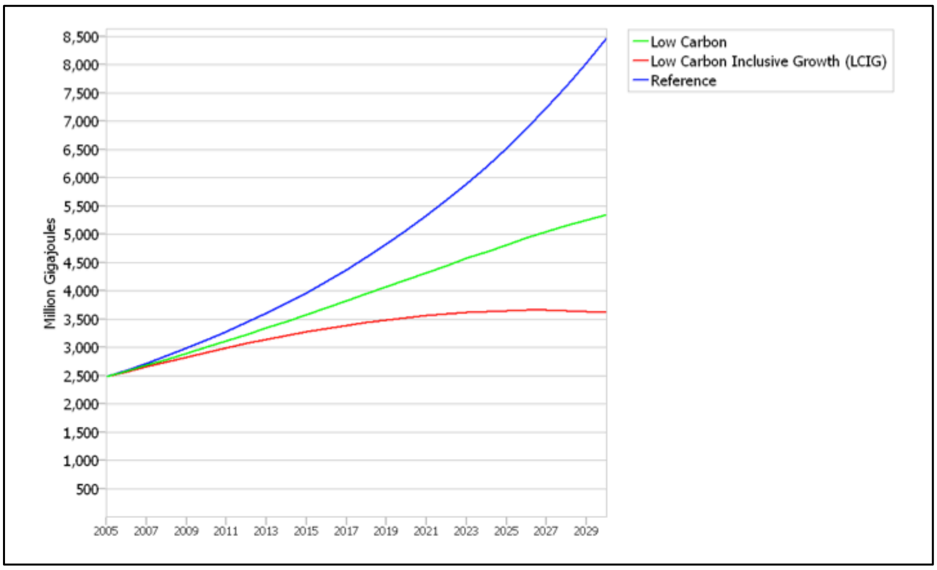


Figure 16. Final Energy Demand from Transport Sector in Three Scenarios.

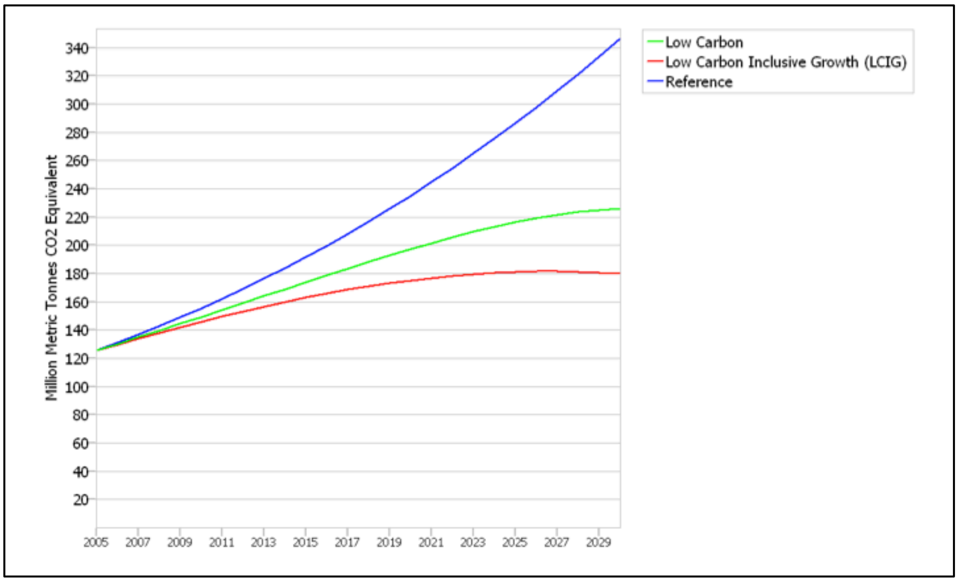


Figure 17. GHG Emissions (Excluding Electricity) from Transport Sector in Three Scenarios.

Figures 18 and 19 show the differences in final energy demand by fuel for the Reference and LCIG scenarios for the transport sector (inclusive of passenger and freight).

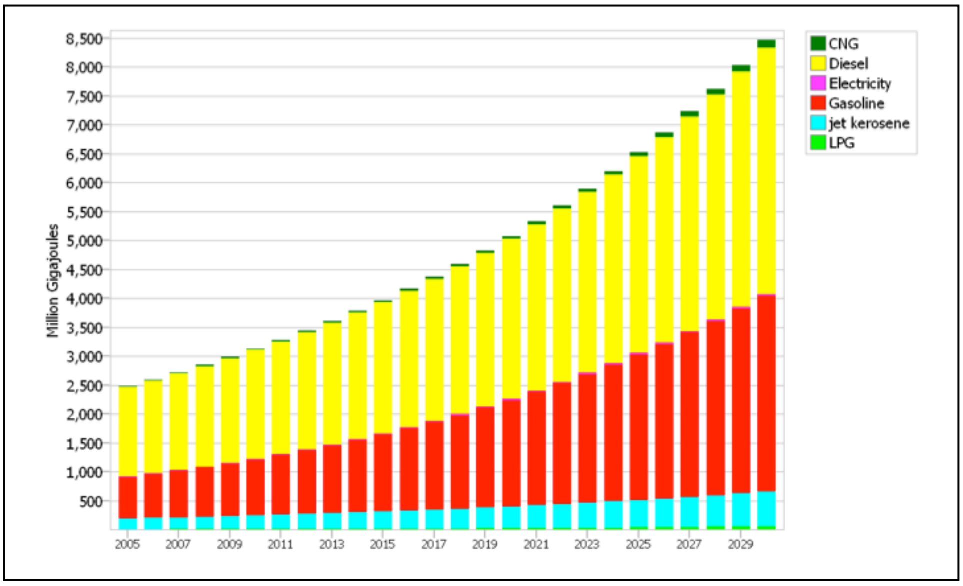


Figure 18. Final Energy Demand (by Fuel) for Transport Sector in the Reference Scenario.

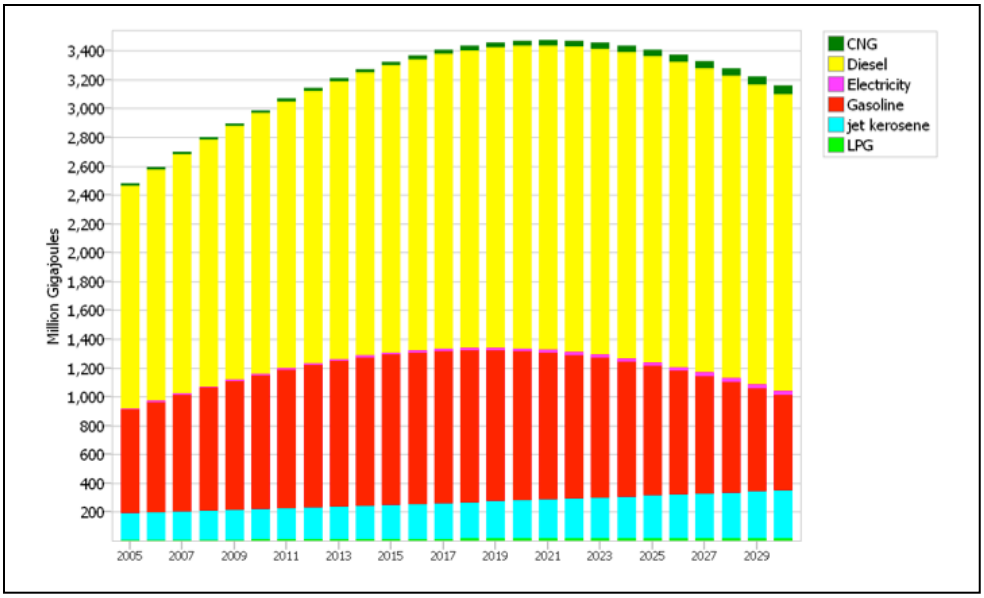


Figure 19. Final Energy Demand (by Fuel) for Transport Sector in the LCIG Scenario.

2. Industry

The industrial sector in India comprises several categories, the largest of which in terms of value added include aluminium, cement, fertilizer, iron and steel, sugar and textiles. In terms of energy use, the dominant industries are iron and steel, cement and fertilizer.

In the Reference scenario, it is assumed that current growth rates in production will roughly remain the same in most industries and that energy efficiency improvements will take place in continuation with current trends (see Figures 20 and 21).

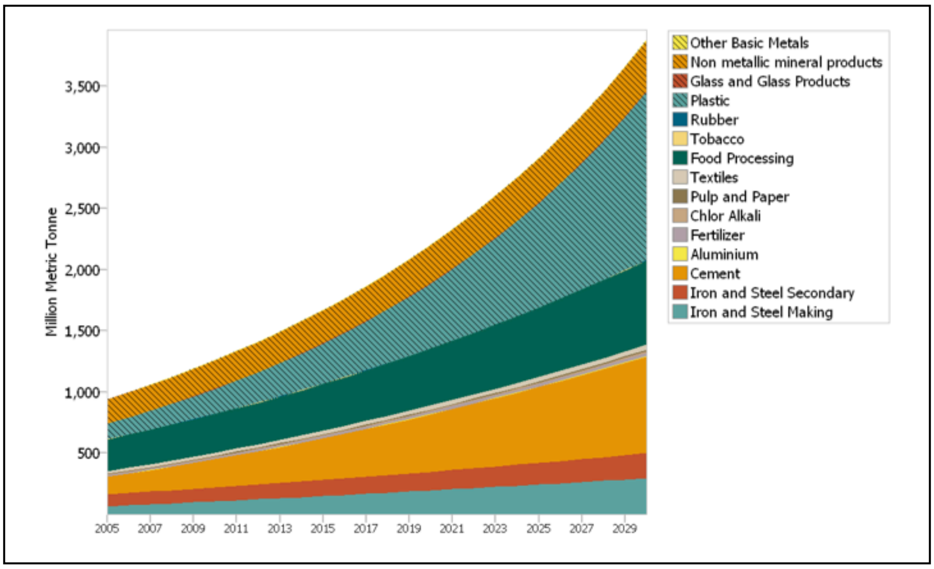


Figure 20. Industrial Production by Category in the Reference Scenario.

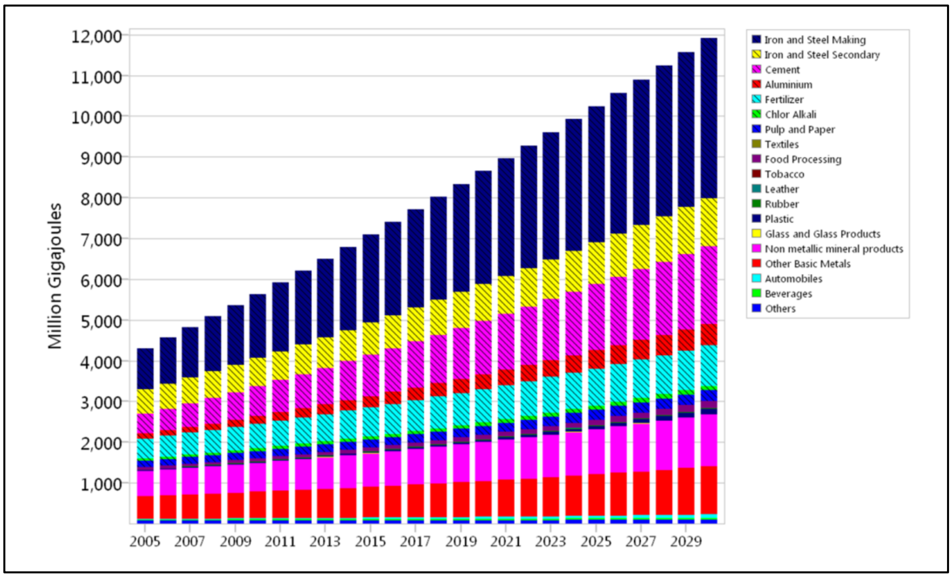


Figure 21. Industrial Energy Demand by Category in the Reference Scenario

In the LC scenario, improvements in energy efficiency by industry take place in a manner that reflects global best practices by about 2015 and further improvements thereafter. For the LCIG scenario is an additional shift towards more modest growth rates in material production itself, reflecting use of less energy-intensive and less material-intensive economic development per se. These reductions are most pronounced in iron and steel production, cement and fertilizer, which also happen to be the largest industrial consumers of energy (Figures 22 and 23).

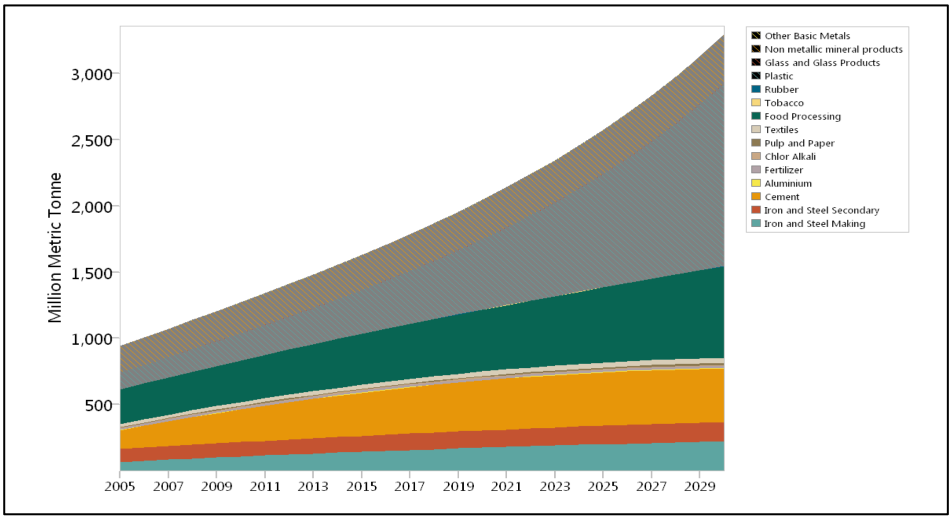


Figure 22. Industrial Production by Category in the LCIG Scenario.

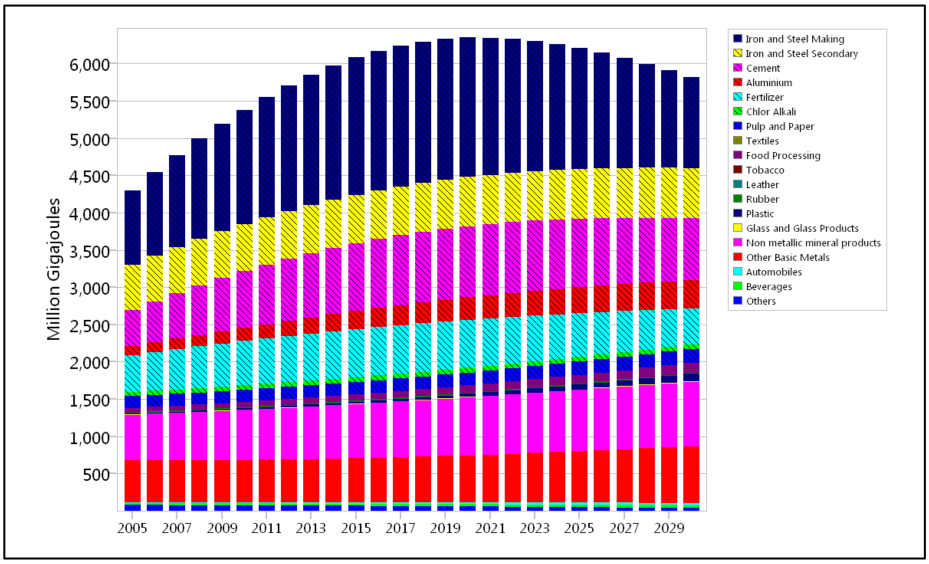


Figure 23. Industrial Energy Demand by Category in the LCIG Scenario.

Figures 24 and 25 show the fuel-wise final energy demand for the Reference and LCIG scenarios respectively.

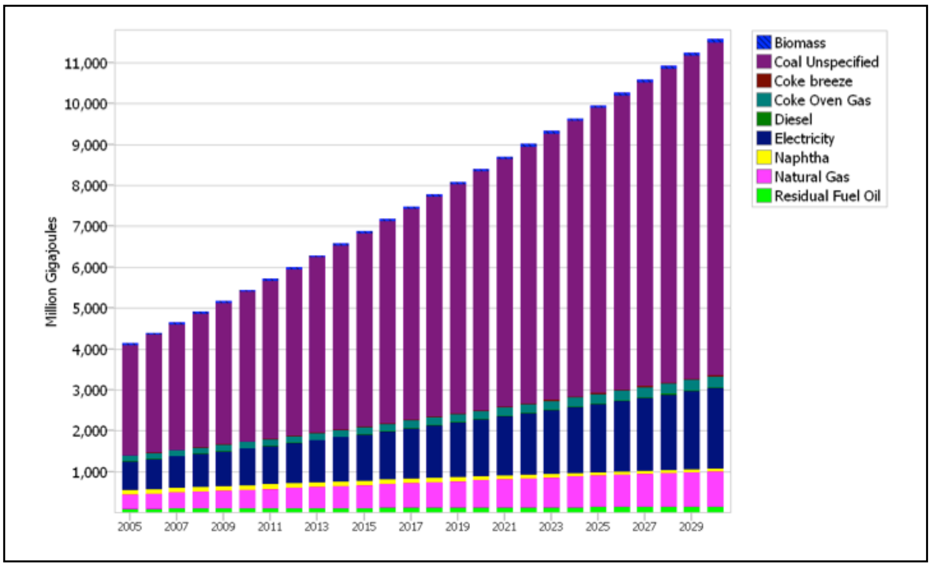


Figure 24. Final Energy Demand (by Fuel) for Industry in the Reference Scenario.

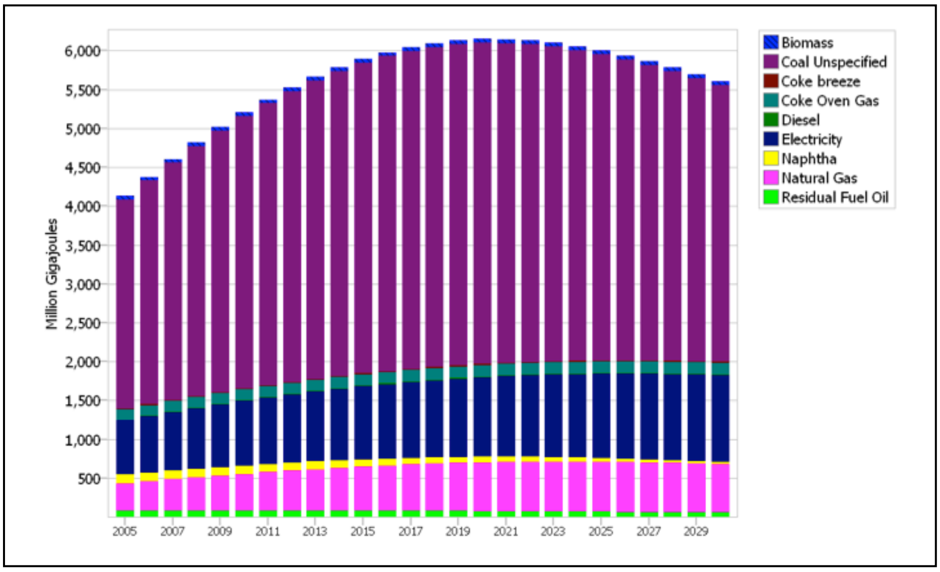


Figure 25. Final Energy Demand (by Fuel) for Industry in the LCIG Scenario.

GHG emissions from industry for the three scenarios are shown in Figure 26. Note the reduction in the LCIG relative to the other two scenarios.

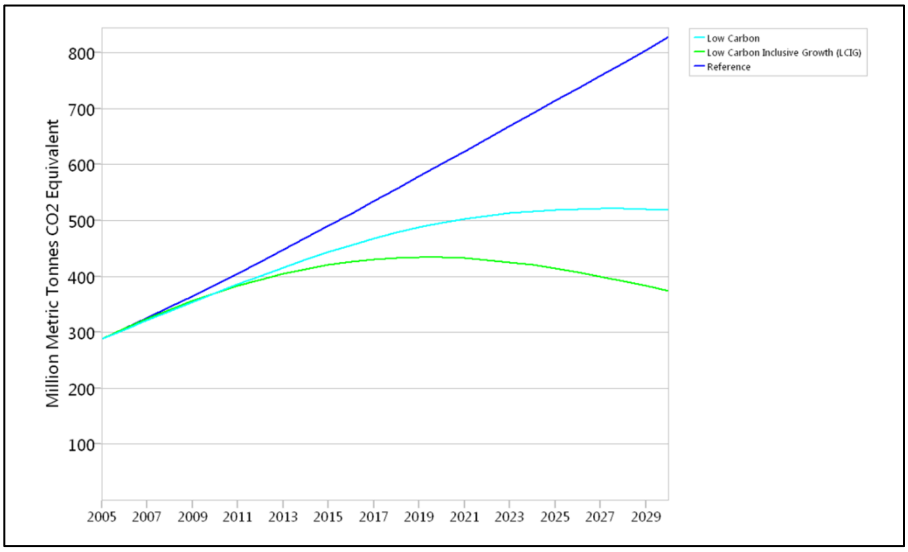


Figure 26. GHG Emissions (Excluding Electricity) from Industry in Three Scenarios

3. Residential

The residential sector is organized in the study in terms of urban and rural households, which are further subdivided into income groups: the lowest 30%, the 30-90%, and the top 10%. Energy use for each of these groups is estimated from activities involving cooking, heating and cooling, lighting, and home appliances, each of which is further subdivided into devices/appliances and fuels. In the Reference scenario, device saturation rates as well as appliance efficiencies follow prevailing trends with little variation. The LC scenario includes some fuel switching to cleaner fuels as well as improvements in appliance efficiency in different segments. The LCIG scenario has an explicit focus on increasing the saturation of modern energy services – primarily cooking and lighting – for those currently without access in the 0-30% income group and above it. This is reflected in Figures 27 and 28 in the way saturation rates for LPG and electricity for cooking change for the urban poor (0-30% income group) in the Reference and LCIG scenarios, respectively. Similar trends are simulated for the rural poor, so that nearly all households are assumed to have electricity, LPG or clean and fuel-efficient biomass cookstoves by 2020. Similarly, for lighting, the LCIG scenario assumes strong growth in penetration of grid electricity and solar power in the poor households (see Figures 29 and 30, for example).

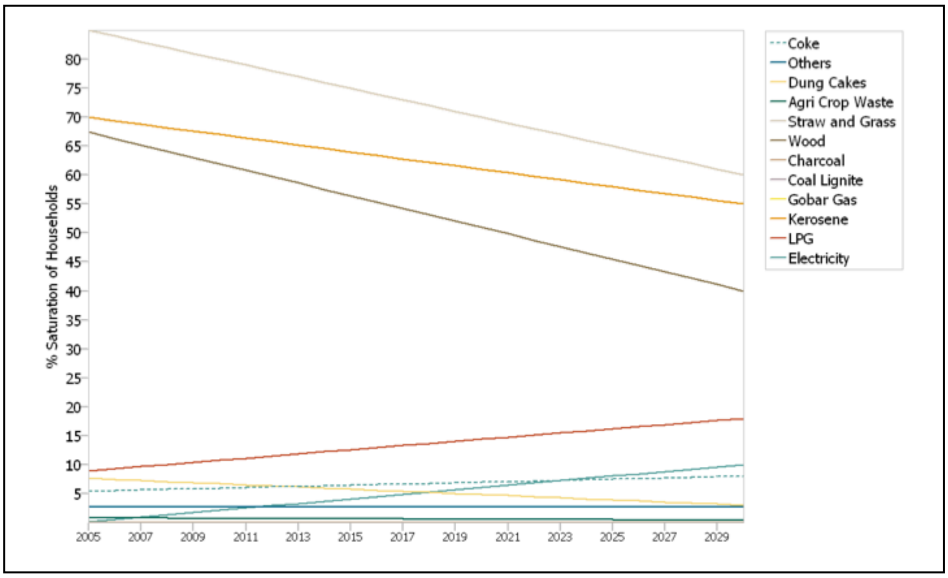


Figure 27. Saturation of Different Cooking Fuels for Lowest 30% Income Urban Households in the Reference Scenario

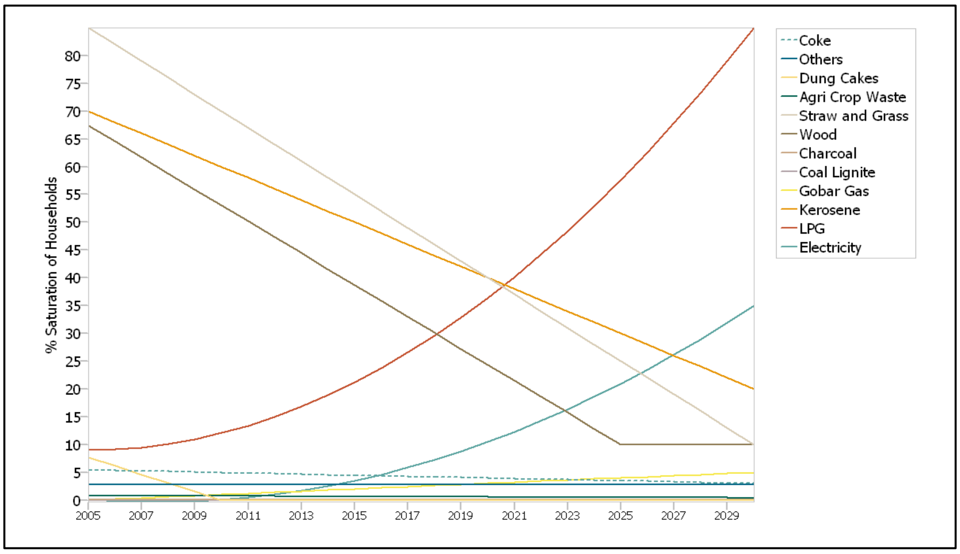


Figure 28. Saturation of Different Cooking Fuels for Lowest 30% Income Urban Households in the LCIG Scenario

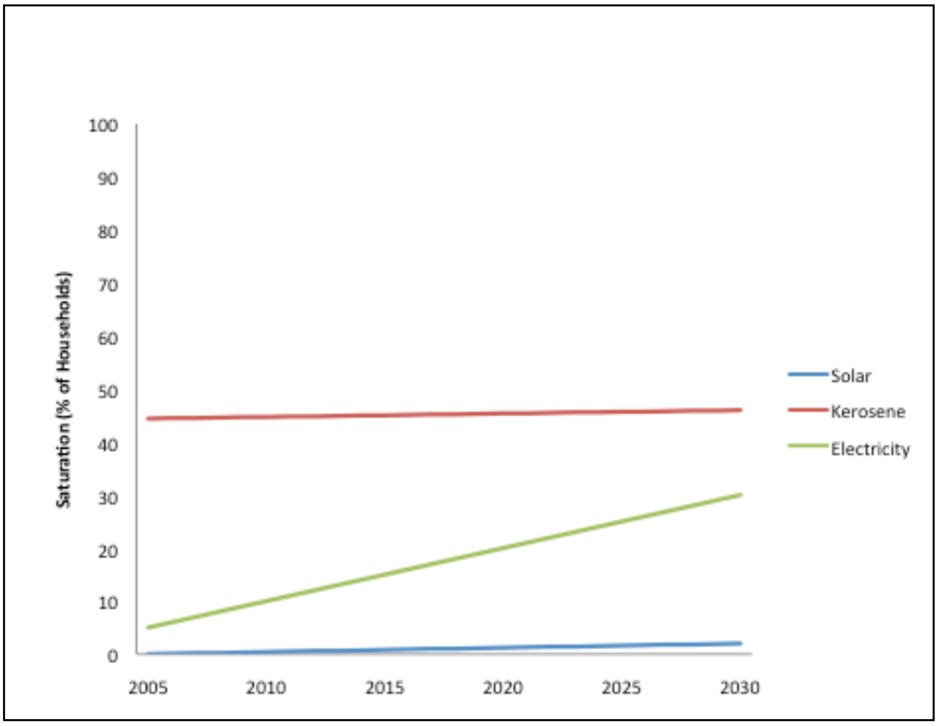


Figure 29. Saturation of Different Lighting Fuels for Lowest 30% Income Rural Households in the Reference Scenario

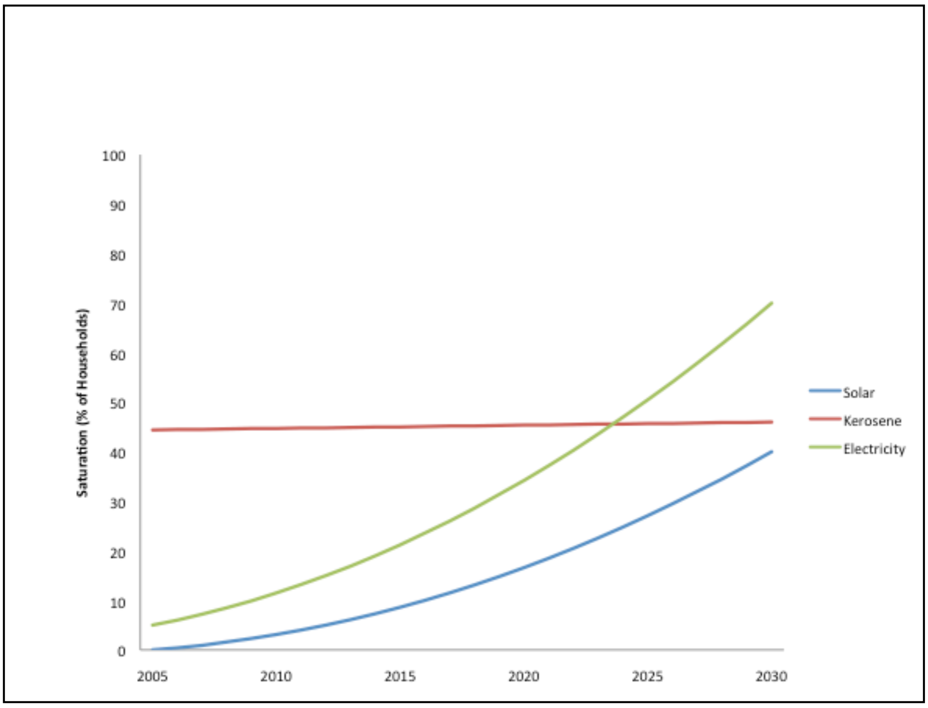


Figure 30. Saturation of Different Lighting Fuels for Lowest 30% Income Rural Households in the LCIG Scenario

Overall, the LCIG scenario will entail an overall *increase* in electricity and LPG, and an increase in GHG emissions overall, relative to the Reference and LC scenarios (Figures 31 and 32). This would be the case even though there are modest *reductions* in electricity use in the top 10%

income category as a result of reduced rates of growth in activity compared to the LC or Reference scenarios.

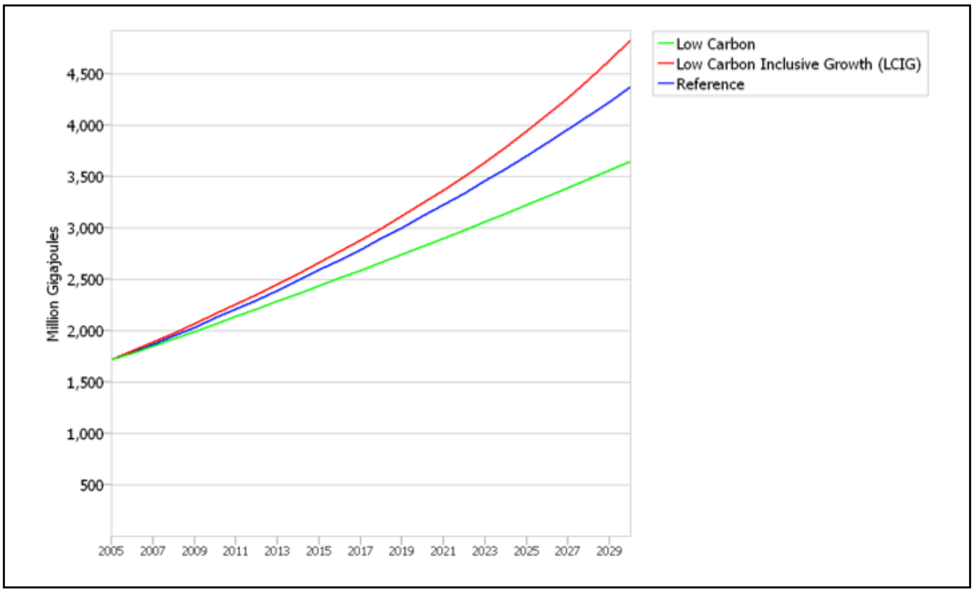


Figure 31. Electricity Demand in the Residential Sector for Three Scenarios.

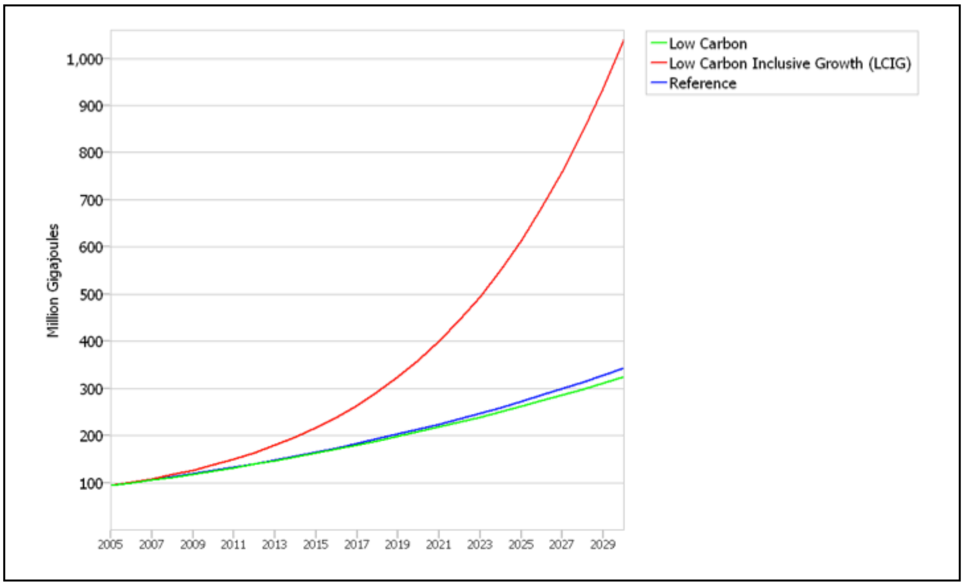


Figure 32. LPG Demand in the Residential Sector for Three Scenarios.

Figures 33 and 34 show the fuel-wise final energy demand in the residential sector in the Reference and LCIG scenarios, respectively.

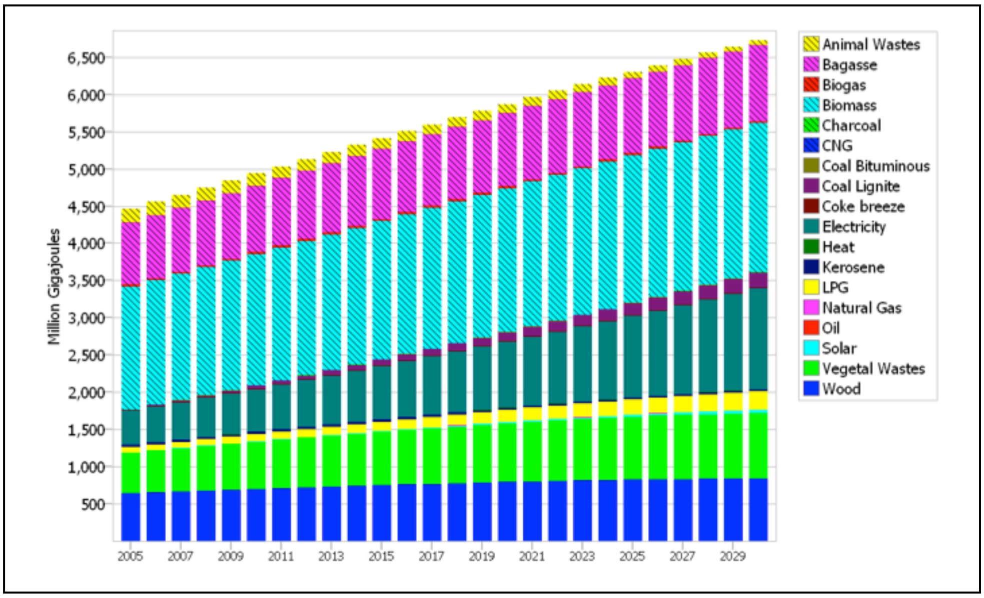


Figure 33. Final Energy Demand (by Fuel) for the Residential Sector in the Reference Scenario.

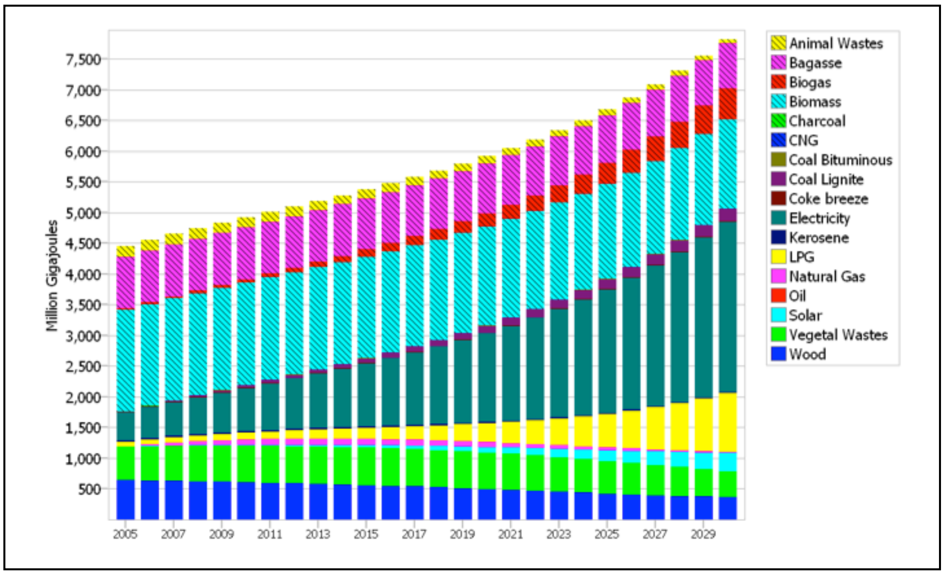


Figure 34. Final Energy Demand (by Fuel) for the Residential Sector in the LCIG Scenario.

4. Farming

Farming contains agriculture, forestry and fisheries, all of which together are expected to grow very modestly (0.3% per year) in acreage till 2030 in the Reference and LC scenarios, and faster (about 1% per year) in the LCIG. In the Reference scenario (Figure 35), energy demand growth is therefore negative, since energy intensity improvements take place at a more rapid rate; for instance, diesel and electric pumps are assumed to, on average, get more efficient at the rate of 0.5% per year.

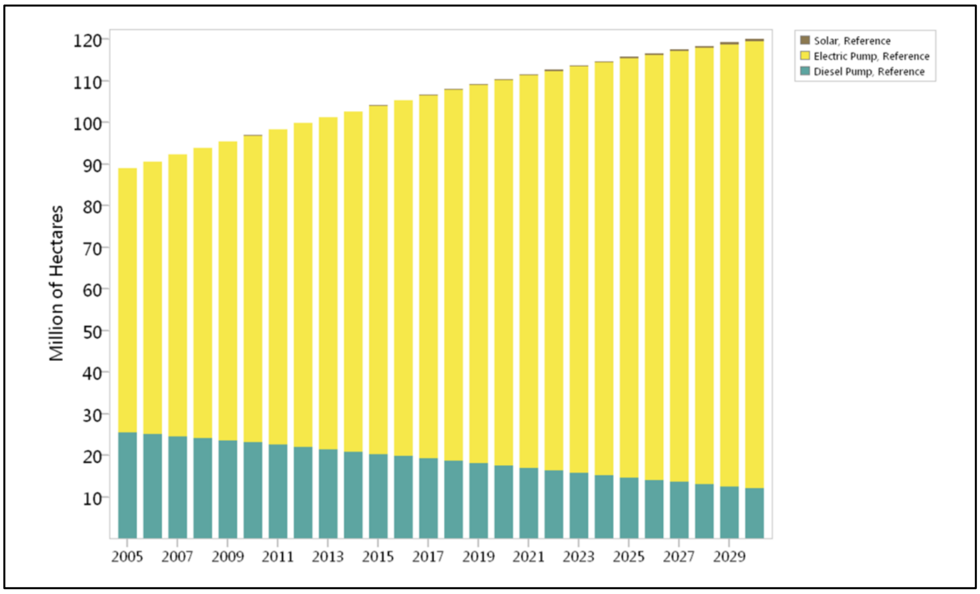


Figure 35. Irrigated Area in the Reference Scenario.

In the LC scenario, the efficiency improvements in irrigated agriculture are twice as fast, with the additional driver for lowering greenhouse gas emissions through the introduction of solar pumps. Solar pumps account for one-fourth of the share of irrigation pumping by 2030, completely replacing diesel and some grid-connected electric. The LCIG scenario (Figure 36) has increased acreage compared with the Reference and LC scenarios, under the expectation that there would be a larger productive labour force entering farming, encouraging a more substantive base of production. Most of the newer farms would be expected to use renewable energy, implying a more significant growth in solar pumps, to about 35% of the share of irrigation pumping in 2030.

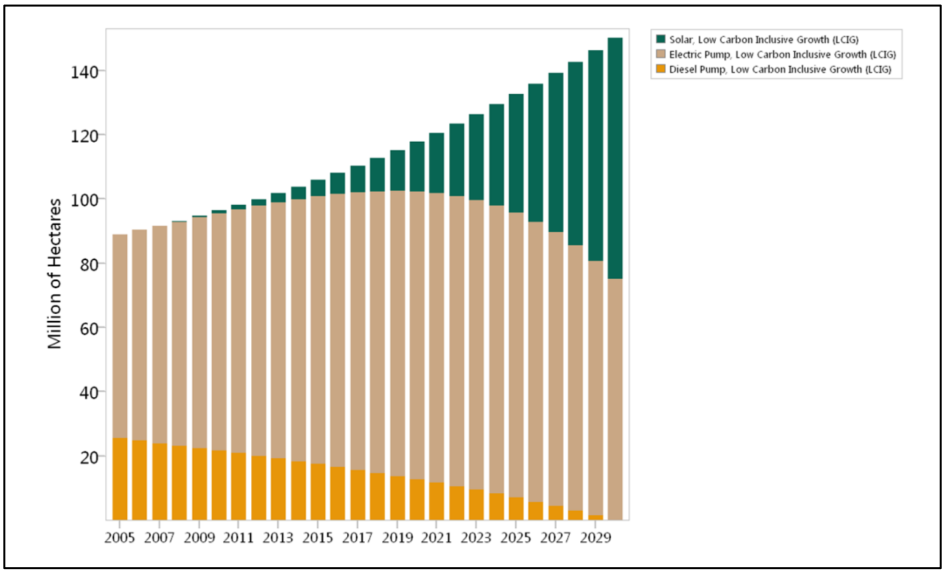


Figure 36. Irrigated Area in the LCIG Scenario.

Figure 37 shows electricity demand in agriculture in the three scenarios.

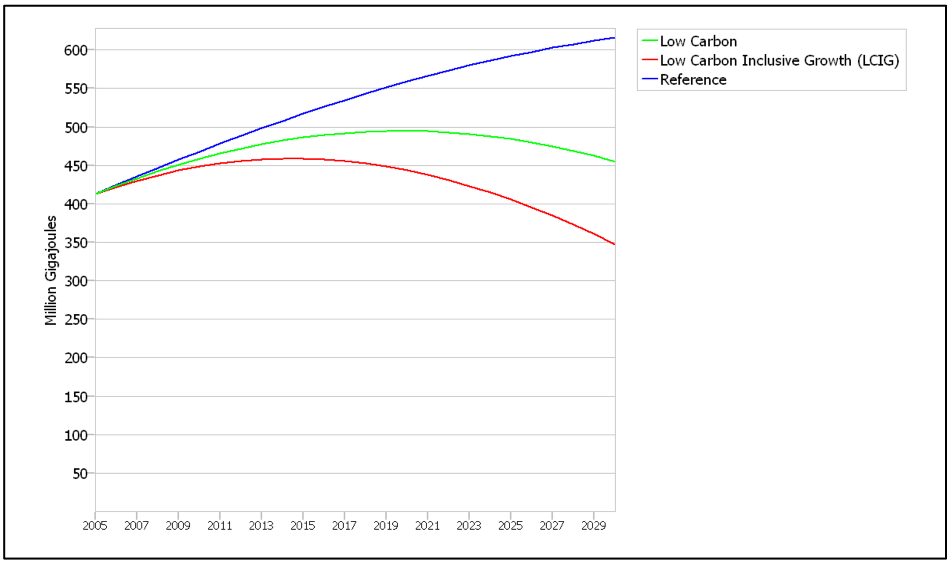


Figure 37. Electricity Demand in Agriculture in 3 Scenarios.

5. Commercial

The Commercial sector comprises Finance and Education, Health, Hospitality, Offices, Trade and Others as categories. Figure 38 shows how these are further broken into other groups.

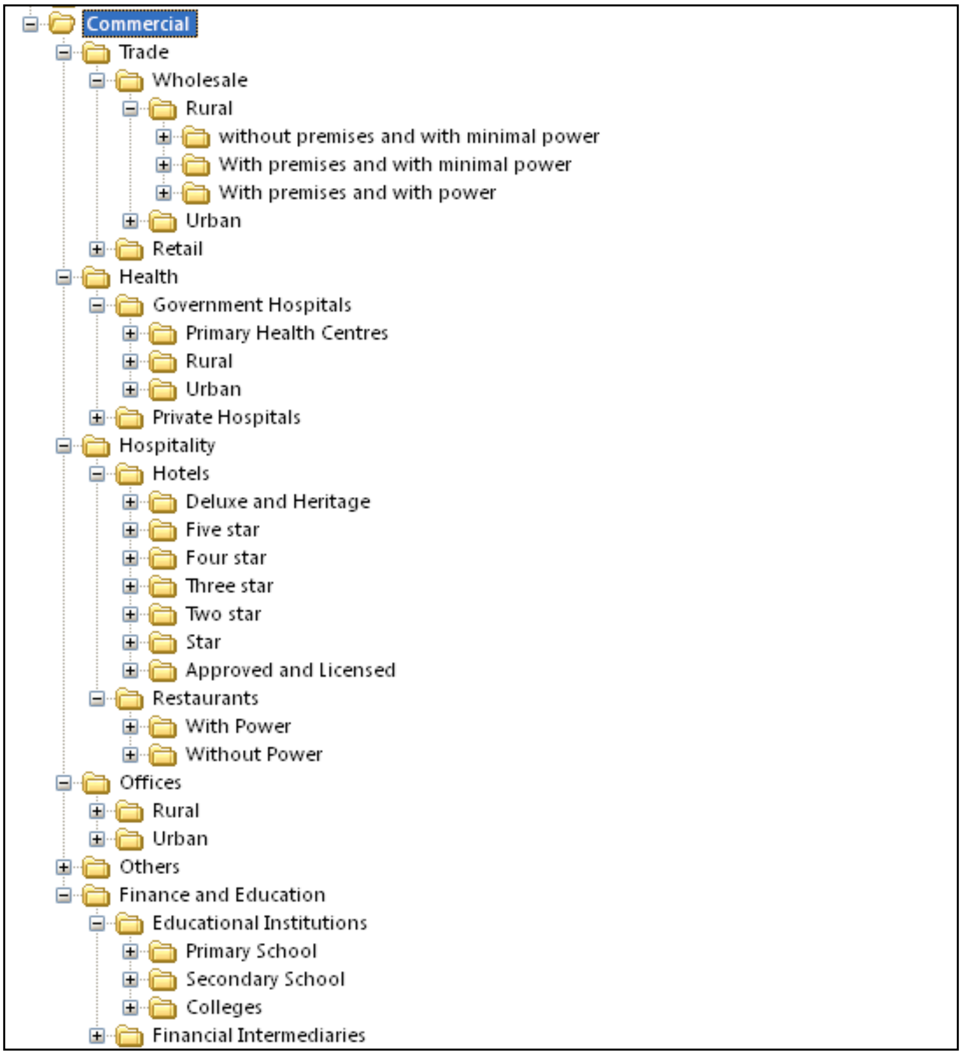


Figure 38. Tree Structure of Commercial Sector in LEAP.

Total commercial activity in the Reference scenario grows at around 3.6% annually. Energy intensity varies across the groups and are either stagnant or drop at relatively low rates (1% per year). In the LC scenario, technological shifts are expected to improve energy efficiency at a slightly faster rate (about 1.5% a year). Part of the difficulty in expecting significant improvements in the Commercial sector has to do with the rapid structural shifts in commercial activity: from mostly informal, low energy establishments to highly modernized ones, albeit typically with higher energy intensities. In the LCIG scenario, more commercial activity accommodating a larger labour force will mean a faster growth rate (about 4% annually – see Figure 39). This will be accompanied by faster structural shifts in some areas to modernize appliances.

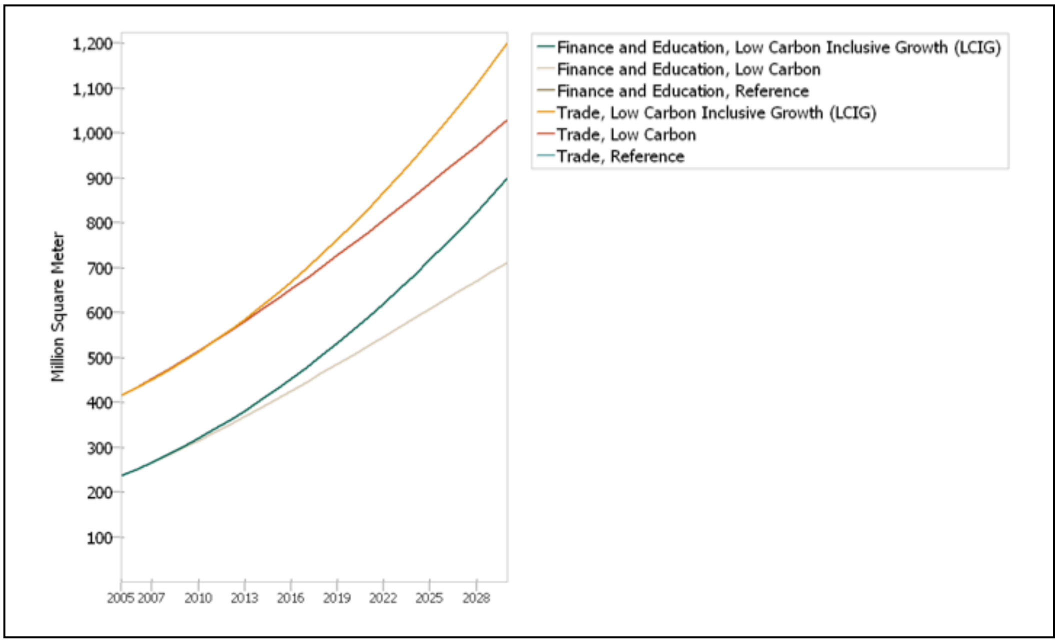


Figure 39. Growth rates in areas of selected Commercial Segments in 3 Scenarios.

Figure 40 shows the total energy demand in the Commercial sector for the three scenarios.

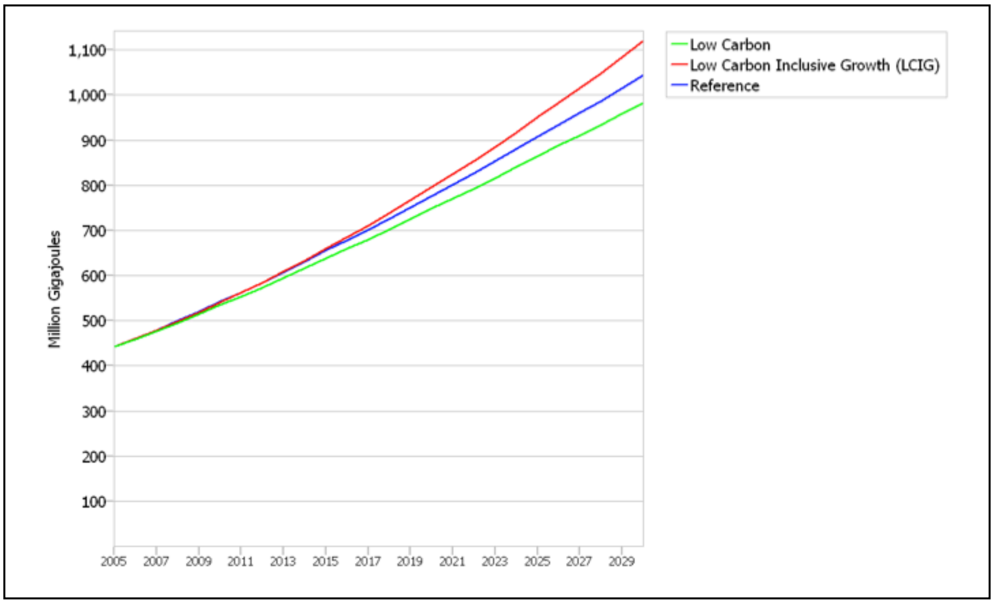


Figure 40. Energy Demand in Commercial Sector in 3 Scenarios.

6. Transformation

The Transformation module in the analysis refers to the conversion of primary energy fuels into final energy carriers, such as electricity, diesel and petrol. In the electricity sector, distribution losses in the Reference scenario is assumed to decline from about 28% in 2005 to 20% in 2030 and to 15% in the LC and LCIG scenarios.

The total final energy demand in the Reference and LCIG scenarios by sector is shown in Figures 41 and 42. The substantial increase in final energy demand in the Residential sector can be attributed to the increased use of electricity and LPG nd in this scenario associated with providing modern energy services to the poor (see Figure 43). The LCIG scenario nevertheless compensates for the increased energy and carbon demand in this sector with reductions in transport and industry as described above.

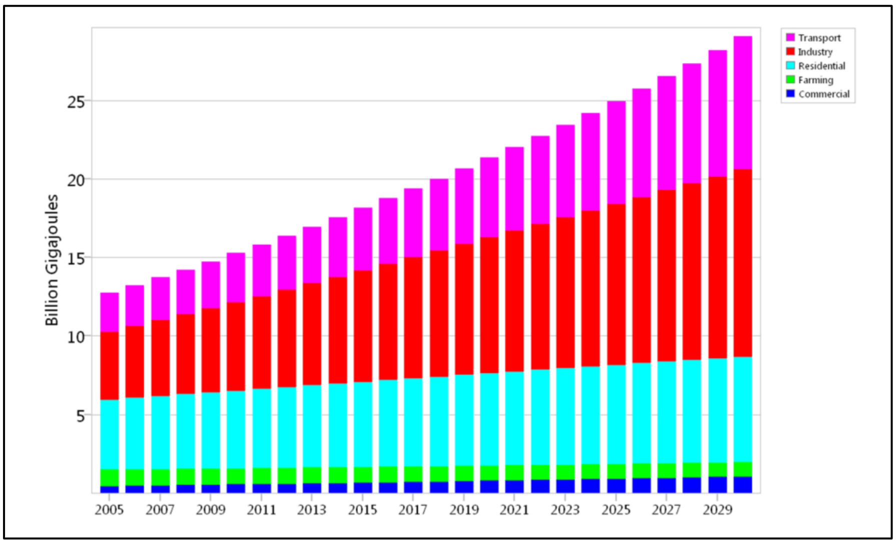


Figure 41. Final Energy Demand by Sector in the Reference Scenario.

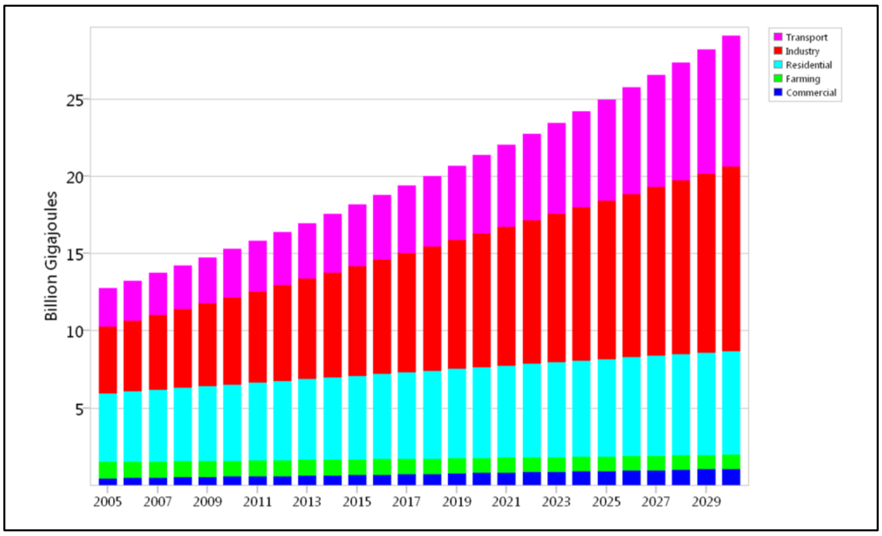


Figure 42. Final Energy Demand by Sector in the LCIG Scenario.

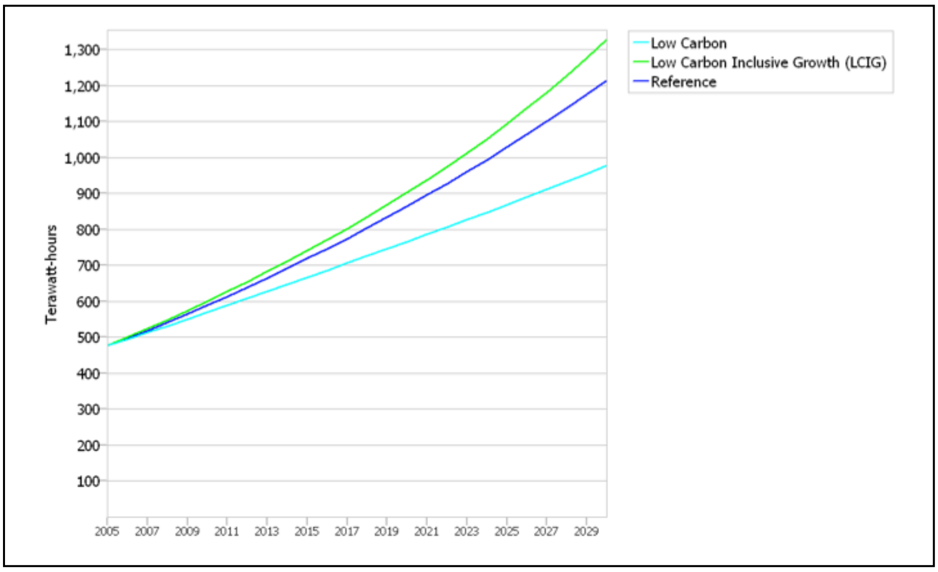


Figure 43. Electricity Demand in the 3 Scenarios.

Capacity requirements in each of the scenarios are computed in terms of the load curve and the dispatch rules that are specified. In the Reference scenario, process shares remain constant but in the LC and LCIG scenarios, the share of renewables, advanced coal and natural gas are allowed to increase significantly by 2030, limited only in by the load curve, which remains constant in all scenarios. Total peak power requirements are shown in Figure 44 for all 3 scenarios. Figures 45 and 46 show the capacity requirements by source for the Reference and LCIG scenarios, respectively. Note how renewables as well as advanced coal are substantial fractions of capacity by 2030 in the LCIG scenario.

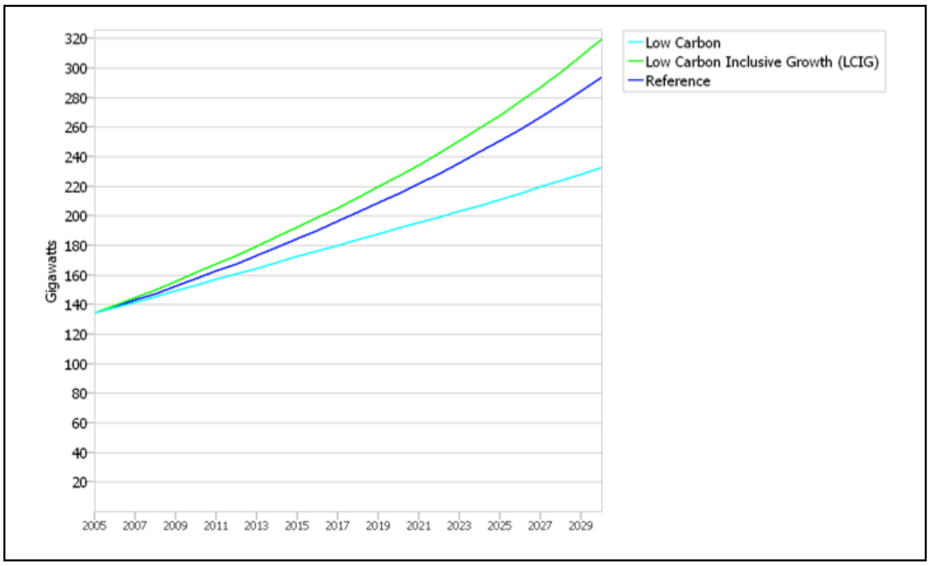


Figure 44. Peak Power Requirements in 3 Scenarios.

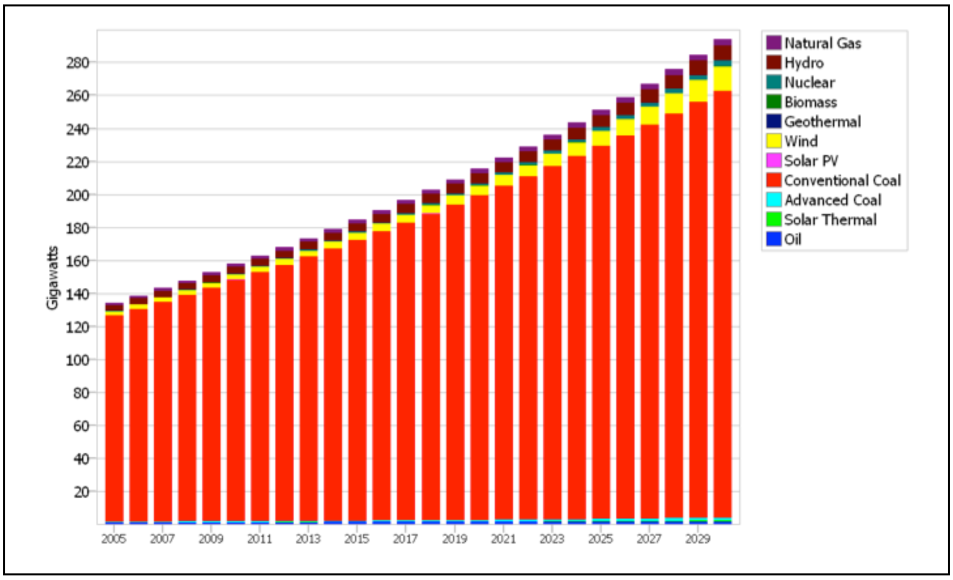


Figure 45. Electricity Capacity Shares in the Reference Scenario.

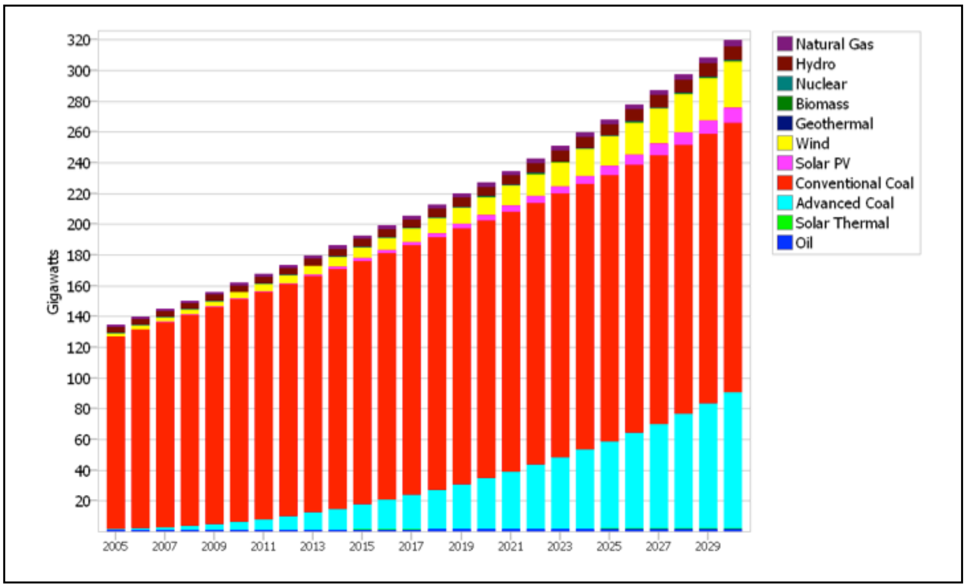


Figure 46. Electricity Capacity Shares in the LCIG Scenario.

Figure 47 shows the GHG emissions from the electricity sector in the 3 scenarios.

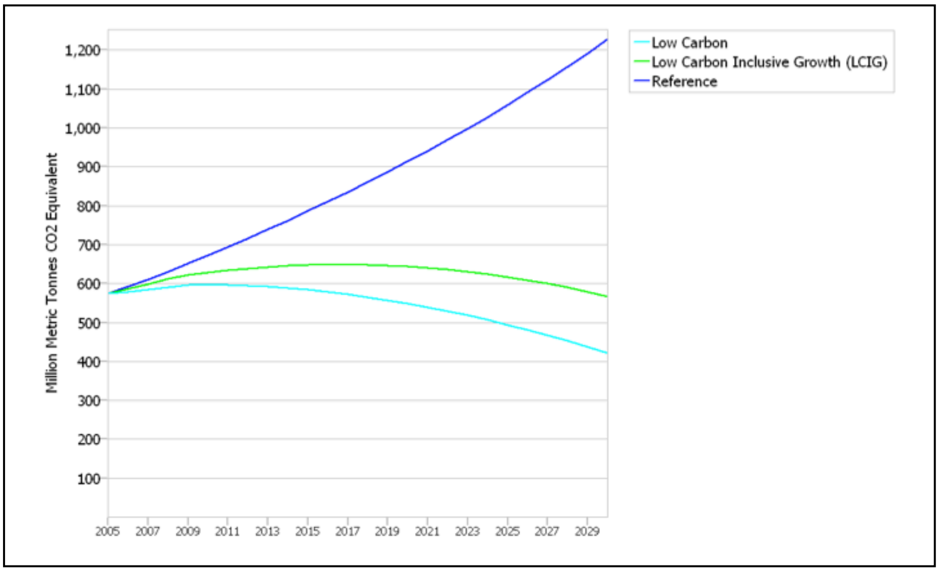


Figure 47. GHG Emissions from the Electricity Sector for 3 Scenarios

7. Energy and GHG Emissions

Final energy demand for the Reference and LCIG scenarios is shown in Figure 48 and 49, respectively. Notice that the increased residential demand is more than compensated for in other sectors, particularly industry and transport.

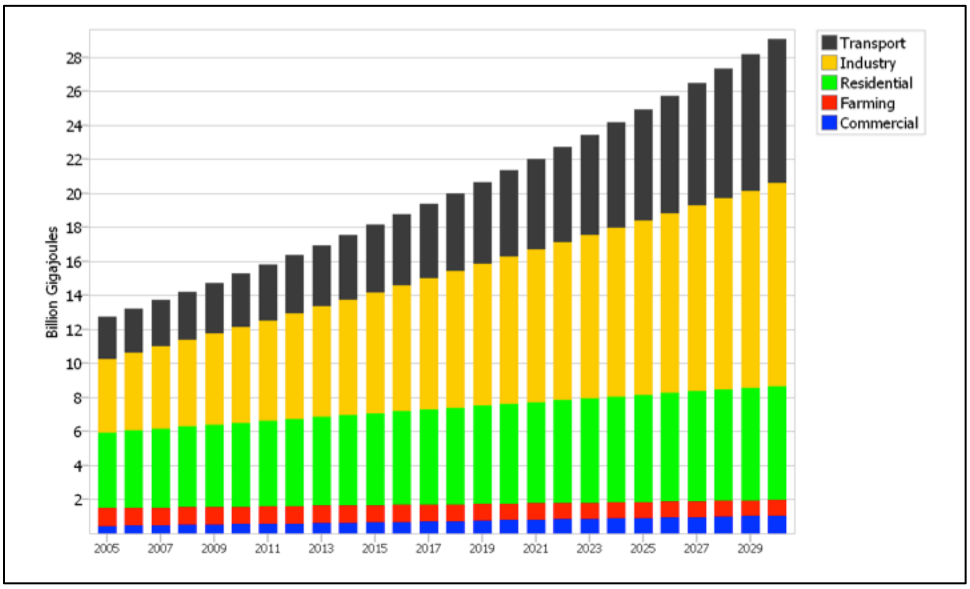


Figure 48. Final Energy Demand in the Reference Scenario

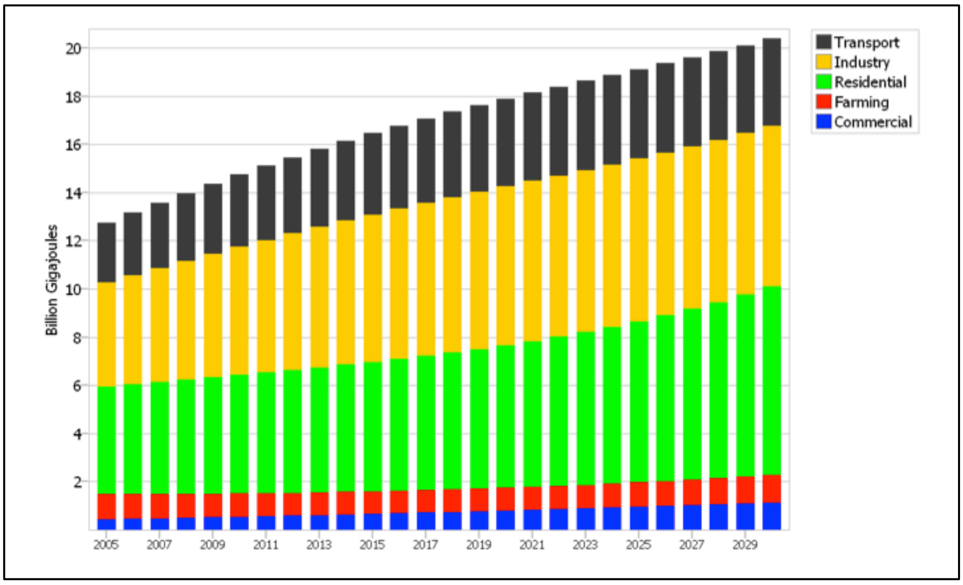


Figure 49. Final Energy Demand in the LCIG Scenario

Primary energy demand in the three scenarios by fuel is shown in Figures 50-52 below. Notice the gradual growth in renewables in the LC and LCIG scenarios which are modest with respect to growth in fossil fuels. That is to say, even the greenhouse constrained scenarios envisage only a modest shift in fuel shares towards renewables, with efficiency playing an equally significant role.

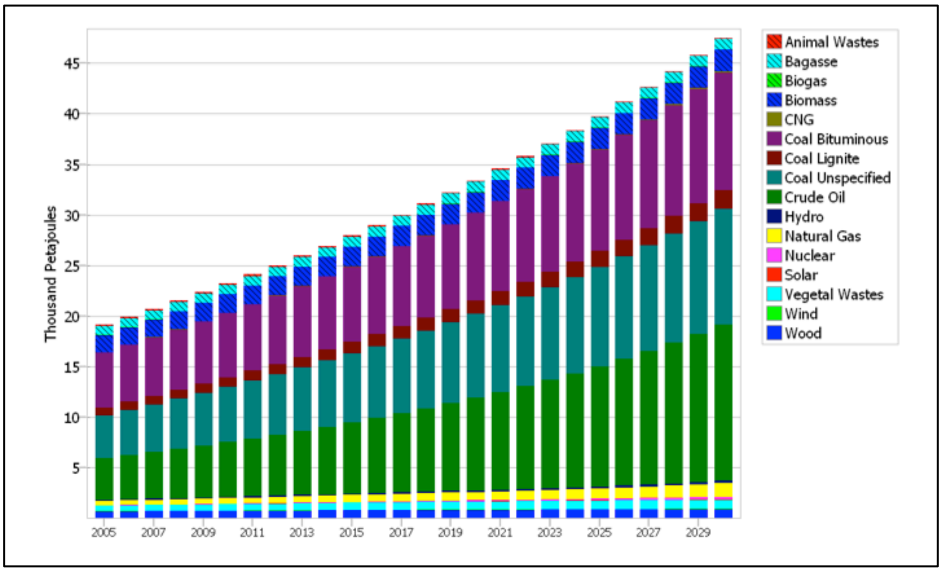


Figure 50. Primary Energy Demand in the Reference Scenario.

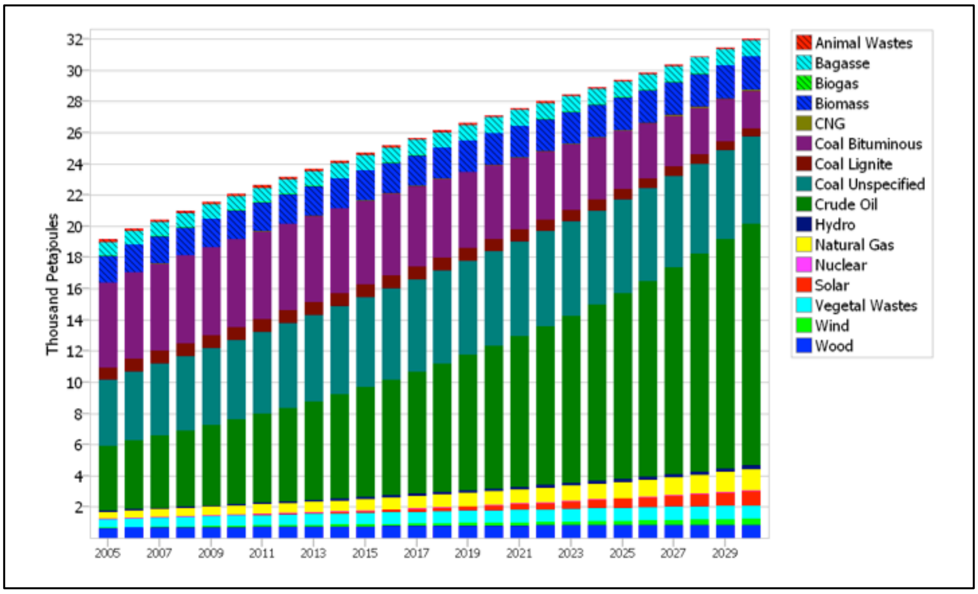


Figure 51. Primary Energy Demand in the LC Scenario.

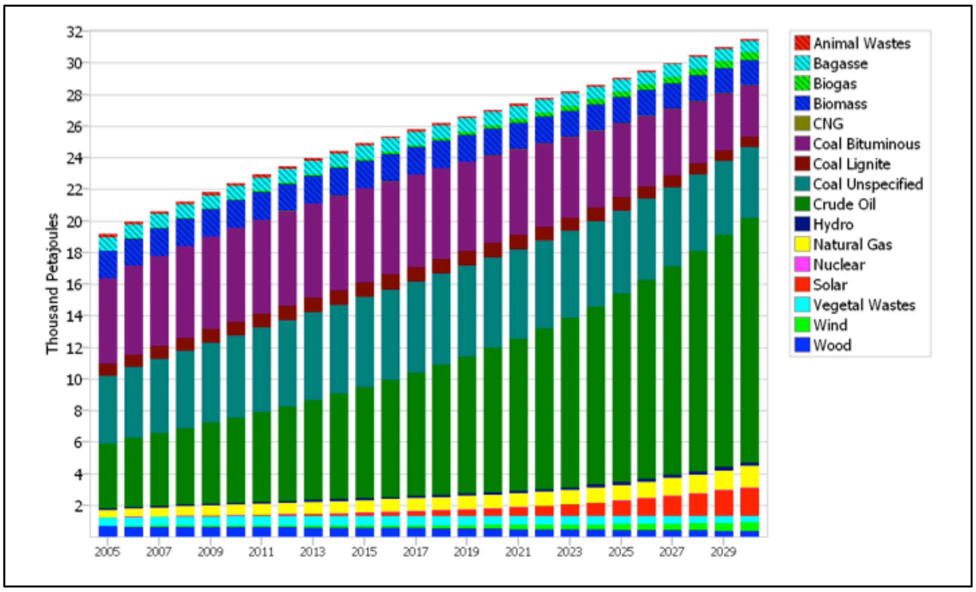


Figure 52. Primary Energy Demand in the LCIG Scenario.

The trajectories of greenhouse gas emissions from all three scenarios are shown in Figure 53. The LC and LCIG scenarios end up with nearly identical carbon reductions by 2030, but have significantly different implications for the poor.

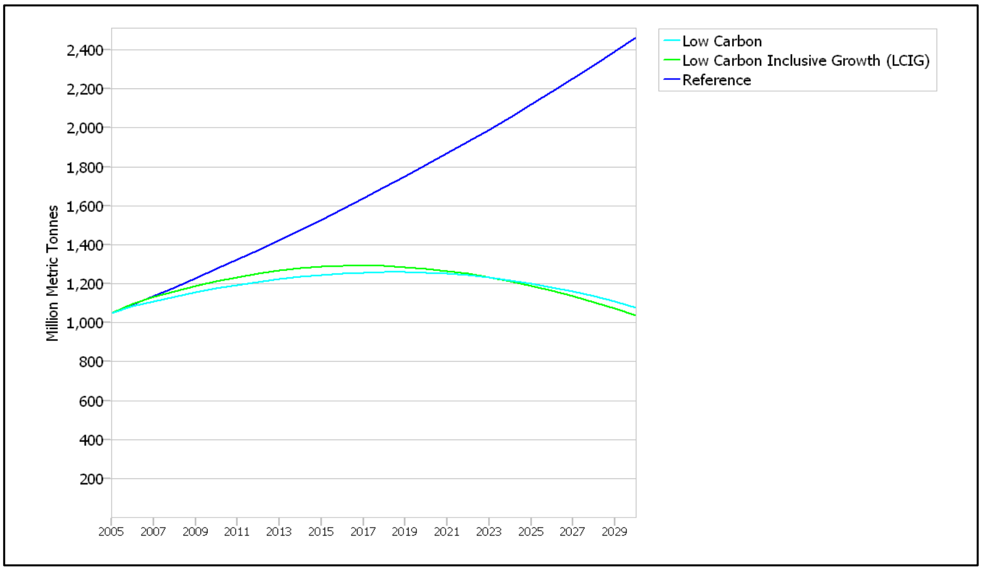


Figure 53. Greenhouse Gas Emissions from Energy Use in 3 Scenarios

V. CONCLUSIONS

This study, using detailed bottom-up scenario-based analysis, has shown that it is possible for India to reduce its greenhouse gas emissions to 2005 levels by 2030 and also provide modern energy services to more than half its population who are currently unserved or under-served in this regard. This would entail having to focus on providing energy services to at least the bottom 50 million or so households by providing LPG or advanced electric cookstoves where feasible, access to electricity for lighting, water, sanitation services, improved access to services in urban areas (involving changes in land-use and transport), improved agricultural services, and so on. At the same time, commitments would be required to improve efficiency across the board and increased penetration of renewable energy in electricity generation and to make efforts to shift transport, housing and industry towards more sustainable models.

Several co-benefits are associated with this strategy. First, a focus on efficiency across all sectors will yield net savings. For instance, Sathaye and Gupta (2010)[3] have estimated the potential for energy efficiency savings for the power sector alone to be in the order of about US$600 billion over about a decade through 2020. It is quite conceivable that the savings could be extended through 2050 and that there are similarly many negative cost efficiency options in the petroleum sector as well. It will not therefore be a stretch to assume benefits of at least 2% of annual GDP from savings through efficiency improvements alone for the next four decades.

Second, investing in low-cost renewable energy options, such as wind, biomass and mini-hydro, and making efforts to disseminate small-scale decentralised solar photovoltaic systems, particularly to areas remote from grid access, will provide tremendous environmental and social co-benefits, including reduced pollution and associated health impacts, improved livelihoods from small-scale manufacturing and services associated with renewable energy industries, and reductions in imports of fossil fuels. The full extent of the scope and scale of non-GHG external costs of energy services from fossil fuels has not been analysed for India, but it may be safe to assume, based on studies carried out elsewhere, that these would amount to close to the private costs especially for coal-based power and petroleum-powered transport. Any investment to replace conventional options with the most appropriate, easy to implement renewable energy options, one might therefore assume, will at worst cause a modest reduction in national income but may generate additional savings, especially if the health impact benefits are significant.

Third is the improvement in income opportunities associated with the provision of energy services for the poor. The availability of modern energy services is a necessary, although not sufficient, condition for improving living standards, education attainment, food security and livelihoods. The improvements in capabilities brought about by these changes will more than likely help add another 100 million or so people into the labour market over the next decade or so, and assuming that other macro-economic conditions prevail to absorb them, one could expect the infusion of substantial economic benefits from having a productive workforce.

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[3] Sathaye, J and A P Gupta (2010): "Eliminating Electricity Deficit through Energy Efficiency in India: An Evaluation of Aggregate Economic and Carbon Benefits". Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California.

Fourth, India could rightfully occupy the moral high ground in the international community by arguing that it is meeting its development objectives and playing a key role (over and above its responsibility) in reducing the risk of global climate change. This implies, moreover, that India could press for recognition of the carbon debt that it, along with other developing countries, have accrued[4]. Under one of the more familiar equity schemes, e.g., historical responsibility and ability to pay, India could claim up to about 200 GtC surplus emissions that could be sold on the international carbon market.

All in all, using a transparent, bottom-up approach to analysing energy demand and supply options in India, this demonstrates that it is possible for India to stabilize its carbon emissions while providing access to modern energy services to its entire population.

[4] Recognising carbon stocks as the basis for equity is in fact the most reasonable ethical framework that India and the rest of the international community ought to claim. See, for instance, Vanderheiden (2008) *Atmospheric Justice*, New Delhi: OUP, pp 143-180.