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WORKING PAPER

India's Energy and Emissions Outlook:

Results from India Energy Model

Energy, Climate Change and Overseas Engagement Division
NITI Aayog

India's Energy and Emissions Outlook: Results from India Energy Model

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India currently ranks as one of the top energy consumers in the world. With India's population and GDP expected to grow in the future, energy demand will see a significant rise and with that associated greenhouse gas (GHG) emissions as well. In keeping with these developments, numerous policy measures are being discussed, which though focused on increasing access to energy, also aim to keep emissions in check.

In this paper, *using a bottom- up energy systems model*, we present a modeling based approach to understand the future development of India's complex energy system and also look at how India's commitments on climate change, as outlined in its Nationally Determined Contribution (NDC), which is a part of the Paris Agreement (UNFCCC, 2015), will affect its future energy and emissions scenarios. By increasing the installed capacity of renewables to 175GW by 2022, India will be able to surpass its NDC target of achieving 40% non-fossil capacity by 2022. With a 45% installed capacity from non-fossil sources by 2030, power sector emissions will consequently decline by 11% (375MtCO_2) from a business-as-usual development, depicted as a baseline scenario, and thermal generation will continue to be the major source of power supply in the country.

This study also found that solar penetration in India is highly cost sensitive. By analyzing alternative renewable energy technology cost developments in the future, we find that a decrease in solar cost by 50% can increase solar penetration by more than eight times as compared to the baseline scenario. This shows that penetration of renewable energy is highly cost elastic in the Indian market and therefore continued policy support to promote RE is essential to achieve the target.

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Acknowledgments

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1. Introduction

India is expected to be one of the fastest growing economies of the world in the near future. With the population anticipated to grow in the future and improvements in socioeconomic developments, energy demand is expected to rise consequently. Considerable progress has been made in improving energy access in the country in the past few years, nevertheless, almost 27 million households (Saubhagya Dashboard, 2018) still do not have access to electricity and 780 million people (IEA, 2017) rely on biomass for cooking. The country faces the trilemma of achieving objectives of higher energy access alongside higher energy security and higher sustainability. While energy security and sustainability are mutually reinforcing as India's energy imports are predominantly fossil based, the goal of accessibility will conflict with the goal of sustainability as long as fossil fuels are the cheapest source of energy (GOI, Draft National Energy Policy, 2017). To ensure that the country achieves a fine balance in attaining these objectives integrated energy planning is extremely important.

Energy modeling can contribute immensely towards integrated energy planning and policy analysis. Energy modeling involves replicating real-world energy systems to create sub-national, national, regional or global models. Once these models are developed, they can be used to create scenarios to display alternative futures with different technologies and fuel supply options It provides an integrated outlook to the energy domain, which is straddled across different sectors—coal, oil, gas, nuclear and renewables.

Among the numerous advantages of energy modeling for domestic policy making, the one that stands out is that it can provide a useful platform to model energy systems as per the requirements of the country and therefore it can provide insights to assist the process of energy and environmental decision making. Often, modeling results of international organizations that supply periodic country analysis are derived from global and regional energy modeling systems, which do not necessarily provide sufficient detail on individual countries (Reddy, D' Sa, Sumithra, & Balachandra, 1995). Data for these studies is sourced from a common pool of international or regional data with assumptions that sometimes do not account for country specific variations. Developing an energy systems model using domestic data can better represent the ground realities. It can also go a long way in better understanding the use of energy systems analysis for policy making as well as facilitate appreciation of results of regional and global energy systems models. Energy systems models can also be used to inform policy on how uncertainties about the future course of some variables could affect the system. Assessment reports of Intergovernmental Panel on Climate Change, (IPCC) assess the impact of a diverse array of risks and uncertainties for informing climate policy using integrated assessment models (IPCC, 2015). Understanding the system's response to uncertainty can improve policy preparedness to handle the effect of uncertainties.

The Planning Commission of India (now NITI Aayog), came out with two notable studies in the direction of energy systems modeling: (1) (GOI, Integrated Energy Policy: Report of the Expert Comittee, 2006) and (2) (GOI, Integrated Energy Policy: Report of the Expert Comittee, 2006). The first study estimated carbon dioxide generation profile of India's energy sector up to 2031-32 using a multi-sectoral, multi period optimizing model. The second study used a macro model with inter-sectoral linkages to develop scenarios of low carbon, inclusive growth to see the effect of low carbon strategies on economic growth. These studies have facilitated energy policy discussions until now but in the recent past significant changes have taken place in the energy policy landscape of India, especially in the field of renewable energy, which have not been included in these studies.

NITI Aayog being the central think tank for the country recognizes that the time is ripe to build in-house energy modeling capability. At present, there is no government institution in India that carries out integrated energy modeling. Government agencies like Central Electricity Authority (CEA), Petroleum Planning and Analysis Cell (PPAC) have engaged in modeling studies, but only for their respective sectors. The inter-disciplinary nature of functioning of NITI Aayog and its role as a think tank places it in an excellent position for developing an energy systems model.

With this background, NITI Aayog set up an energy model for India. In the past year, concerted efforts have been made to develop the first version of this energy model using the MESSAGE*ix* (Huppmann, et al., 2018) platform of International Institute of applied System Analysis (IIASA). IIASA's modeling work has been used for prominent international assessments like World Energy Outlook (WEO), Intergovernmental Panel on Climate Change (IPCC) and Global Energy Assessment (Riahi, et al., 2012). In the coming years, this first version of the India model has the potential to develop into a full-fledged integrated model covering multiple nexus. It can be extended to cover currently modeled sectors, such as the transport and industry sectors, in more detail. It can also be extended to cover pollution, land-use and agriculture or incorporate water requirements, therefore turning it into a full-fledged integrated assessment framework, which will be extremely beneficial for NITI Aayog given its cross-cutting nature of work.

This paper is organized as follows. Objectives of this paper are presented in Section 2. Summary of the methodology, the drivers and assumptions are covered in Section 3 followed by a presentation of results in Section 4. The results along with policy implications are discussed in Section 5 and finally, Section 6 presents the way forward.

2. Objectives

India is home to 18% of the world's population but uses only 6% of the world's primary energy. India's energy consumption has almost doubled since 2000 and the potential for further rapid growth is enormous (IEA, India Energy Outlook, 2015). Per capita final energy consumption in India is very low and there is wide disparity between urban and rural areas. In 2015-16, India's per capita energy and electricity consumption stood at 1075 KWh/year (GOI, Power Sector Executive

Summary, 2015), which was just one third of the world average (IEA, WEO Factsheet, 2015). Nearly 25% of the population does not have access to electricity and a large proportion of the population especially in rural areas rely on non-commercial biomass like firewood for their cooking needs, exacerbating health concerns due to poor air quality (GOI, Draft National Energy Policy, 2017).

In future, India is set to be at the center of the world's energy stage. It is set to contribute more than any other country to the projected rise in global energy demand, around one-quarter of the total. Urbanization will be a key diver of this trend as an additional 315 million people, almost the population of the United States today, are expected to live in India's cities by 2040. This will push up the demand from energy intensive sectors (IEA, India Energy Outlook, 2015)

In addition, climate change will be a major challenge. Few countries in the world are as vulnerable to the effects of climate change as India is with its vast population that is dependent on the growth of its agrarian economy, its expansive coastal areas and the Himalayan region and islands (UNFCCC, 2015). The Government of India is taking significant steps towards adopting clean energy. As a part of its international commitment, India put forward eight Nationally Determined Contributions (NDCs) under the Paris Agreement of UNFCCC (UNFCCC, 2011). Three of the eight NDCs set quantifiable targets to be met by 2030: Goal 3, aims to reduce the emissions intensity of its GDP by 33%-35% from 2005 level, Goal 4, is to have 40% of cumulative electric power installed capacity from non-fossil, and Goal 5, aims to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent.

Given the background of India's current and future energy situation especially in the context of multidimensional targets of the sector, this study would like to investigate the following issues:

a) Assess the impact of renewable energy capacity addition given under the Nationally Determined Contribution (NDC) targets on mid to long term electricity generation in India
b) Examine the emissions reduction potential of India under the NDC targets of renewable energy
c) Assess the penetration of renewable energy technologies under different cost scenarios
d) Assess the penetration of electric vehicle in the market under different cost structures and its emissions reduction potential

3. Methodology

3.1 Key Drivers

Population growth is a strong propeller of energy demand. Population is projected to increase from 1.1 billion to 1.7 billion by 2042 (UN, 2017). India can be expected to overtake China as the world's most populous country by 2025 (UNPD, 2015). Most of this growth in population will be absorbed in cities, resulting in the urbanization rate to increase from 30% to 50% as shown in panel a. of Figure 1. The degree of urbanization in the country will have significant implications on the trend of energy consumption because of increase in demand from industries that use energy for construction and manufacturing.

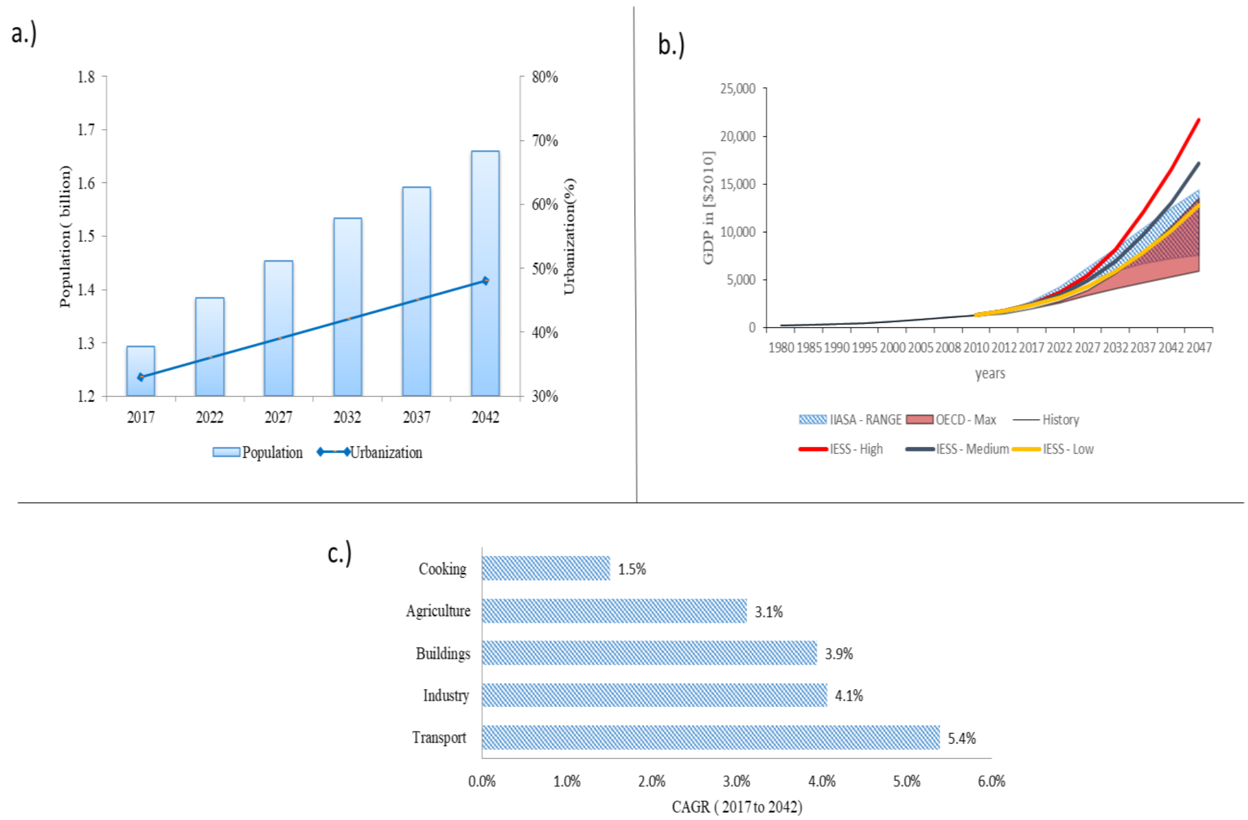

Figure 1: Key drivers and final energy demand. Panel a.) shows the population development trend for India from 2017-2047 in [billion] person as well as the share of urbanization in [%]. Panel b.) shows historic GDP based on World Bank data and ranges for the projected developments based on the Shared Socioeconomic Pathways by OECD and IIASA, along with the three trajectories from IESS. Panel c.) shows the CAGR for different sectors based on the selected GDP development trajectory in [%].

Growth rate of Gross Domestic Product (GDP) is one of the main drivers of energy demand in a country as can be seen in panel b. in Figure 1. Given the uncertainty, associated with projecting the GDP developments for a country, energy systems often model scenarios with different GDP growth rates to show the impacts of different socio-economic developments. NITI Aayog's energy calculator the India Energy Security Scenarios 2047 (GOI, IESS 2047, 2015), for instance, assumes three numbers of Compounded Annual Growth Rate (CAGR) for GDP for the period, 2012 to 2047 — a low growth rate of 5.8%, a medium growth rate of 6.7% and a high growth rate of 7.4%, leading to a GDP of 12.8, 17.1 and 21.7 trillion respectively.

There are numerous discussions on the future growth trajectory of India in both domestic and international literature; there are studies that acknowledge that the above numbers of the Indian government are on a slightly higher side compared to international projections. Paladugula et al (2018) compared the official GDP growth rate numbers with Shared Socioeconomic Pathways (SSP2) of IIASA and OECD. As per IIASA's SSP2, India's GDP growth rate can be expected to decline from 6.9% per year in the 2020s to 3.8% in the 2030s and 2.4% in the 2040s. Similarly, according to OECD's long-term GDP growth forecast, India's GDP growth rate would be less than 5% in the 2030s and less than 4% in the 2040s (Paladugula, et al., 2018). For ease of understanding, this is depicted in panel b. of Figure 1) where the GDP projections of Indian government can be seen alongside international data.

For the purpose of this paper, the GDP growth rate for the India Energy Model was synchronized with Level 2, the default scenario of IESS.

On the demand side, there are five broad demand sectors in the model, industry, agriculture, transport, cooking and buildings. The grouping of end use demand and its sub-parts is shown in the appendix (see Detailed Breakdown of Demand).

Demand for all forms of energy including electricity is determined in the end use sector. The growth trajectory of demand sub- sectors is linked to the growth rate of GDP; it is calculated by using elasticity of the demand sector to GDP growth rate. Based on the assumption of population and GDP growth projections, the five sectors considered in the model grow in the range of 1.5% to 5.4% CAGR, with the transport sector growing the fastest, at 5.4% CAGR between 2017 and 2042, depicted in panel c.) of Figure 1.

3.2 The Energy Model Structure

MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) was developed by the International Institute for Applied Systems Analysis (IIASA) in Austria in 1980s (Schrattenholzer, 1981). Under a special agreement between IIASA and the International Atomic Energy Agency (IAEA), MESSAGE was also used for country studies within the IAEA and its Member States. The MESSAGE model presents a framework for representing an energy system with all its interdependencies from resource endowments and potentials to extraction rates, imports and exports, generation of electricity and conversion of fuels, transportation, transmission and distribution, to conversion of energy for end use demand in the form of heat, light or kinetic energy (Messner & Strubegger, 1995). The model obtains the least-cost solution subject to constraints, to satisfy a given demand level over pre-defined time periods.

India Energy model has been built on the MESSAGE*ix* platform, which is an updated version of the MESSAGE platform. The model includes 100 supply side technologies. In the power sector, the supply system includes a range of options including fossil based plants (sub critical, super critical coal plants and combined cycle gas plants) as well as renewable technologies like solar PV, solar CSP, nuclear power plants, hydropower, biomass plants, as well as onshore and offshore wind. Carbon capture and storage for gas and coal plants has also been modeled. Important input parameters for technologies include economic parameters such as capital, fixed and variable costs as well as technical parameters such as the technical lifetime, plant load factor, conversion efficiencies etc. These are based on IESS data. Costs in IESS are backed by a range of sources based on literature survey as well as consultation with key stakeholders in the government. On comparison with international cost estimates for similar technologies, it was found that some of these costs and their trajectories were higher than what is provided in international assessments like Global Energy Assessment (GEA, 2012). Nevertheless, it was decided to use IESS data for this exercise, given that the IESS data is based on consultation with government ministries. In this respect, one area of future work will be to analyze the difference in costs across technologies in the power sector and arrive at an acceptable range of divergence in cost data.

To reflect the current prices of solar and wind electricity, investment and operation costs of solar and wind are matched to their values as of 2017, and from that we calculated, Levelized Cost of Electricity (LCOE) using technical lifetime, plant load factor and discount factor. For the future cost trajectory, a fixed reduction in cost is assumed. Table 1 gives details of these assumptions.

Solar and Wind Costs based on calculations using the IESS data

Cost components	Solar PV	Wind Onshore
Investment Cost	560 lakh / MW (1043$/ Kw)	619 lakh/ MW (1149 $/Kw)
Fix Cost	11 INR lakh/ MW (20$/ Kw)	10. 4 INR Lakh/ MW (16$/ KW)
LCOE	Rs 2.9/kwh	Rs 2.2/kwh

The modeling framework allows for the explicit modeling of vintage structures of energy infrastructure, therefore allowing issues related to the timing of technology diffusion and substitution to be addressed, also creating capacity inertia in the system for replacing existing facilities with new generation systems. To account for integration concerns of renewable energy technologies specially wind and solar which bring unreliability to the power system due to their variability in supply; we have modeled constraints on renewable capacity factor and renewable potential by adopting a framework developed by Sullivan (Sullivan, Krey, & Riahi, 2013). This approach provides a way to devise reduced-form constraints, that allows variable integration impacts to be quantified.

As the total demand increases, total sectoral energy demand also can be expected to increase, all other factors remaining unchanged. In the end use sector, alternative forms of fuel based technologies compete with each other on relative costs and efficiencies in meeting useful demand, for e.g. oil based vehicles compete with gas based vehicles in meeting transport demand and electric stoves compete with stoves that use gas. CO_2 emission for India specific fuel types are modeled for individual technologies, based on Parikh J et al. (2009) (Parikh, Panda, Ganesh-Kumar, & Singh, 2009).

Data for the recent years is calibrated to data from authorized government sources; data for fossil resources for the year 2017 is taken from Director General of Hydrocarbons (DGH) (GOI, India's Hydrocarbon Outlook, 2017) , data on generation and installed capacity for the year 2017 is taken from Central Electricity Authority (GOI, Annual Generation Review, 2017) . The Appendix to this paper provides the Reference Energy System used in developing this model.

3.3 Scenario Description

Scenario assessments have been used extensively to inform energy and climate policy worldwide. Scenarios can be created with combinations of different types of assumptions, for instance, higher economic growth or higher renewable energy penetration. For this study, we have modeled three types of scenarios as discussed below:

Baseline Scenario

The baseline scenario takes into account energy and climate-related policies of the Government of India, which have already been implemented. It shows a future deemed most achievable by the implementation of current policies and programmes. It assumes gradual improvement in end-use energy management in all sectors as a result of technological improvement. This scenario provides the basis for assessing alternative policy impacts.

NDC Scenario

India submitted its NDC to the UNFCCC in October, 2015 which became a part of the Paris Agreement signed by countries. NDC represents the commitment of each member country to reduce emissions and adapt to climate change (UNFCCC, 2015). As a part of India’s domestic targets towards meeting NDCs, the government has set the target of achieving 175 GW of renewable energy by 2022, with 100 GW coming from solar and 60 GW from wind. These targets could be seen as ambitious until a few years ago, but with the falling costs of solar and wind, along with falling costs of battery storage, they are within reach. The country’s renewable energy capacity has come a long way, solar installed capacity reached 12.28 GW in year 2016-17 as compared to 6.76 GW during the year 2015-16 (GOI, Energy Statistics, 2018).

To this end, the NDC Scenario is an assessment of current NDC target of India in terms of renewable energy utilization. Under this scenario, India meets its target of 40% installed capacity from non-fossil sources by 2030. Increase in installed capacity comes by meeting the national target of 175 GW of renewables capacity by 2022, of which 100 comes from solar and 60 comes from wind.

Sensitivity Analysis

Sensitivity analysis provides a way to model uncertainties, by varying one or more inputs in the model at a time to test how the change/changes in the input/inputs affect any given output in the model. Of course, an energy systems model consists of numerous inputs, future trajectory of several of these inputs could be bound by uncertainty, some related to energy prices like oil, some related to how a certain technology will evolve etc. In this section, we focus on two types of uncertainties, one, which directly effects the supply side of the system, and the other, which affects the demand side of the system. On the supply side, based on recent debates in India's energy and climate change circles, we can gather that costs of renewable technology are highly uncertain. Falling trend in the cost of renewable energy has an important bearing in determining the supply mix of the country. To understand the impact of decline in costs of equipment and subsequent fall in prices of energy generated from renewable sources, we do a sensitivity analysis by changing the cost of solar by varying degrees.

On the demand side, we analyzed the uptake of small electric vehicle to meet passenger transport demand. Electric mobility is one of the priority areas for India. The Government launched the National E-Mobility programme which aims to provide impetus to the entire ecosystem of e-mobility. To understand the uptake of electric vehicle to cost of the vehicle, we do a sensitivity analysis by changing the cost of passenger electric vehicles.

4. Key Findings

4.1 Baseline Assessment

Total Primary Energy Supply

Total primary energy will increase almost 3 times between 2017 and 2042 as can be seen in Figure 2, equivalent to an annual growth rate of approximately 4%. With increased access to modern energy, the share of biomass particularly, non-commercial biomass is expected to decline fast in the coming decades and will get replaced by other sources of modern and commercial energy. Coal will continue to remain predominant among all other commercial sources of energy in India until the foreseeable future because of its cost advantage relative to other energy sources. Moreover, as compared to other fuels like oil and natural gas which are mainly imported due to limited domestic resource availability, coal is available domestically in abundance. Efforts in the direction of reducing oil imports and improving energy security are already underway.

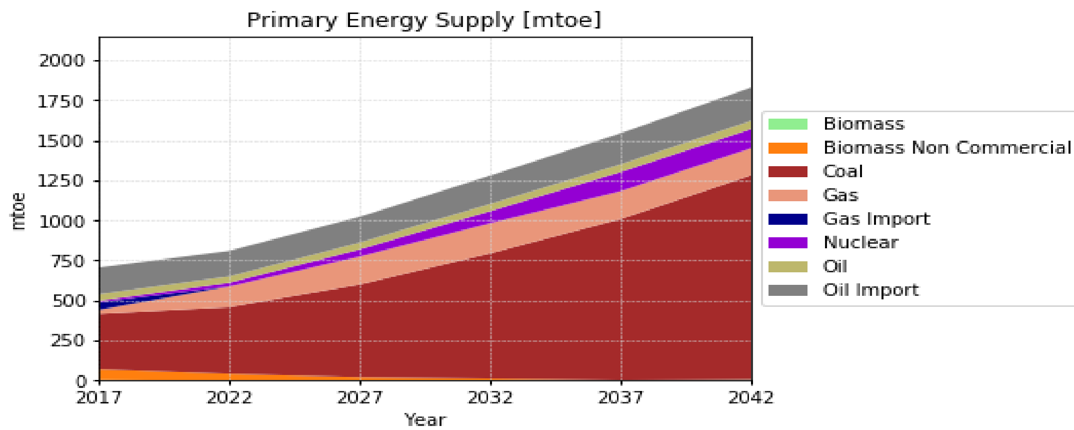

Figure 2: Primary energy mix of India for the baseline scenario in [mtoe]

Total Final Energy Demand

Total final energy demand (see panel a.) Figure 3) will double from almost 600 mtoe to about 1200 mtoe from 2017 to 2042, at the rate of 8% per annum as can be seen in Figure 3. Transport and industry sector account for a major share of total final energy demand, boosted by urbanization. The Make in India initiative and the associated increase in domestic manufacturing will propel demand for raw materials from steel, cement, iron and steel industries among others. The movement of freight across different cities of India to support domestic manufacturing will drive energy demand in the transport sector.

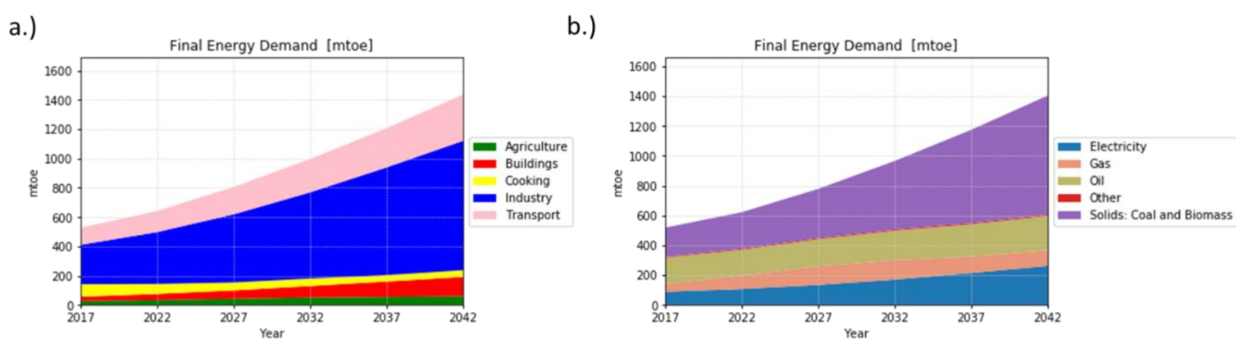

Figure 3: Final energy demand for India in the baseline scenario in [mtoe]. Panel a.) differentiates the final energy demand by fuel. Panel b.) shows the final energy demand by sector.

The use of electricity in final energy will increase steadily implying a movement towards cleaner form of energy. However, in the total fuel mix (see panel b.) of Figure 3), coal and oil will continue to be the dominant source. Increase in the share of coal may be because of increase in coal used for captive power generation by the industrial sector. It is difficult to say how much of coal goes for non-power uses, as at present the model does not differentiate between the use of coal for captive generation and use of coal for other purposes. The increase in oil demand is mainly due to demand from the transport sector — in particular, the freight sector. The share of gas picks up only marginally in the total fuel mix in the baseline scenario.

In the total final energy mix, there is gradual transition towards cleaner and modern form of energy. Although the share of electricity in the final energy mix remains more or less the same at around 20% as can be seen in panel a. Figure 4, in absolute terms the use of electricity increases three times compared to the 2017 level.

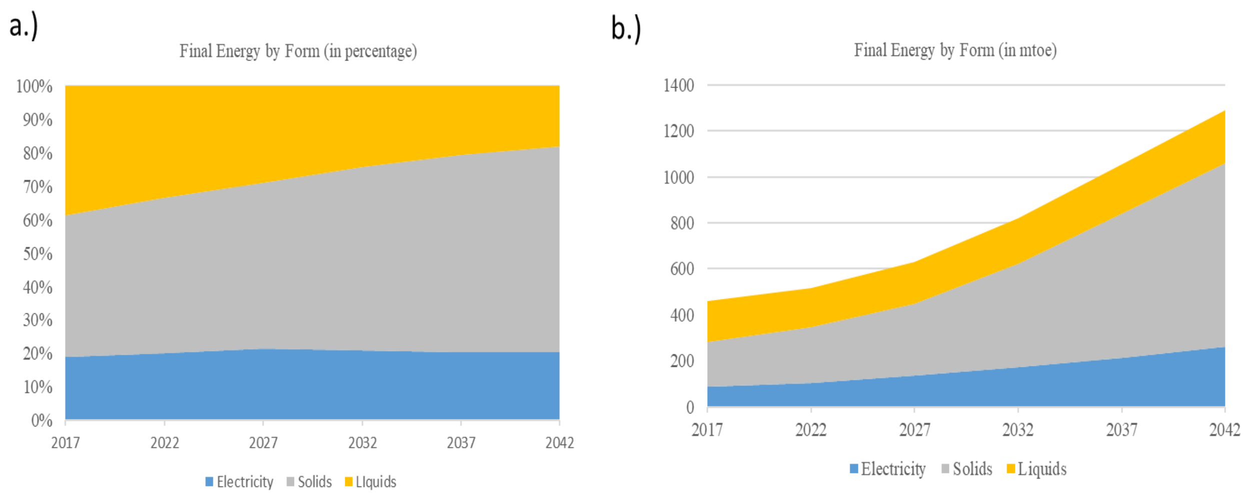

Figure 4: Final energy demand by form in the baseline scenario Panel a.) shows the share of electricity in the total final energy in percentage terms. Panel b) shows the final energy demand by form in absolute terms.

Buildings drive the consumption of electricity. The increase in demand from buildings is due to increased demand and not due to fuel substitution. The non-substitutable demand for electricity from the buildings sector can be expected to increase significantly as appliance ownership rises with higher standard of living. One reason for increase in demand for electricity in the buildings sector could be the rapid increase in the demand for air cooling. In hot countries like India, the demand for cooling can be expected to increase significantly with rising incomes. There are studies that confirm this trend for India and for other countries with long summer months (Phadke, Abhyankar, & Shah, 2014). Lion's share of the projected growth in energy use for space cooling by 2050 can be expected to come from the emerging economies, with just three countries – India, China and Indonesia – contributing half of global cooling energy demand growth (IEA, 2018).

Sectoral Final Energy Demand

The major consumer of final energy is the industry sector. Within this sector, demand for energy is driven by thermal uses, which is met mainly by coal. As explained earlier, captive power generation for industry sector is covered under coal consumption and therefore, significant growth in coal consumption by the industry sector is observed. Under the baseline scenario, gas consumption by the industry sector gradually decreases, due to lack of domestic gas supply in the market. However, electricity continues to grow in the overall supply mix of the industry sector.

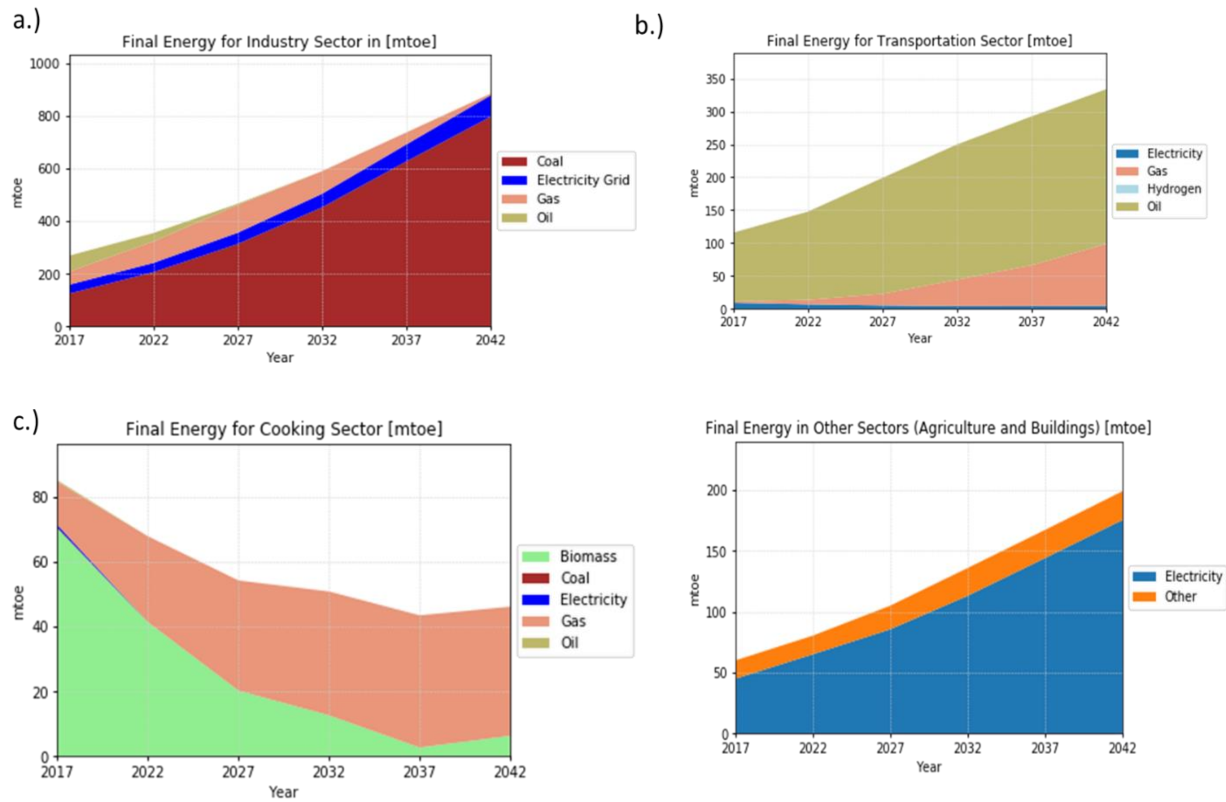

Figure 5: Sector specific final energy demand for India in the baseline scenario in [mtoe] for the industry sector depicted in panel a.) for the transport sector in panel b.), the cooking sector in panel c.) and the remaining sectors aggregated in panel d.)

The second largest final energy consumer in India is the burgeoning transport sector of the country. Oil will continue to be the preferred choice of fuel in the transport sector but a gradual increase in gas can be expected. The increase in gas is driven by demand for gas in the small vehicle segment which includes cars, taxis and three-wheelers. The total transport demand can be expected to increase three times, by 4% per annum, irrespective of continuous improvement in vehicular fuel efficiency.

In the cooking sector, energy consumption comes down significantly. This is mainly due to efficiency improvement, as a result of less use of non-commercial biomass, which has an extremely low conversion efficiency of, just 13%. Hence, the overall efficiency of the cooking sector improves and energy consumption decreases despite rising population. The use of electric stoves continues to be negligible in the baseline scenario as they are costly relative to other options. The share of gas gradually increases, this could be due to improved access in urban and rural areas, a result of existing government policies. The decrease in dirty fuels like non-commercial biomass and cleaner fuels like gas will have a positive impact on the emission reduction potential of the country.

Electricity Generation

Given the scale of demand in the country and availability of low cost coal, coal will remain be the primary source of electricity followed by other cost-effective sources like hydro, gas, nuclear and renewable energy. In usage of coal for power generation, however a gradual transition towards clean coal technologies like super critical and ultra-super critical power plants could be seen. This is reflected in the diminishing coal capacity in the near term, despite increasing levels of electricity from coal. As far as solar and wind capacity is concerned, without any significant improvement in cost, capacity addition of these renewables in baseline scenario is limited. This is reflected in the renewable share of total electricity generation, as without improvement in technical efficiency capacity addition in solar and wind translates into a lesser than proportionate increase in generation from these sources.

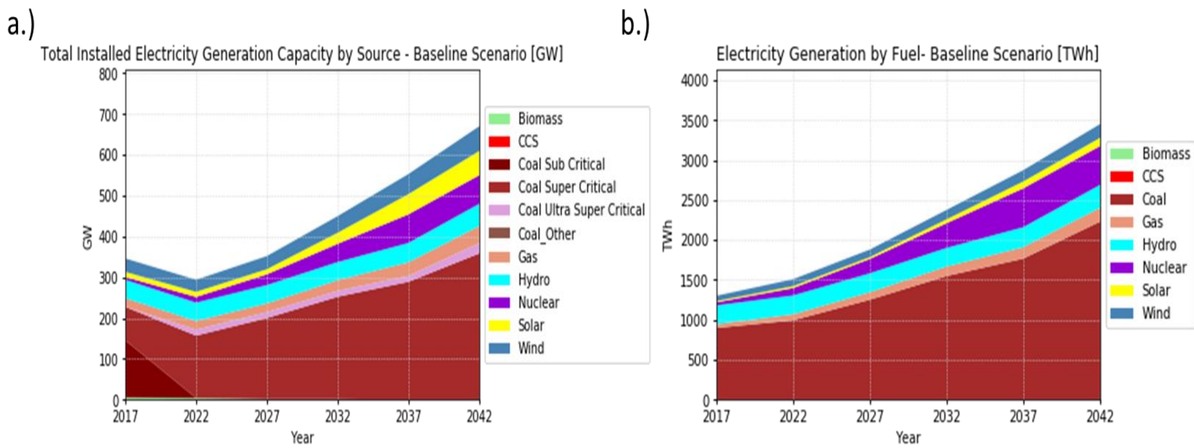

Figure 6: Electricity generation and capacity for India in the baseline scenario Panel a.) shows total installed capacity in [GW] and panel b.) shows electricity generation by fuel in [TWh]

4.2 NDC Scenario Assessment

In this section, we study the impact of NDC scenario as explained in section 3.3.

Installed Capacity and Generation

By achieving its targets for increasing renewable capacity as per the NDC commitments, India can increase the share of renewables in power generation to 22% in 2032 as compared to almost 16% in the baseline, seen in the Figure 7. In this scenario, the share of non-fossil sources in installed capacity is 45% in 2030, as compared to 35% in the baseline scenario.

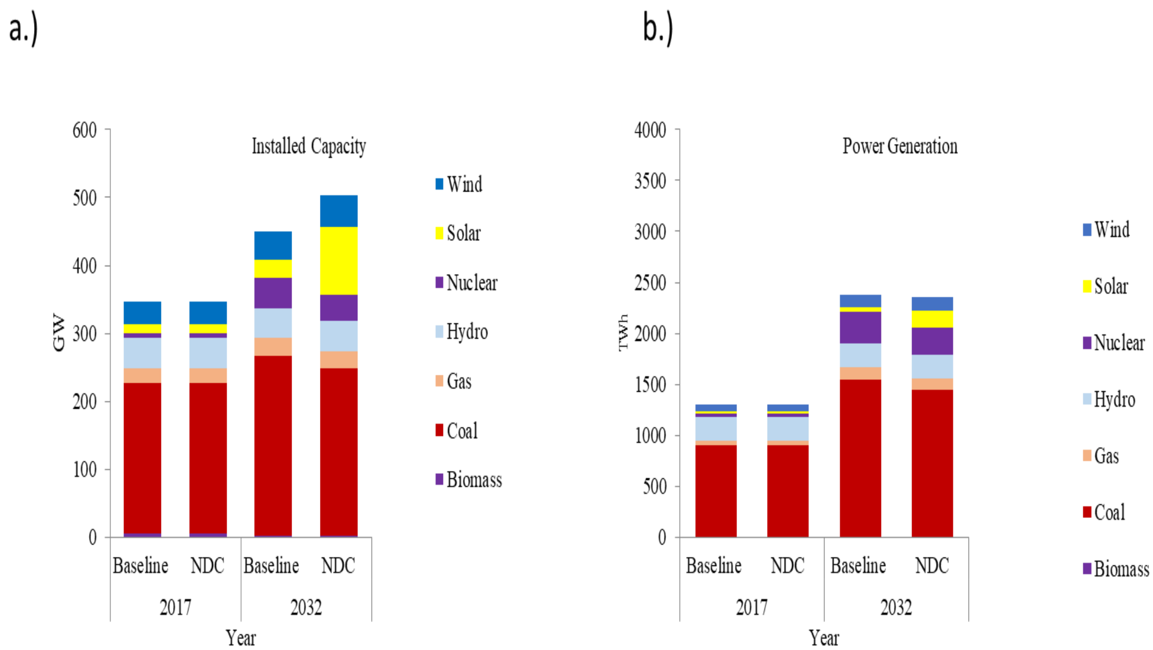

Figure 7: Assessment of NDC scenario and baseline. Panel a.) shows total installed capacity in [GW] and panel b.) shows electricity generation by fuel in [TWh].

Emissions

As a result of this transition to clean energy, cumulative CO_2 emissions from the power sector will reduce by 375Mt CO_2 under the NDC scenario in 2032, an 11% decrease compared to the baseline. This can be seen from blue and dotted blue line in Figure 8. The impact of NDC is lesser on the total emissions, which decrease by only 5% in the NDC scenario compared to the baseline.

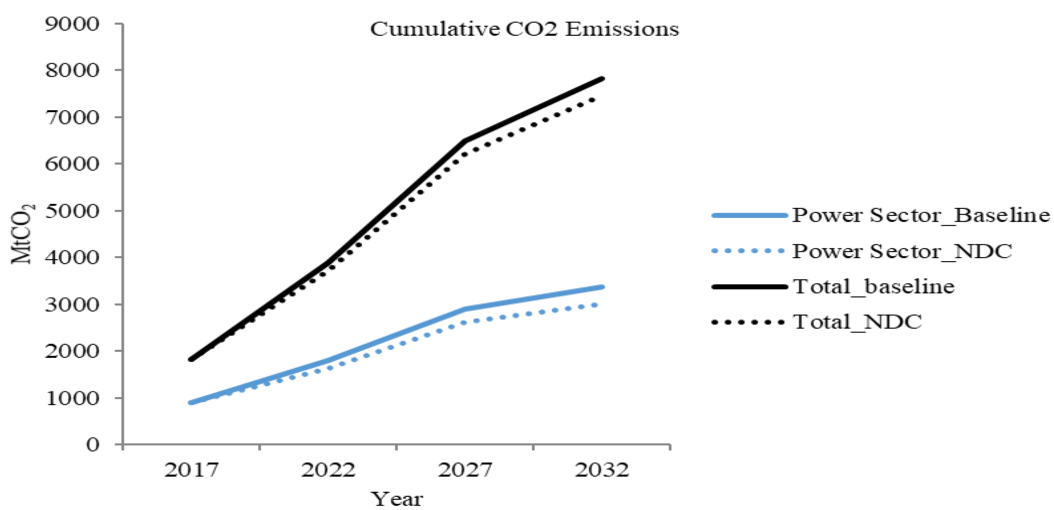

Figure 8:Cumulative CO2 emissions for India for the baseline and NDC scenario in [MtCO2]

It can be seen that despite emissions decreasing in the NDC scenarios compared to the baseline, in absolute terms they continue to grow.

Due to increases in the share of non-fossil installed capacity, (to be able to meet the national target of 175 GW by 2022), emissions intensity improves significantly—falling by 41% in the NDC scenario by 2032, relative to 2017 level and 80% compared to 2005 level as mentioned in India's First Biennial Update Report to the United Nations Framework (GOI, First Biennial Update Report to the United Nations Framework Convention on Climate Change, 2015). However, the decline is slow, as it gets dampened due to cumulative increase in absolute emissions (Figure 9). This implies that deeper decarbonisation is required to slow down the growth of total CO_2 emissions.

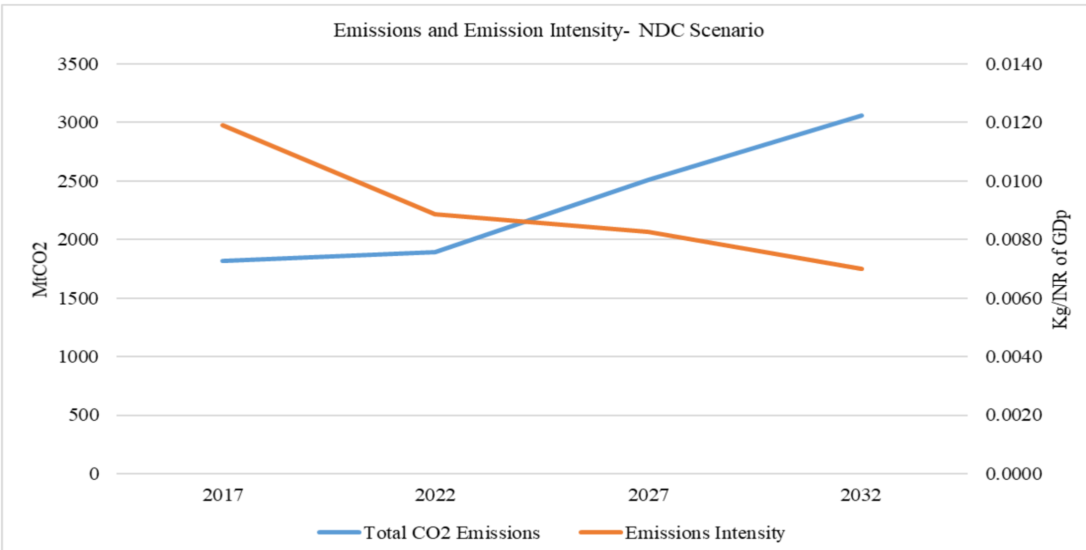

Figure 9:CO2 and Emissions Intensity under NDC scenario

4.3 Sensitivity Analysis

Cost sensitivity of Renewable Energy

Renewable technology penetration is found to be highly cost elastic. Lower the cost of installing and maintaining the services, higher the chances of newer capacity addition in the system. Figure 10 shows the sensitivity of solar penetration in different cost scenarios. A decrease in solar cost by 50% can increase solar penetration by more than eight times as compared to the baseline scenario. A decrease in solar cost in the range of 10% and 20% will help in meeting the generation level met by the NDC scenario, as can be seen by the NDC scenario penetration line super imposed on the graph.

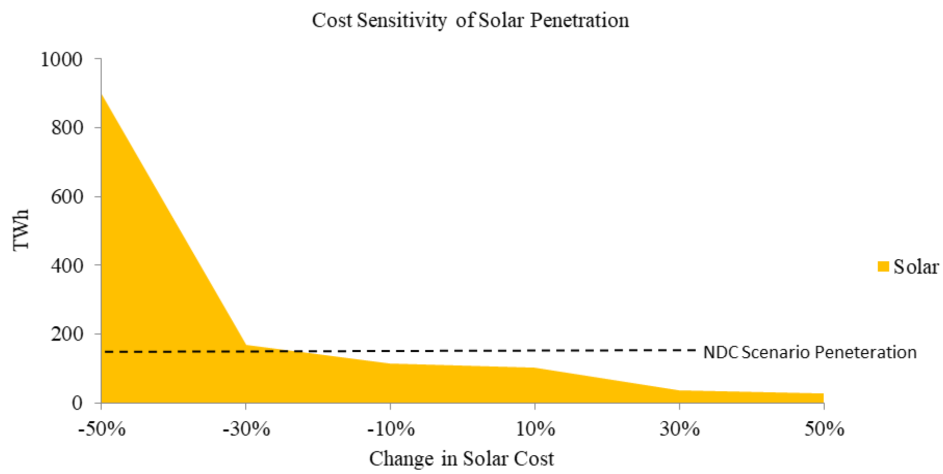

Figure 10: Penetration of Solar under different costs scenarios (in 2042)

Cost sensitivity further indicates that to achieve the NDC target of 40% renewable energy capacity by 2022, it is important to have continued policy support in the sector to keep the supply cost low. Increase in solar penetration in the total generation mix comes by displacing the share of coal. Panel a.) in Figure 11 shows the effect on generation under two cost reduction scenarios for solar. When costs are decreased by 50% of the baseline, solar penetration increases to 896 TWh and the share of coal decreases to 1433 TWh by 2042. On the other hand, with a 10% decrease in cost, solar penetration increases only up to 114 TWh and share of coal decreases only up to 2216 TWh by 2042. This implies that the cost of renewables is an important factor in contributing towards cleaner generation mix.

The CO_2 reduction potential is highest when the cost decrease from solar is the highest (see panel b.) in Figure 11. We can also see that a cost decrease greater than 10% will help in meeting the emission reduction potential similar to that achieved by meeting the NDC scenario.

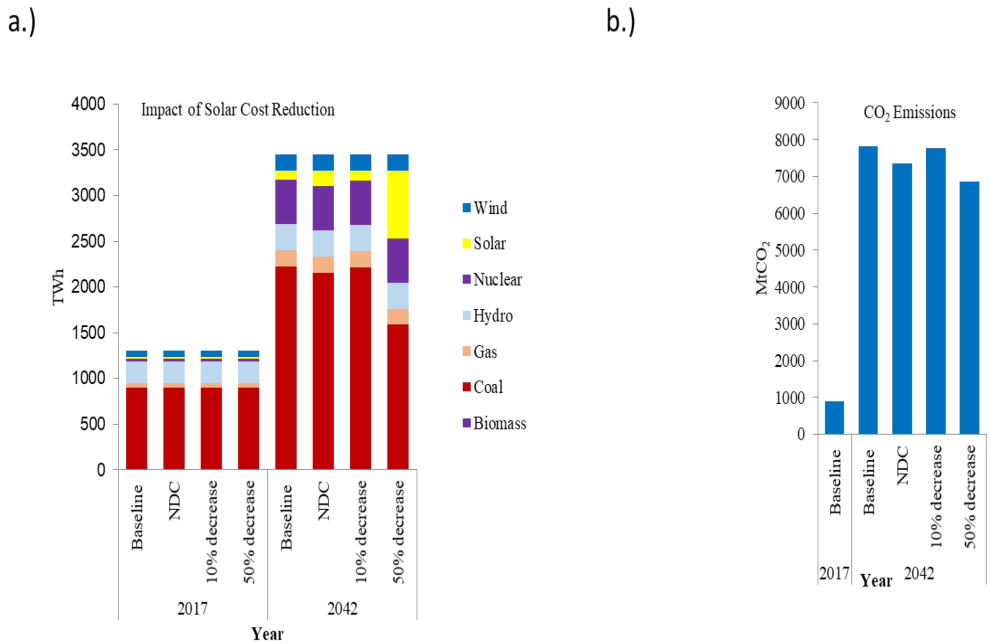

Figure 11:Impact of reduction in solar costs on electricity generation (panel a.) and on CO2 emissions (panel b.)

Cost Sensitivity of Small Electric Vehicles

To analyze the penetration of electric vehicles in the small vehicle category, different cost scenarios for small vehicles have been created. The cost of small vehicles in the model are taken as the weighted average of the four types of vehicle category, cars, two wheelers, three wheeler and taxi. The sensitivity analysis shows that the penetration of small electric vehicles increases with the decrease in the price of EVs, as can be seen in Figure 12

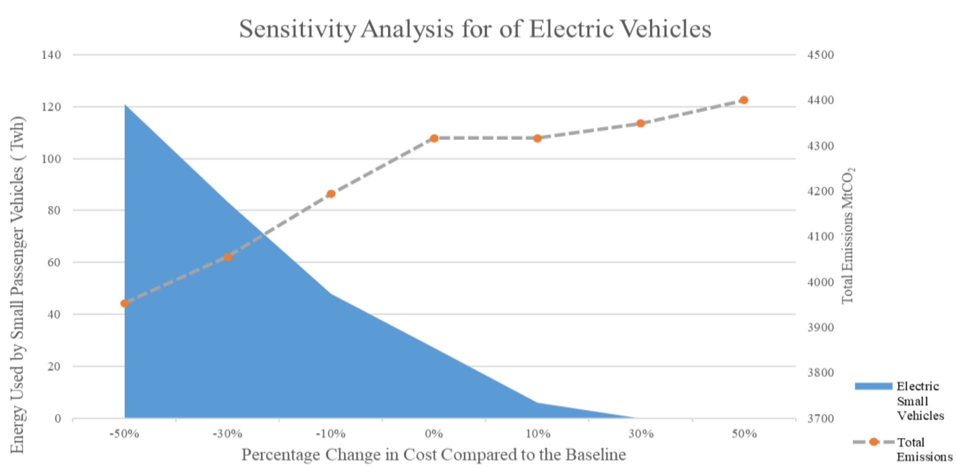

Figure 12:Penetration of EV under different costs scenarios (in 2042)

A positive correlation is seen between cost of electric vehicle and total emissions from road passenger vehicles. As cost decreases associated emissions of the transport sector fall. A 50% decrease in cost, causes total emissions to decrease by around 363 Mt CO_2, while a 50% increase in cost causes the emissions to increase by 83 Mt CO_2.

5. Discussion and Policy Implications

The findings from this study have some important policy implications. It can be seen that for power generation, coal will continue to be the major source of energy in the county until foreseeable future although a shift towards clean coal technologies can be expected. In the total supply mix, there is a great scope for increasing the share of electricity in consumption and cleaning the system. Coal is the preferred fuel in the total supply mix as well; this is because of its cost competitiveness in select end-use sectors. There is a scope for balancing this preference for coal through appropriate policy intervention in other green and clean technologies. Use of electricity to meet final energy demand is low and the demand for electricity is not increasing rapidly perhaps due to continuous efficiency improvement and energy conservation activities. Use of electricity in the useful energy consumption level such as industry, transport and household is envisaged to increase rapidly provided access to electricity is provided.

With respect to emissions, it could be seen that emission intensity to GDP improves significantly but gets dampened due to continuous increase in absolute emissions. This indicates that only RE capacity addition will not be sufficient for the energy system to become clean; there is need for significant improvement in RE generation by improving efficiency.

This study also found that solar penetration in India is highly cost sensitive. This finding underlines the need to design appropriate policies that focus on reducing cost of generation as much as possible, in order to ensure a higher share of renewable generation and capacity in the power system. This also shows that cost is a prime factor in determining inter-fuel substitution, highlighting the importance of providing a level playing pricing platform to different types of fuels. Cost is also a prime factor in inducing penetration of electricity in small vehicle category. Greater penetration of small electric vehicles will have a direct effect on reducing the total emissions from the transport sector. Therefore, policies to increase small electric vehicles are beneficial.

Finally, it could also be seen that the NDC target of reducing emission intensity of GDP is not a difficult task for India. Nevertheless, given the increasing growth trajectory of energy consumption, India may need to put more effort to curb the increasing trend of emissions.

6. Way forward

This exercise is a novel initiative as it combines the strengths of the MESSAGE*ix* platform of IIASA with the IESS 2047 calculator of NITI Aayog. As a first step, it has been able to give promising insights but there are several areas of improvement. At present, the model has not included the electrification policies of India to assess changes in the transport sector, which is an important area of future work given the tremendous push being given to this sector in India. In general, the methodology of the entire end-use demand sector can be further refined. The model can also be used to see changes to the energy supply system under different GDP trajectories, which will have an impact on sectoral demand and hence the supply to the system. On the supply side, there can be a greater representation of energy supply, e.g., waste to energy and biofuels. For future work, it is also important to add taxes on various types of fossil fuels considered in the model to see how they affect the cost dynamics in the model.

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Appendix

Detailed Breakdown of Demand

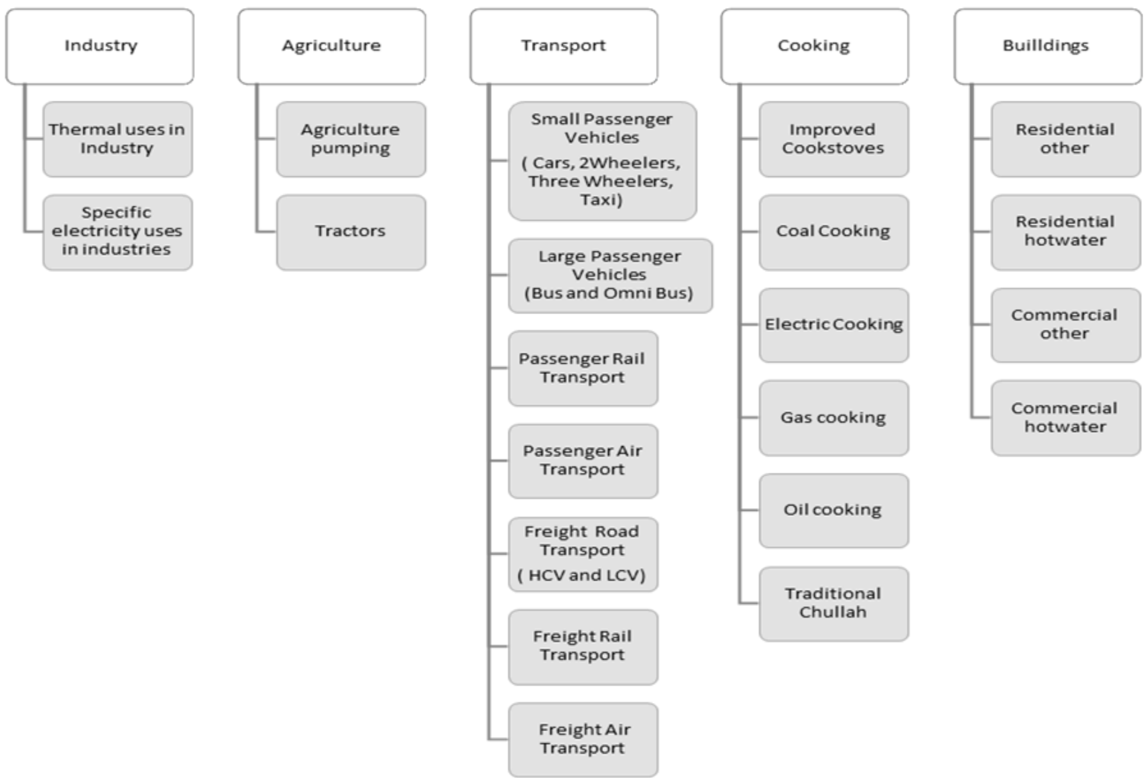

Figure 13:Detailed breakdown of demands modeled in India Energy model

Energy Model Structure

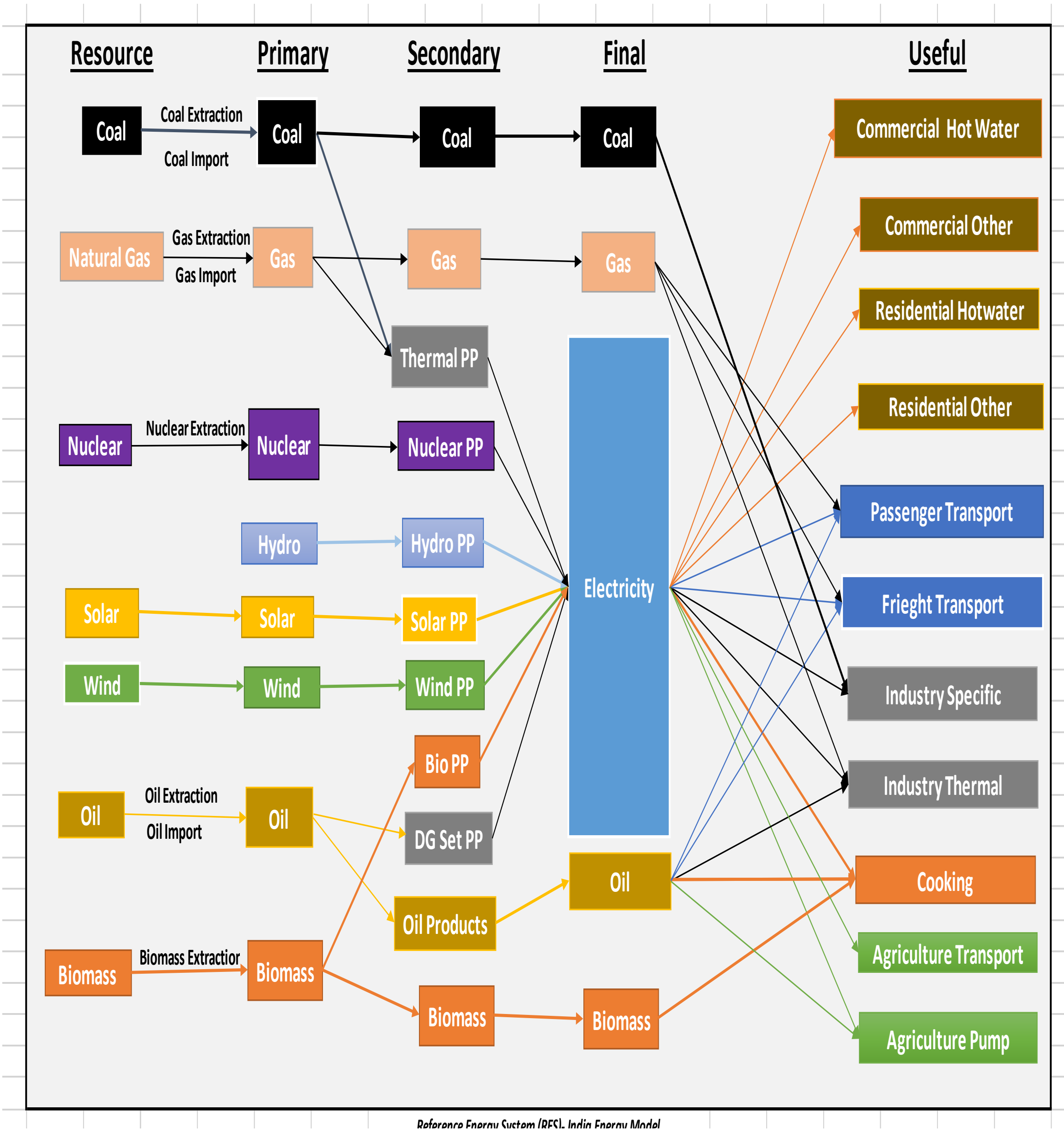

Figure 14: Reference Energy System